

## Techno-Economic Analysis of Rooftop Photovoltaic Systems for Smart Buildings in Indonesia

Genrawan Hoendarto<sup>1\*</sup>, Abdul Muchlis<sup>2</sup>, Sandy Suryady<sup>3</sup>

<sup>1</sup> Computer Science, Universitas Widyadharma Pontianak, Indonesia

<sup>2,3</sup> Mechanical Engineering, Universitas Gunadarma, Email, Indonesia

Email: [genrawan@widyadharma.ac.id](mailto:genrawan@widyadharma.ac.id), [muchlis07@staff.gunadarma.ac.id](mailto:muchlis07@staff.gunadarma.ac.id), [sandy22@staff.gunadarma.ac.id](mailto:sandy22@staff.gunadarma.ac.id)

**Abstract.** *The increasing demand for energy-efficient and sustainable buildings has encouraged the integration of rooftop solar photovoltaic systems into smart-building environments. In Indonesia, this approach is particularly relevant because of the country's high solar energy potential and the growing need to optimize electricity use in buildings through better energy management. However, the feasibility of rooftop solar photovoltaic systems in smart buildings cannot be assessed only from electricity generation potential, because their performance is also influenced by building load characteristics, self-consumption behavior, and operational control strategy. Therefore, this study aimed to analyze the techno-economic feasibility of rooftop solar photovoltaic systems for smart buildings by evaluating their technical performance and economic viability within an energy-managed building environment. This study employed a quantitative case-study approach using a simulated smart-building case. The analysis included rooftop assessment, photovoltaic system sizing, electricity generation simulation, load matching, and discounted cash flow analysis. The evaluated indicators consisted of annual electricity generation, specific yield, performance ratio, self-consumption ratio, self-sufficiency ratio, net present value, internal rate of return, discounted payback period, and levelized cost of electricity. A smart-operation scenario was also compared with a baseline operating condition to examine the effect of load shifting on photovoltaic utilization. The results showed that the proposed rooftop solar photovoltaic system achieved an installed capacity of 46.2 kilowatt-peak and generated 63,050 kilowatt-hours per year, with a specific yield of 1,364.7 kilowatt-hours per kilowatt-peak per year and a performance ratio of 79.2 percent. Under the smart-operation scenario, direct photovoltaic self-consumption increased from 39,720 to 48,250 kilowatt-hours per year, while the self-consumption ratio increased from 63.0 percent to 76.5 percent. Economically, the system produced a positive net present value of 119,295,923 Indonesian rupiah, an internal rate of return of 10.30 percent, and a discounted payback period of 15.99 years. These findings indicate that rooftop solar photovoltaic systems are technically and economically feasible for smart buildings and that smart load management plays an important role in improving on-site solar utilization and investment performance.*

**Keywords** Rooftop Photovoltaic, Smart Building, Techno-Economic Analysis, Self-Consumption, Energy Management

### INTRODUCTION

Buildings remain one of the largest energy-consuming sectors, which has intensified the transition from conventional facilities toward smart, data-driven, and energy-responsive buildings. In this context, smart buildings are increasingly defined not only by automation, but also by their ability to integrate monitoring, control, and decision-support systems to improve operational efficiency and sustainability (Mariano-Hernández et al., 2021). The smart-building concept is also closely associated with performance-based indicators, digital infrastructure, and intelligent building management

---

Submitted: June 26, 2025; Revised: July 15, 2025; Accepted: July 19, 2025

\*Corresponding author, [genrawan@widyadharma.ac.id](mailto:genrawan@widyadharma.ac.id),

systems that support energy optimization and adaptive operation (Al Dakheel et al., 2020). Recent reviews further indicate that the development of smart buildings depends on the maturity of Internet of Things integration, interoperability, and system intelligence, while practical challenges such as data management, security, and implementation barriers remain significant (Moudgil et al., 2023; Poyyamozi et al., 2024). From the Indonesian perspective, this discussion is particularly relevant because the country has considerable solar resources and large urban rooftop potential, which create favorable conditions for distributed photovoltaic deployment in the built environment (Silalahi et al., 2021; Triana et al., 2024).

