International Journal on Advanced Technology, Engineering, and Information System
https://ojs.transpublika.com/index.php/IJATEIS
Online ISSN 2828-5425

https://doi.org/10.55047/ijateis.v4i3.1982

Original Article

Assessment of Existing Green Building Implementation in Government Buildings toward Energy Efficiency

Guntaryono[1], Darmansjah Tjahja Prakasa[2*], Andarita Rolalisasi[3], Nur Azizah Affandy[4]

[1-3]Departement of Magister Architecture, Faculty of Engineering, Universitas 17 Agustus 1945, Surabaya, Indonesia
[4]Departement of Civil Engineering, Faculty of Sains and Technology, Universitas Islam Lamongan, Lamongan, Indonesia
Email: 1) 5422400003@surel.untag-ac.id, 2) darmansjahtp@untag-sby.ac.id,
3) roolalisasi@untag-sby.ac.id, 4) nurazizah@unisla.ac.id

Received : 6 October - 2025
Accepted : 3 November - 2025
Published online : 4 November - 2025

Abstract

Government buildings represent a major portion of public-sector energy consumption and contribute substantially to greenhouse gas emissions due to intensive cooling, lighting, and suboptimal building envelopes. In many developing countries, including Indonesia, the majority of government facilities were constructed prior to the adoption of green building regulations, resulting in poor energy performance and elevated operational costs. This study aims to critically assess the energy performance of an existing government building and to identify practical retrofit strategies based on Green Building principles that can support national carbon reduction commitments and Sustainable Development Goals. A mixed-methods case study was conducted on the East Java Public Works and Human Settlements Office Building (6,000 m²; three stories; pre-regulation construction). Data collection combined field inspection, structured interviews with facility managers, and policy-document review. The evaluation proceeded through four stages: calculation of Energy Use Intensity (EUI), disaggregation of energy consumption by end-use, performance assessment of the building envelope, ventilation, and lighting, and compliance analysis against national standards, Greenship GBCI criteria, and relevant SDG targets. The results indicate that cooling, lighting, and deficiencies in the building envelope account for the largest share of total energy consumption. Consequently, the most effective retrofit strategies involve improving the thermal performance and insulation of the building envelope, replacing conventional lighting with energy-efficient systems, and optimizing HVAC operations through equipment upgrades and better control management. This study provides an evidence-based framework to guide public retrofit policies and contributes valuable empirical insights to the broader discourse on energy efficiency in government buildings.

Keywords: Building Performance, Energy Efficiency, Government Buildings, Green Buildings

1. Introduction

Climate change and global warming have become increasingly urgent challenges, and the building sector plays a major role by contributing significantly to global energy use and greenhouse gas emissions (IEA, 2022; Olabi et al., 2025). The construction industry adds further pressure on the environment, making a transition toward more sustainable practices essential. One promising pathway is the integration of renewable energy such as solar, wind, geothermal, and biomass into buildings. Studies show that wind energy can meet around 15% of a building's energy demand, while solar can boost the renewable share to as much as 83%, especially when supported by financial incentives like a 30% technology adoption subsidy

(Chen et al., 2024). Alongside technological innovation, green building concepts are gaining momentum as an effective strategy to reduce emissions. However, most green building assessment systems still focus more on the design and construction stages than on actual building operations, creating gaps in regulation, market incentives, and technological readiness (Karamoozian & Zhang, 2025). In Indonesia, government buildings fall into the high energy-use intensity category, which not only increases operational costs but also worsens environmental impacts. Emphasizing energy efficiency through green building principles is therefore considered a strategic pathway for reducing costs while supporting national efforts to mitigate and adapt to climate change (GGGI, 2024). The issues addressed in this study include identifying relevant energy efficiency parameters for government buildings, analyzing the extent to which these parameters are currently being met, and formulating effective strategies for their improvement. This research is important because energy efficiency in government buildings not only contributes to budget savings but also holds strategic value as a model of sustainable practice that can be replicated across other public buildings.

Recent studies have begun to focus on energy efficiency parameters in green buildings. Kajjoba et al. (2025) highlight that thermal comfort, building thermal mass, ventilation, and construction materials play a significant role in energy efficiency in low-income tropical buildings. The study by Lendra et al. (2025) shows that approximately 47% of green building implementation case studies in Indonesia focus on the operational phase, primarily related to energy efficiency and resource management. Furthermore, the study done by Kusumastuti et al. (2025) identifies cooling load, Overall Thermal Transfer Value (OTTV), and lighting density as the main factors contributing to variations in EUI in tropical government buildings.