The techno-economic feasibility of rooftop photovoltaic systems has been widely studied, but the literature consistently shows that project performance is shaped not only by solar yield and installed capacity, but also by load behavior and self-consumption characteristics. Earlier review work established that self-consumption and demand-side management are central variables in building-level photovoltaic performance, especially where locally generated electricity is more valuable when consumed on-site rather than exported (Luthander et al., 2015). More recent studies likewise confirmed that demand profile significantly affects self-consumption and self-sufficiency outcomes, reinforcing the need to evaluate photovoltaic systems together with building operation patterns (Miranda et al., 2024). In Indonesia, recent studies have examined rooftop photovoltaic incentives for residential users, the feasibility of grid-connected rooftop systems under domestic regulatory conditions, and case-specific installations such as mosque buildings, all of which demonstrate the growing relevance of rooftop solar investment analysis in the country (Pramadya & Kim, 2024; Tarigan, 2024; Suparwoko & Qamar, 2022). Meanwhile, the smart-building literature has advanced toward integrated energy management with distributed storage, flexible loads, and coordinated control strategies, showing that photovoltaic value can improve when generation is synchronized with consumption and supported by intelligent energy management (Hernández et al., 2024; Costa et al., 2024). This tendency is further strengthened by recent research showing that alternative demand-side strategies in photovoltaic-battery systems can substantially alter electricity cost and grid interaction outcomes across different building communities (Liao et al., 2024).

Despite this progress, an important gap remains in the literature. Indonesian rooftop photovoltaic studies are still dominated by residential analysis, urban potential estimation, or individual facility case studies, while smart-building studies generally emphasize digital architecture, sensing systems, or broad energy-management concepts rather than integrated rooftop photovoltaic techno-economic assessment in real smart-building settings (Triana et al., 2024; Pramadya & Kim, 2024; Suparwoko & Qamar, 2022). Conversely, studies on smart-building management and self-consumption optimization are mostly developed in broader international contexts and are rarely translated into an Indonesian analytical framework that simultaneously captures photovoltaic technical performance, financial viability, and smart operational behavior (Taboada-Orozco et al., 2024; Hernández et al., 2024; Costa et al., 2024). To the best of the authors' knowledge, no prior peer-reviewed study has specifically integrated rooftop photovoltaic technical assessment, economic feasibility, self-consumption logic, and smart-building energy management into a single framework for smart buildings in Indonesia. This gap is important because photovoltaic investments in intelligent buildings cannot be adequately represented by conventional yield-and-payback analysis alone; they also depend on how building intelligence modifies load timing, on-site energy use, and cost performance (Luthander et al., 2015; Miranda et al., 2024; Liao et al., 2024).

Therefore, this study aimed to analyze the techno-economic feasibility of rooftop photovoltaic systems for smart buildings by evaluating their technical performance and economic viability within an energy-managed building environment. The study was intended to examine how rooftop photovoltaic generation could be aligned with smart-building load characteristics, self-consumption potential, and operational control strategies so that investment decisions could be assessed more realistically. This study is expected to contribute an integrated framework that connects rooftop photovoltaic assessment, smart-building energy management, and techno-economic decision-making, thereby enriching the literature and supporting more practical renewable energy planning for intelligent buildings.

## **METHODS**

This study employed a quantitative case-study approach to evaluate the techno-economic feasibility of a rooftop photovoltaic system for a smart building. A simulated

case was developed to illustrate the techno-economic behavior of rooftop photovoltaic integration in a smart building. This approach was chosen because the technical and economic performance of rooftop photovoltaic systems depended on specific building characteristics, including electricity demand, available roof area, solar exposure, and operational control strategy

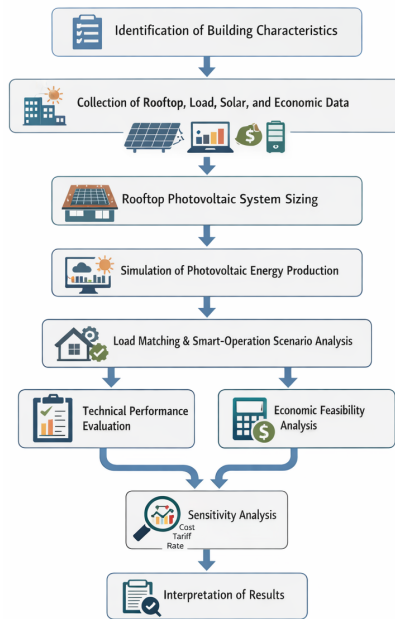
The data used in this study consisted of technical, operational, and economic data. The technical data included rooftop dimensions, usable roof area, roof orientation, tilt angle, and shading conditions. The operational data consisted of building electricity consumption records obtained from smart meters, electricity bills, or the building management system. Hourly load data for one year were preferred because they enabled a more accurate comparison between photovoltaic generation and building demand. The economic data included photovoltaic module prices, inverter prices, installation costs, operation and maintenance costs, electricity tariffs, project lifetime, and discount rate.

**Table 1.** Data requirements and sources used in the study

<b>Data category</b>	<b>Data required</b>	<b>Source</b>
Building data	Building type, floor area, operational hours	Building profile
Rooftop data	Usable roof area, roof orientation, tilt angle, shading condition	Field observation / building drawing
Load data	Hourly or monthly electricity consumption	Smart meter / electricity bill / BMS
Solar data	Solar irradiation, ambient temperature	Meteorological database
PV system data	Module capacity, inverter capacity, module efficiency, inverter efficiency	Manufacturer datasheet
Economic data	Investment cost, O&M cost, electricity tariff, discount rate, project lifetime	Market data / utility tariff

The research procedure was carried out in several stages, as illustrated in Figure 1. First, the building and rooftop characteristics were identified to determine the maximum feasible photovoltaic installation capacity. Second, the rooftop photovoltaic system was sized based on the available roof area and the selected module specifications. Third, the photovoltaic electricity output was estimated using local solar irradiation data and system performance assumptions. Fourth, the hourly photovoltaic generation profile was compared with the building load profile to determine the amount of electricity directly

consumed by the building, imported from the grid, and exported as surplus electricity. Fifth, the technical and economic performance of the system was evaluated.



**Figure 1.** Research flowchart

The technical analysis included the estimation of installed photovoltaic capacity, annual electricity generation, specific yield, performance ratio, self-consumption ratio, and self-sufficiency ratio. Installed capacity was determined from the usable rooftop area and the area requirement of the selected photovoltaic modules. Annual electricity generation was estimated from installed capacity, local solar irradiation, and system efficiency assumptions. The self-consumption ratio was used to measure the proportion of photovoltaic electricity directly utilized by the building, while the self-sufficiency ratio was used to indicate the proportion of building electricity demand supplied by the rooftop photovoltaic system.

The economic analysis was conducted using a discounted cash flow approach. The investment cost included photovoltaic modules, inverter, mounting structure, balance-of-system components, and installation cost. Annual costs included operation and maintenance cost, while replacement cost was considered if inverter replacement was required during the project lifetime. The annual economic benefit was calculated from the reduction in purchased grid electricity resulting from photovoltaic self-consumption.

Project feasibility was then evaluated using net present value, internal rate of return, discounted payback period, and levelized cost of electricity.

To represent smart-building operation, a scenario-based analysis was also performed. The first scenario represented the existing building load profile without photovoltaic integration. The second scenario represented rooftop photovoltaic integration under the actual building load profile. The third scenario represented rooftop photovoltaic integration with smart load management, in which selected electrical loads were shifted to daytime periods to better match photovoltaic generation. This scenario analysis was conducted to determine whether smart operational control could improve self-consumption and economic performance.

The results were analyzed descriptively and comparatively. Descriptive analysis was used to present the technical and economic characteristics of each scenario, while comparative analysis was used to identify differences in performance among the scenarios. Sensitivity analysis was also performed on selected economic variables, including investment cost, electricity tariff, and discount rate, to test the robustness of the feasibility results under different financial conditions.

The tools and software used in this study included PVsyst for photovoltaic system simulation, Microsoft Excel for hourly energy balance and economic calculations, and building electricity records obtained from smart metering or building management system data. These tools were selected because they were sufficient to estimate photovoltaic production, compare it with building demand, and evaluate long-term economic feasibility in a transparent and replicable manner.