Studies on green buildings in Indonesia and other countries have been widely conducted, covering aspects such as regulatory developments, implementation trends, and investment challenges in adopting sustainability concepts in the building sector (Adamson & Medeiros, 2023; Kadek et al., 2021). International research highlights that buildings are significant contributors to global energy consumption and carbon emissions, leading to extensive investigations on low-carbon portfolio strategies, building material analyses, and thermal comfort evaluations in the context of energy efficiency (Chiradeja & Ngaopitakkul, 2019; Kajjoba et al., 2025; Su et al., 2024). Nevertheless, most of these studies remain general in nature, focusing on literature reviews, technical aspects, or macro-level policy development, without specifically addressing the context of government buildings in Indonesia.

This study offers novelty by positioning government buildings as the primary object of analysis, recognizing their strategic role as public assets as well as policy models that can be replicated in other public facilities. It not only identifies relevant energy efficiency parameters within the framework of Green Buildings (GB), but also evaluates the extent to which these parameters are met in existing government buildings and formulates more practical implementation strategies. Thus, this research goes beyond previous studies that were largely descriptive, providing practical contributions in the form of recommendations that can serve as a reference for policy and the implementation of energy efficiency in the public sector (Kusumastuti et al., 2025; Lendra et al., 2025; Olabi et al., 2025; Zacki & Pathirana, 2025).

This study aims to assess the implementation of Green Building practices in government buildings in Indonesia by examining the existing conditions, with a primary focus on energy efficiency performance. Specifically, the research seeks to identify the key energy efficiency parameters, formulate their fulfillment levels based on the evaluation of existing buildings, and compare them against established performance standards. Furthermore, the study is directed toward providing implementable strategic recommendations to ensure that energy efficiency can be enhanced in a consistent and sustainable manner.

2. Literature Review

Energy efficiency in buildings has emerged as a critical global concern due to its substantial contribution to overall energy consumption and carbon emissions, particularly in humid tropical regions where cooling loads, lighting requirements, and building envelope performance demand precise optimization strategies. The building envelope plays a decisive role in moderating energy use through the thermal properties of materials, especially thermal conductivity (Pezeshki et al., 2018), with thermal transmittance commonly evaluated using the hot box method under steady-state and dynamic conditions (Trgala et al., 2019). Strategic selection of opaque materials for walls and roofs therefore becomes a key determinant of energy efficiency (Balaji et al., 2019). Complementary insulation techniques, ranging from fiberglass and air gaps as cost-effective solutions (Cao et al., 2015; Zhang & Yang, 2019) to advanced dynamic insulation systems with superior thermal performance (Favoino et al., 2017; Jin et al., 2017), further enhance building energy control. Additionally, transparent envelope innovations such as vacuum and evacuated glazing balance thermal regulation with natural daylighting (Cuce & Cuce, 2016; Fang & Arya, 2019; Sun et al., 2018).

In Indonesia, the regulatory framework set by Ministry of Public Works and Housing (Regulation No. 21/2021) establishes structured implementation of Green Buildings through certification and assessment across seven dimensions, including energy efficiency, water management, indoor air quality, and sustainable material use (Ministry of Public Works and Housing, 2022; Praptomo, 2024). Empirical evidence demonstrates that Green Buildings reduce operational costs, enhance thermal comfort and occupant well-being, and increase asset value (Kevin et al., 2016), while the use of locally sourced, climate-appropriate materials contributes to both energy performance and environmental identity (Edyas et al., 2017). Energy conservation, water recycling, and waste management strategies have also been shown to improve green rating outcomes (Adhiwibowo et al., 2021). Despite persistent challenges such as limited financial resources and technical capacity, phased implementation strategies including pilot projects, workforce development, and digital integration offer viable pathways to scaling adoption. Within this landscape, government buildings hold strategic potential as living laboratories and demonstration sites that can accelerate the diffusion of green building practices, foster public-private collaboration, and reinforce national sustainability commitments (Periyannan et al., 2023). This integrative perspective underscores the importance of aligning technical, regulatory, and behavioral dimensions to strengthen the role of public buildings as key drivers in advancing energy-efficient and sustainable built environments in Indonesia.