### Equations Used in the Analysis

$$SCR = \frac{E_{self}}{E_{PV}} \times 100\%$$
$$SSR = \frac{E_{self}}{E_{load}} \times 100\%$$
$$NPV = \sum_{t=0}^n \frac{B_t - C_t}{(1+r)^t}$$

$$LCOE = \frac{\sum_{t=0}^n \frac{C_t}{(1+r)^t}}{\sum_{t=0}^n \frac{E_t}{(1+r)^t}}$$

Where:

$E_{self}$  = electricity directly consumed from the photovoltaic system

$E_{PV}$  = total photovoltaic electricity generated

$E_{load}$  = total building electricity demand

$B_t$  = benefit in year  $t$

$C_t$  = cost in year  $t$

$E_t$  = energy generated in year  $t$

$r$  = discount rate

$n$  = project lifetime

## RESULTS

The results of this study are presented sequentially, beginning with the rooftop photovoltaic system design, followed by technical performance, load-matching performance, economic feasibility, and sensitivity analysis. The findings are presented objectively through tables and figures.

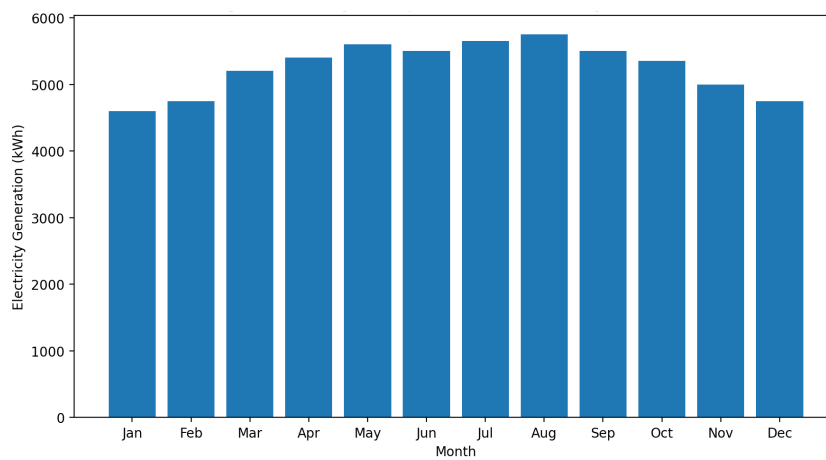
The rooftop assessment showed that the building had a usable roof area of 620 m<sup>2</sup>, which allowed the installation of a rooftop photovoltaic system with an estimated capacity of 46.2 kWp. The selected system consisted of 84 photovoltaic modules with a unit capacity of 550 Wp, connected to an inverter with a rated capacity of 40 kW. The roof tilt angle was 10°, the roof orientation was north-facing, and the estimated shading loss was 3.5%. The technical design parameters are summarized in Table 2.

**Table 2.** Rooftop photovoltaic system design results

Parameter	Unit	Value
Usable rooftop area	m <sup>2</sup>	620
Number of PV modules	units	84
PV module capacity	Wp/module	550
Total installed capacity	kWp	46.2
Inverter capacity	kW	40
Roof tilt angle	degree	10
Roof orientation	-	North
Estimated shading loss	%	3.5

Parameter	Unit	Value
Performance ratio	%	79.2
Specific yield	kWh/kWp/year	1,364.7

The simulation results showed that the rooftop photovoltaic system generated 63,050 kWh/year of electricity. The highest monthly electricity generation was recorded in August, with a value of 5,750 kWh, while the lowest generation was recorded in January, with a value of 4,600 kWh. The monthly electricity generation profile is shown in Figure 2.

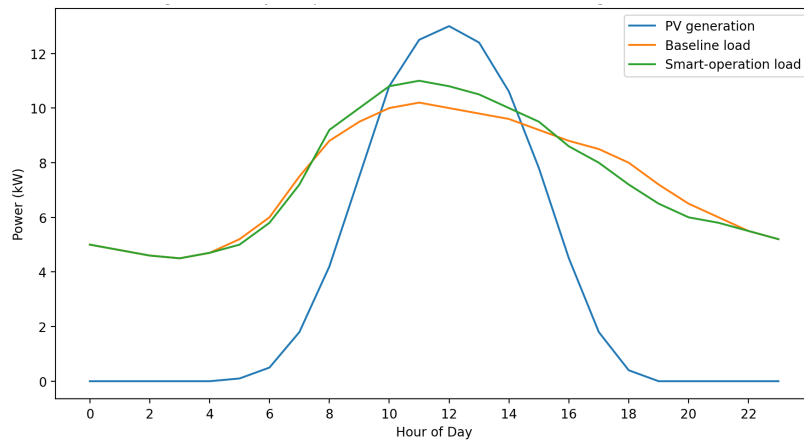


**Figure 2.** Monthly rooftop photovoltaic electricity generation

The annual building electricity demand was 151,200 kWh/year. Under the baseline operating condition, the rooftop photovoltaic system supplied 39,720 kWh/year through direct on-site consumption, while 23,330 kWh/year was exported as surplus electricity. Grid import under this condition was 111,480 kWh/year. Under the smart-operation scenario, direct photovoltaic utilization increased to 48,250 kWh/year, exported surplus electricity decreased to 14,800 kWh/year, and grid import decreased to 102,950 kWh/year. The resulting self-consumption ratio increased from 63.0% to 76.5%, while the self-sufficiency ratio increased from 26.3% to 31.9%. The annual energy balance is presented in Table 3, and the hourly comparison of photovoltaic generation and building load is shown in Figure 3.

**Table 3.** Annual energy balance results

Parameter	Unit	Baseline scenario	Smart-operation scenario
Annual building electricity demand	kWh/year	151,200	151,200
Annual PV electricity generation	kWh/year	63,050	63,050
Direct PV self-consumption	kWh/year	39,720	48,250
Grid import	kWh/year	111,480	102,950
Exported surplus electricity	kWh/year	23,330	14,800
Self-consumption ratio	%	63.0	76.5
Self-sufficiency ratio	%	26.3	31.9



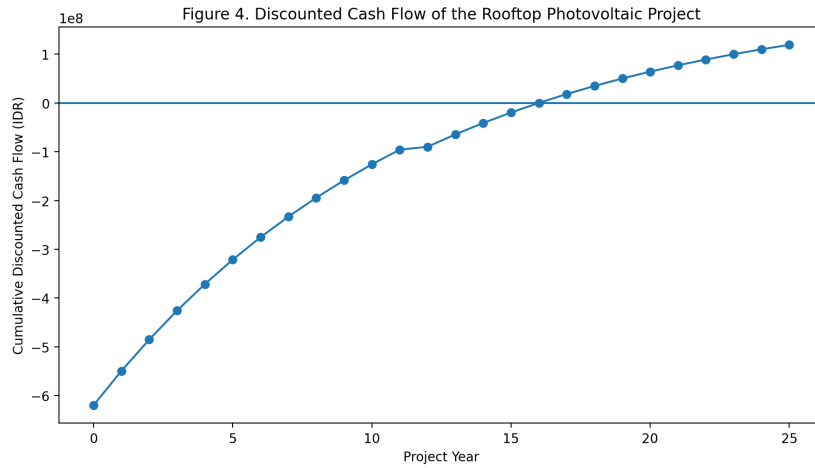
**Figure 3.** Hourly comparison of photovoltaic generation and building load demand

The economic calculation results showed that the proposed rooftop photovoltaic system required an initial investment of IDR 620,000,000. The annual operation and maintenance cost was IDR 6,200,000/year, while the annual electricity cost savings under the smart-operation scenario reached IDR 82,025,000/year. The net present value of the project was IDR 119,295,923, the internal rate of return was 10.30%, the discounted payback period was 15.99 years, and the levelized cost of electricity was IDR 1,113.36/kWh. The economic results are summarized in Table 4, while the discounted cash flow profile is shown in Figure 4.