2.1. Theory of Energy Efficiency in Buildings

The building sector has been widely recognized as one of the key drivers in reducing global energy demand and mitigating the impacts of climate change. According to the International Energy Agency (IEA), buildings account for nearly 30% of global final energy consumption and around 28% of energy-related CO_2 emissions (IEA, 2022). These proportions are expected to rise further, particularly in developing countries, where rapid urbanization and increasing incomes continue to drive more energy-intensive building operations. In essence, energy efficiency refers to the capacity to lower energy consumption without compromising user comfort or productivity (Kajjoba et al., 2025).

In hot and humid regions, building energy demand is predominantly driven by cooling and lighting requirements. Previous research indicates that upgrading the building envelope through better insulation, advanced glazing, and external shading can reduce cooling loads by 20–30% in climates comparable to Indonesia (El-Darwish & Gomaa, 2017). Yet, lighting remains a major contributor to energy consumption, often due to inefficient luminaires and limited use of daylight. More recently, attention has shifted toward intelligent LED lighting systems as a promising solution for commercial buildings. Evidence from the United States shows that integrating sensor networks, adaptive dimming algorithms, and remote monitoring platforms not only reduced energy use but also enhanced user satisfaction, outperforming conventional lighting approaches (Liu, 2025). Taken together, these findings suggest that while envelope retrofits are essential, the adoption of advanced lighting technologies provides an equally critical pathway for tropical countries like Indonesia, where growing cooling demand and inefficient lighting practices continue to shape unsustainable energy trends.

Discussions on energy efficiency often overemphasize technological fixes, while overlooking the equally important role of human behavior. How people operate HVAC systems, manage lighting, or use electronic devices can alter energy demand by as much as 10–15% (Periyannan et al., 2023). Ignoring this behavioral dimension risks creating buildings that perform well on paper but underdeliver in practice. A genuinely effective strategy must therefore integrate technological improvements with user engagement and sound management practices. Put differently, energy efficiency is not achieved by design alone; it is sustained through the everyday choices people make within the built environment.

2.2. Standards and Assessment of Green Buildings

Green building rating systems offer more than a checklist; they provide a structured framework to assess and guide the performance of building retrofits. Internationally, assessment systems such as Leadership in Energy and Environmental Design (LEED), the Building Research Establishment Environmental Assessment Method (BREEAM), and the WELL standard have been widely adopted (Maqbool et al., 2023). While these systems evaluate key dimensions including energy, water, indoor air quality, materials, and site sustainability they also reveal an important challenge: the tendency to prioritize compliance over context. Without careful adaptation to local climates, cultures, and capacities, such standards risk becoming symbolic rather than transformative.

In Indonesia, green building practices are shaped by a combination of government regulation and voluntary certification. The Ministry of Public Works and Housing issued Circular No. 01/SE/M/2022, which outlines technical guidelines for evaluating the performance of government buildings, with a focus on mandatory energy audits, efficiency assessments, and gradual improvement strategies (Ministry of Public Works and Housing, 2022). Complementing this, the Green Building Council Indonesia (GBCI) introduced the Greenship rating system, which awards credits and certifications for both new and existing buildings. Greenship emphasizes energy efficiency, indoor health, site sustainability, and material selection (GBCI, 2013). While these instruments provide much-needed structure, their effectiveness ultimately depends on consistent enforcement and the willingness of building owners and managers to go beyond compliance. Without this commitment, regulations risk being reduced to formalities rather than catalysts for meaningful transformation.

A green building is one designed to significantly reduce or even eliminate negative impacts on both the environment and its occupants. In Indonesia, the application of green building principles in government facilities is guided by Circular No. 1/SE/M/2022 issued by the Ministry of Public Works and Housing, which emphasizes six core aspects: energy efficiency and conservation, water conservation, indoor air quality and comfort, waste management, site management, and the use of environmentally friendly materials (Periyannan et al., 2023). Performance is assessed through a scoring system that determines certification levels ranging from Pratama to Platinum, with Platinum granted for scores of 85% or higher. As a complementary initiative, the Green Building Council Indonesia (GBCI) developed the voluntary Greenship rating system, applicable to new and existing buildings, industrial sites, and non-government housing. Greenship evaluates seven dimensions: appropriate site development (ASD), energy efficiency and conservation (EEC), water conservation (WAC), material resources and recycling (MRC), indoor health and comfort (IHC), building and environmental management (BEM). Its certification levels including Certified, Silver, Gold, and Platinum reflect both technical rigor and credibility, incorporating independent audits and field inspections. Ultimately, the adoption of green building principles in government projects requires a holistic approach that aligns regulatory frameworks, system efficiency, and managerial capacity. Without such integration, buildings may meet formal standards but fall short of becoming environmentally responsible and adaptive assets for sustainable development.