**Table 4.** Economic feasibility results

Economic indicator	Unit	Value
Initial investment cost	IDR	620,000,000
Annual O&M cost	IDR/year	6,200,000
Annual electricity cost savings	IDR/year	82,025,000
Net present value (NPV)	IDR	119,295,923
Internal rate of return (IRR)	%	10.30

Economic indicator	Unit	Value
Discounted payback period (DPP)	years	15.99
Levelized cost of electricity (LCOE)	IDR/kWh	1,113.36

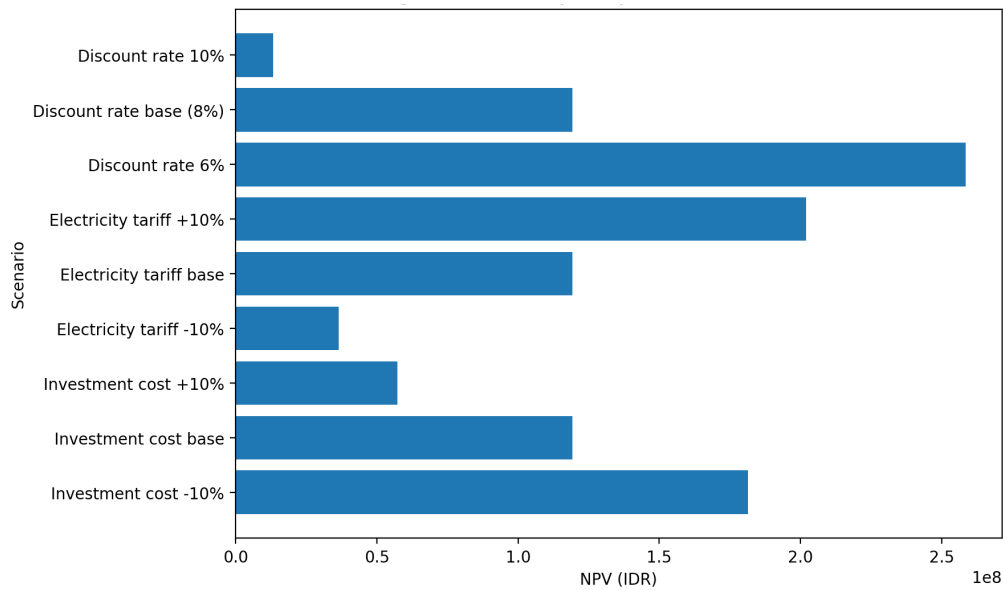


**Figure 4.** Discounted cash flow of the rooftop photovoltaic project

The sensitivity analysis showed that the project feasibility changed under variations in investment cost, electricity tariff, and discount rate. When the investment cost decreased by 10%, the net present value increased to IDR 181,295,923, while an increase of 10% in investment cost reduced the net present value to IDR 57,295,923. When the electricity tariff decreased by 10%, the net present value fell to IDR 36,563,844, whereas an increase of 10% in tariff raised the net present value to IDR 202,028,002. At a discount rate of 6%, the net present value reached IDR 258,356,269, while at 10% it decreased to IDR 13,428,813. The sensitivity analysis results are presented in Table 5 and Figure 5.

**Table 5.** Sensitivity analysis results

Variable	Scenario	NPV (IDR)	IRR (%)	DPP (years)	LCOE (IDR/kWh)
Investment cost	-10%	181,295,923	11.82	13.10	1,015.87
Investment cost	Base case	119,295,923	10.30	15.99	1,113.36
Investment cost	+10%	57,295,923	9.02	19.83	1,210.85
Electricity tariff	-10%	36,563,844	8.72	21.08	1,113.36
Electricity tariff	Base case	119,295,923	10.30	15.99	1,113.36
Electricity tariff	+10%	202,028,002	11.82	13.07	1,113.36
Discount rate	6%	258,356,269	10.30	13.06	959.71
Discount rate	8%	119,295,923	10.30	15.99	1,113.36
Discount rate	10%	13,428,813	10.30	22.84	1,276.25



**Figure 5.** Sensitivity analysis of net present value

## DISCUSSION

The results showed that the proposed rooftop photovoltaic system was technically and economically feasible under the simulated smart-building case. The system generated 63,050 kWh/year, achieved a specific yield of 1,364.7 kWh/kWp/year, and produced a positive net present value of IDR 119,295,923 with an internal rate of return of 10.30%. These findings answer the main research question by showing that rooftop photovoltaic integration can provide meaningful technical output and positive long-term economic returns when the system is sized according to rooftop constraints and building demand. In this study, the feasibility of the system was not determined only by installed capacity, but also by how much photovoltaic electricity could offset purchased grid electricity under actual building operation.

A more important finding emerged from the comparison between the baseline and smart-operation scenarios. Direct photovoltaic self-consumption increased from 39,720 kWh/year to 48,250 kWh/year, the self-consumption ratio rose from 63.0% to 76.5%, and surplus electricity export decreased substantially. This result indicates that smart operational control improved the utilization of locally generated solar electricity without increasing photovoltaic capacity. This interpretation is consistent with previous studies showing that load management and energy storage are key approaches for increasing photovoltaic self-consumption in buildings (Luthander et al., 2015). It also aligns with

studies explaining that building energy management systems support managers in reducing energy use through coordinated control and demand-side strategies (Mariano-Hernández et al., 2021). In addition, demand-side energy management strategies have been shown to substantially alter self-consumption and grid interaction in photovoltaic-integrated building communities (Liao et al., 2024).

The technical performance obtained in this study also fits the broader Indonesian context. The specific yield achieved in the simulation suggests that rooftop photovoltaic systems in smart buildings can generate meaningful annual electricity under local solar conditions. This interpretation is reasonable because Indonesia has been identified as having very large solar photovoltaic potential, with solar PV far exceeding many other renewable options in technical and economic potential (Silalahi et al., 2021). At the same time, the present findings extend earlier Indonesian rooftop photovoltaic studies, which have mainly focused on residential users and conventional techno-economic assessments rather than smart-building operation. Previous research on residential rooftop PV in Indonesia highlighted that investment attractiveness remains strongly influenced by cost and policy conditions (Pramadya & Kim, 2024). In that sense, the present study adds a building-operation perspective by showing that smart load management can materially affect rooftop photovoltaic value.

The economic results further showed that project feasibility was sensitive to changes in investment cost, electricity tariff, and discount rate. This means that rooftop photovoltaic feasibility in smart buildings is influenced not only by energy generation, but also by financing conditions and operational strategy. Such an interpretation is in line with previous work showing that the value of building-integrated photovoltaic systems depends heavily on self-consumption behavior, local demand, and economic assumptions (Luthander et al., 2015). Other studies also emphasized that increasing photovoltaic generation in smart buildings strengthens the importance of coordinated energy management for improving self-consumption efficiency and reducing reliance on retailer electricity (Costa et al., 2024). From a knowledge contribution perspective, this study therefore supports the view that rooftop photovoltaic systems in smart buildings should be evaluated as managed energy assets rather than as static generation systems (Al Dakheel et al., 2020). However, because the present work was based on a simulated case, the numerical results should be interpreted as illustrative rather than universally

representative. Future studies should test this framework using real smart-building load data, measured meteorological conditions, and additional scenarios such as battery storage or dynamic electricity tariffs.

## CONCLUSION

This study was conducted to analyze the techno-economic feasibility of rooftop photovoltaic systems for smart buildings and to examine whether smart operational control could improve technical and economic performance beyond conventional rooftop photovoltaic assessment. The findings showed that the simulated rooftop photovoltaic system was technically viable, producing 63,050 kWh/year with a specific yield of 1,364.7 kWh/kWp/year and a performance ratio of 79.2%, while the economic evaluation indicated positive feasibility with a net present value of IDR 119,295,923, an internal rate of return of 10.30%, and a discounted payback period of 15.99 years. The results also showed that smart-operation control improved system utilization, as reflected by the increase in self-consumption ratio from 63.0% to 76.5% and the reduction in surplus electricity export, confirming that rooftop photovoltaic performance in smart buildings depends not only on generation capacity but also on load synchronization and operational strategy.

Therefore, this study contributes to the existing literature by offering an integrated framework that links rooftop photovoltaic technical assessment, self-consumption behavior, and economic evaluation within a smart-building context, which is still rarely addressed as a unified analysis. However, this study was limited by the use of a simulated case, meaning that the numerical results should be interpreted as illustrative rather than fully representative of all real buildings and operating conditions. Future studies should apply this framework to real smart-building case studies, include actual measured load and meteorological data, and compare additional scenarios such as battery storage, dynamic tariffs, and advanced energy management systems.

Practically, the findings suggest that building managers and decision-makers should prioritize not only rooftop photovoltaic installation but also smart load management strategies in order to maximize on-site solar utilization and improve long-term investment performance.