3. Methods

This research employs a mixed-methods approach, combining quantitative and qualitative techniques to capture a comprehensive understanding of how Green Building principles are implemented in government facilities. The study aims to evaluate energy efficiency, existing building conditions, and alignment with both national and international standards, providing insights that can inform more sustainable strategies for Green Building implementation. The case study focuses on the East Java Public Works and Human Settlements Office building in Indonesia, a three-story facility with a floor area of approximately 6,000 m², constructed prior to the introduction of green building regulations. Its typology reflects the prevailing characteristics of government buildings: reinforced concrete structure, uninsulated walls and roofing, single glazing, and heavy reliance on mechanical cooling systems. The choice of this building is deliberate, as it represents both the energy consumption patterns typical of public infrastructure and the regulatory obligations set out in Government Regulation No. 16/2021 and No. 33/2023. By situating the analysis within such a representative context, the study highlights the critical tension between regulatory aspirations and the realities of an aging building stock, raising questions about the feasibility of retrofitting strategies and the broader challenge of mainstreaming sustainable practices in the public sector.

3.1. Data Collection

3.1.1. Field Observations

On-site visits were conducted to document existing building conditions, including HVAC configuration, lighting systems, user behavior, construction materials, equipment types, and energy control mechanisms. These observations also captured patterns of daily energy consumption, providing a grounded view of how the building operates beyond technical specifications.

3.1.2. Interviews with Facility Managers

Semi-structured interviews were carried out with facility management staff to gain insights into energy management practices, maintenance routines, and institutional barriers. These perspectives proved essential in identifying non-technical obstacles to the adoption of Green Building principles, highlighting the human and organizational dimensions often overlooked in efficiency assessments.

3.1.3. Policy and Regulatory Documents

Key regulatory instruments including Circular No. 01/SE/M/2022 of the Ministry of Public Works and Housing, Government Regulation No. 16/2021, and Government Regulation No. 33/2023 were reviewed to establish compliance requirements. Comparative references were also drawn from national energy codes and international practices to calibrate baseline energy evaluations (Sari et al., 2024). This triangulation not only anchored the study in existing policy frameworks but also underscored the gap between regulatory intent and practical implementation.

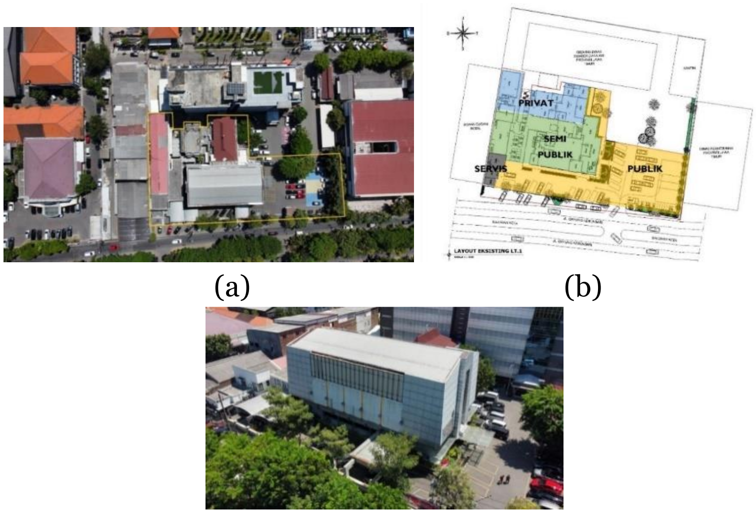
3.2. Analytical Framework

The analytical framework of this study begins with identifying the current condition of government buildings in relation to green building principles, focusing on energy efficiency. The assessment is carried out through data collection on building envelope components, including walls, roofs, and windows, followed by the calculation of the Overall Thermal Transfer Value (OTTV) as the main indicator. The obtained values are then compared against national energy efficiency standards to determine compliance. Finally, the analysis highlights which building elements require improvement and provides recommendations for enhancing energy performance toward sustainable green building implementation.