## REFERENCES

- Al Dakheel, J., Del Pero, C., Aste, N., & Leonforte, F. (2020). Smart buildings features and key performance indicators: A review. *Sustainable Cities and Society*, 61, 102328. <https://doi.org/10.1016/j.scs.2020.102328>
- Costa, R., Silva, R., Faia, R., Gomes, L., Faria, P., & Vale, Z. (2024). Empowering energy management in smart buildings: A comprehensive study on distributed energy storage systems for sustainable consumption. *Energy and Buildings*, 324, 114953. <https://doi.org/10.1016/j.enbuild.2024.114953>
- Hernández, J. L., de Miguel, I., Vélez, F., & Vasallo, A. (2024). Challenges and opportunities in European smart buildings energy management: A critical review. *Renewable and Sustainable Energy Reviews*, 199, 114472. <https://doi.org/10.1016/j.rser.2024.114472>
- Liao, W., Xiao, F., Li, Y., Zhang, H., & Peng, J. (2024). A comparative study of demand-side energy management strategies for building integrated photovoltaics-battery and electric vehicles (EVs) in diversified building communities. *Applied Energy*, 361, 122881. <https://doi.org/10.1016/j.apenergy.2024.122881>
- Luthander, R., Widén, J., Nilsson, D., & Palm, J. (2015). Photovoltaic self-consumption in buildings: A review. *Applied Energy*, 142, 80–94. <https://doi.org/10.1016/j.apenergy.2014.12.028>
- Mariano-Hernández, D., Hernández-Callejo, L., Zorita-Lamadrid, A., Duque-Pérez, O., & Santos García, F. (2021). A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis. *Journal of Building Engineering*, 33, 101692. <https://doi.org/10.1016/j.jobe.2020.101692>
- Miranda, M. T., Sepúlveda, F. J., Fernández, A., Arranz, J. I., & Montero, I. (2024). Analysis of photovoltaic self-consumption as a function of the demand profile in detached houses. *Energy and Buildings*, 316, 114375. <https://doi.org/10.1016/j.enbuild.2024.114375>
- Moudgil, V., Hewage, K., Hussain, S. A., & Sadiq, R. (2023). Integration of IoT in building energy infrastructure: A critical review on challenges and solutions. *Renewable and Sustainable Energy Reviews*, 174, 113121. <https://doi.org/10.1016/j.rser.2022.113121>
- Poyyamozi, M., Murugesan, B., Rajamanickam, N., Shorfuzzaman, M., & Aboelmagd, Y. (2024). IoT—A promising solution to energy management in smart buildings: A systematic review, applications, barriers, and future scope. *Buildings*, 14(11), 3446. <https://doi.org/10.3390/buildings14113446>
- Pramadya, F. A., & Kim, K. N. (2024). Promoting residential rooftop solar photovoltaics in Indonesia: Net-metering or installation incentives? *Renewable Energy*, 222, 119901. <https://doi.org/10.1016/j.renene.2023.119901>

- Silalahi, D. F., Blakers, A., Stocks, M., Lu, B., Cheng, C., & Hayes, L. (2021). Indonesia's vast solar energy potential. *Energies*, *14*(17), 5424. <https://doi.org/10.3390/en14175424>
- Suparwoko, & Qamar, F. A. (2022). Techno-economic analysis of rooftop solar power plant implementation and policy on mosques: An Indonesian case study. *Scientific Reports*, *12*, 4823. <https://doi.org/10.1038/s41598-022-08968-6>
- Taboada-Orozco, A., Yetongnon, K., & Nicolle, C. (2024). Smart buildings: A comprehensive systematic literature review on data-driven building management systems. *Sensors*, *24*(13), 4405. <https://doi.org/10.3390/s24134405>
- Tarigan, E. (2024). Techno-Economic analysis of residential grid-connected rooftop solar PV systems in Indonesia under MEMR 26/2021 regulation. *International Journal of Energy Economics and Policy*, *14*(1), 412–417. <https://doi.org/10.32479/ijeep.15277>
- Triana, D., Garniwa, I., Rosadi, A. H., & Martono, D. N. (2024). Performance analysis simulation of urban rooftop photovoltaic potential in Jakarta City, Indonesia. *Environmental Research, Engineering and Management*, *80*(4), 21–38. <https://doi.org/10.5755/j01.ere.m.80.4.34200>