4. Results and Discussion

4.1. Existing Condition of the Building

The Office of Public Housing, Settlement Areas, and Public Works (PRKPCK) of East Java Province is located at Jalan Gayung Kebonsari No. 169, Gayungan Sub-district, Gayungan District, Surabaya City. The building complex consists of three main structures: the four-story Main Building, the three-story Building Arrangement Office, and the two-story Dharma Wanita Building, which is adjacent to the Water Resources (SDA) Building. The spatial layout of the complex is divided into several zones, including: a public zone directly connected to the main road and functioning as both a vehicle access route and parking area; a semi-public zone serving as the workspace and service area with moderate mobility; and a private zone restricted for internal activities.



(a) (b)

(c)

Figure 1. (a) Location of the PRKPCK East Java Office Building, (b) Existing Layout of the PRKPCK Office Building, and (c) Side View of the Building Facing the South Side

Source: Research Data, 2025

Figure 1a shows the location of the PRKPCK East Java Office Building, while Figure 1b presents its existing layout. On the southern side (Figure 1c), the building features a façade predominantly clad with Aluminium Composite Panels (ACP), which conveys a modern, orderly, and representative appearance in line with the formal and authoritative image expected of government buildings. From a technical perspective, ACP offers advantages such as lightweight properties, ease of installation, and flexibility in color and finishing, thereby strengthening the contemporary expression of the façade. However, the southern orientation exposes the building to prolonged solar radiation, which raises concerns regarding thermal performance.

While the aluminium surface of ACP reflects part of the heat, its conductive core may facilitate heat transfer into the interior, making it necessary to integrate additional insulation layers to ensure indoor thermal comfort. From a sustainability standpoint, this façade also faces challenges such as the potential for weathering and streaking ("ACP bleeding") due to rainwater and pollutant exposure, which could diminish the visual quality of the exterior. Thus, beyond the selection of high-quality materials and proper installation techniques, routine maintenance is required to preserve both the appearance and performance of the façade. In this way, the southern façade functions not only as an external protective layer but also as a balanced representation of aesthetics, energy performance, and building sustainability.

4.2. Water Supply

The primary water source for the PRKPCK office operations is provided by the municipal water company (PDAM), which is first stored in a Ground Water Tank (GWT) before being pumped into the rooftop reservoir. However, the limited capacity of the GWT often fails to meet the demand for clean water and daily operations, resulting in frequent complaints from building users. In addition, the plumbing system is poorly organized, leaving the piping network untidy and inefficient. The inadequate storage capacity also leads to unnecessary electricity consumption, as the pumping process is often triggered when the GWT is empty, causing the pump to run under dry conditions and leading to frequent mechanical failures.

Figure 2. Ground Water Tank (GWT), Water Pump, and Electrical Panel
Source: Research Data, 2025

4.3. Energy Supply

The PRKPCK office receives its primary electricity supply from the State Electricity Company (PLN), supported by an emergency back-up generator. All operational equipment including lighting systems, air conditioners and fans, office devices such as computers and printers, as well as water pumps relies entirely on this power source. However, the existing conditions reveal irregularities in cable placement and non-standard wiring practices, which pose serious risks such as electrical short circuits, potential fire hazards, and accidental electric shocks. Moreover, energy consumption in the building tends to be inefficient, characterized by the continued use of non-LED lighting and the operation of air conditioning units at temperatures consistently below 26 °C. These inefficiencies are further exacerbated by the lack of optimization of natural lighting and ventilation, resulting in unnecessary energy waste and reducing the overall sustainability performance of the building.

Figure 3. Existing Condition of Electricity Use
Source: Research Data, 2025

Figure 3 illustrates that indoor lighting still relies on fluorescent lamps (TL) with wiring installations that lack proper safety considerations. This condition not only poses potential hazards to occupants but also reflects inefficient electricity usage. Therefore, mapping the existing energy consumption of the building is essential to establish a baseline for developing effective energy efficiency strategies. Such mapping serves as a reference for meeting the energy efficiency requirements recommended in the Ministry of Public Works and Housing (PUPR) Circular on Green Buildings (BGH).

4.4. Analysis of Existing Energy Consumption in Government Buildings

Assessing the existing energy consumption of government buildings is crucial to determine their current level of energy efficiency and readiness to meet Green Building (BGH) criteria. Field observations show that energy intensity is measured using the kWh/m²/year indicator, a standard metric for building energy performance. The analysis reveals that the HVAC (Heating, Ventilation, and Air Conditioning) system contributes the largest share of energy consumption, primarily due to the high cooling demand in tropical climates. This burden is exacerbated by suboptimal room temperature control and inadequate building insulation. Artificial lighting also consumes a significant portion of energy, as conventional lamps remain in use and natural daylighting is underutilized due to limited window design and spatial layout that do not follow energy-efficient architectural principles.

These findings highlight a significant gap between actual performance and both national efficiency standards, such as PUPR Circular No. 01/SE/M/2022, and international green building benchmarks. Excessive energy consumption not only increases operational costs and places financial pressure on government budgets but also carries ecological consequences through higher carbon emissions, contributing to climate change. Thus, the challenges for government buildings extend beyond technical issues of reducing cooling and lighting loads, encompassing institutional aspects such as management commitment, budget allocation, and user awareness of energy-saving practices. This underlines that energy efficiency is an integral component of sustainable building management strategies.

Given these conditions, the adoption of retrofit strategies emerges as an urgent measure, particularly targeting HVAC systems and lighting. Such interventions are expected to enhance energy efficiency while improving comfort, productivity, and extending the building's service life. The following section will discuss energy-saving technologies, design integration to better harness natural daylight, and the application of BGH assessment standards within the framework of national regulations. In this way, evaluating the existing condition not only provides a diagnostic baseline but also forms the foundation for realistic policy and technical strategies to achieve energy-efficient, sustainable government buildings aligned with Indonesia's low-carbon development agenda.

4.4.1. Electricity Consumption Data

The following data reflects electricity consumption during the period 2021–2023.

Table 1. Electricity Consumption

Years	Electricity Consumption (kWh/years)
2021	155,827.92
2022	157,961.69
2023	166,537.55

Source: Processed Data, 2025

From Table 1, the increase in energy consumption can be explained by the working arrangements during the observed years. In 2021, most activities were carried out under a Work From Home (WFH) scheme due to the Covid-19 pandemic. As a result, office operations were limited, and energy consumption remained relatively low. However, in 2022–2023, work gradually shifted back to a Work From Office (WFO) setting. With full office operations resuming, energy usage naturally rose, leading to higher electricity bills compared to the WFH period when only a limited number of employees were present on-site.

To set an appropriate energy-saving target, the baseline will be taken from the period of normal office operations, starting from 2022 onward. Based on the data, it is evident that the most influential factor affecting total energy consumption is the number of building occupants.

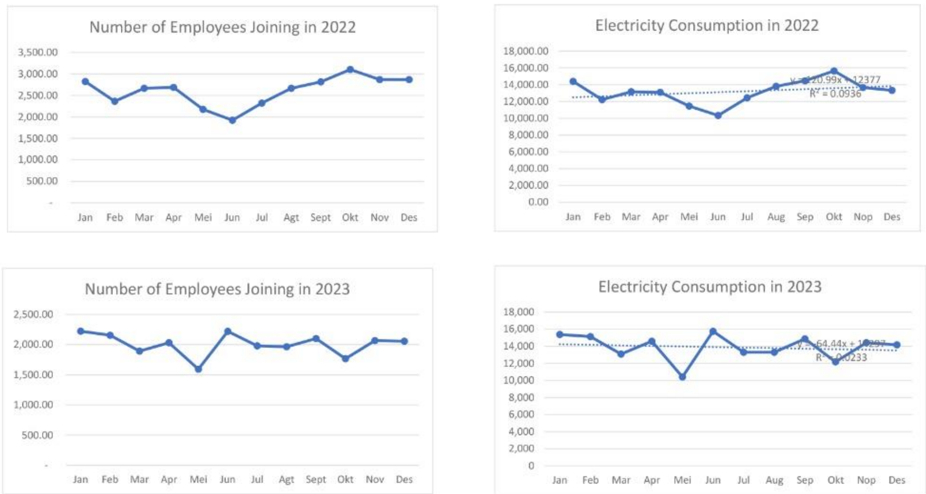
Table 2. Number of Employees at DPRKPCK

No.	Division/Unit	Civil Servants (ASN)	Contract Staff (PTT)	Front Desk	Office Boy (OB)	Security	Total
1	General Affairs and Personnel Subdivision	14	16	3	1		34
2	Program Compilation Sub-Section	11		1	1		13
3	Finance	14	4	1	1		20
4	Building and Construction Management	36	7	2	1		46
5	Spatial Planning	25	2	2	1		30
6	Security					11	11
	Total	100	29	9	5	11	143

* DPRKPCK (Department of Public Housing, Settlement Areas, and Cipta Karya)

Source: Head of Administration and Personnel, DPRKPCK

The table shows the distribution of employees across DPRKPCK divisions. The largest share is in Building and Construction Management with 46 people, followed by General Affairs and Personnel (34), Spatial Planning (30), Finance (20), Sungram (13), and the Security Unit with 11 guards. In total, there are 143 employees, the majority being civil servants. This staffing structure helps explain the rise in energy consumption. As office work returned to normal after the pandemic, more employees were present daily, leading to higher use of lighting, air conditioning, and office equipment compared to the work-from-home period.



	Notes 2022
Jan	ok
Feb	ok
Mar	lowered but still above feb
Apr	ok
Mei	ok
Jun	lower than May
Jul	slightly above average
Agt	ok
Sept	ok
Okt	raised above the sept
Nov	ok
Des	slightly reduced from Nov

	Notes 2023
Jan	ok
Feb	February is the same as January
Mar	March below February and April
Apr	April is the same as February
Mei	under april
Jun	above the april
Jul	the same as march
Agt	the same as july
Sept	the same as april
Okt	above May below August
Nov	under september
Des	under november

Figure 4. Energy Consumption Graph
Source: Processed Data, 2025

From Figure 4 and Table 2, the main factors influencing energy consumption are the use of work equipment such as computers, mobile phone chargers, fans, and air conditioners (AC). During the pandemic, the number of employees was limited to only 50%, and the use of AC was prohibited. As a result, energy consumption mainly came from lighting and computers, which led to relatively low monthly electricity bills. In contrast, under normal conditions, all employees use computers and air conditioners almost throughout the day, causing a significant increase in electricity costs. Surabaya's hot climate often leads to the AC being set as low as 18 °C, even though the Green Building Guideline (GBG) recommends a maximum room temperature of 26 °C while utilizing natural ventilation and airflow to support comfort.

4.4.2. Initial Data of Overall Thermal Transfer Value (OTTV) at PRKPCK Office

Measuring the Overall Thermal Transfer Value (OTTV) at the PRKPCK Office is an essential step in assessing the performance of the building envelope in controlling heat transfer through exterior walls, roofs, and window openings, which directly affects the cooling load of the HVAC system. The initial OTTV data serves as an indicator of how well the building design can reduce heat gain and contributes to energy efficiency analysis, where a higher OTTV value indicates the need for improvements due to higher electricity consumption for cooling. In addition to being a technical requirement under SE PUPR No. 01/SE/M/2022, OTTV evaluation is also a key parameter in the Green Building assessment by the Green Building Council Indonesia (GBCI). An analysis of the existing OTTV data not only provides an initial overview of compliance with energy efficiency standards but also forms the basis for retrofit strategies through the selection of better thermal insulation materials, the addition of shading devices, or facade optimization. Therefore, it plays a strategic role in transforming government buildings toward energy efficiency and sustainability.

NOTIFIED

	Surabaya
ΔT	5

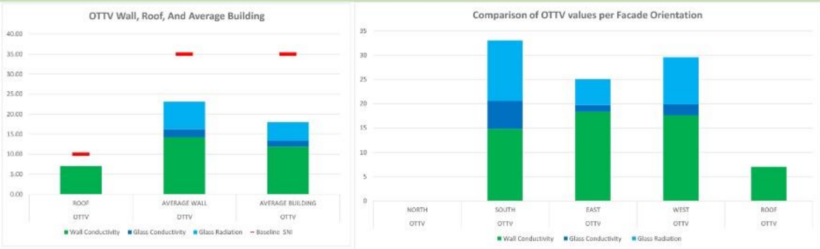
DETERMINED

Orientasi		NORT	SOUTH	EAST	WEST	ROOF
WWR		0%	24%	6%	10%	0%
Wall	Area	153.92	124	280.96	276.48	394
	α	0.00	0.47	0.47	0.47	0.67
	U_w	0.00	2.77	2.77	2.77	0.52
	TD_{ek}	15.00	15.00	15.00	15.00	20.00
Fenestration	Area	-	29.92	16.32	26.87	0.00
	U_f	4.75	4.75	4.75	4.75	4.75
	SC	0.47	0.47	0.47	0.47	0.47
	SF	155	110	194	211	470

CALCULATION

	Orientasi		OTTV NORTH	OTTV SOUTH	OTTV EAST	OTTV WEST	OTTV ROOF	OTTV AVERAGE WALL	OTTV AVERAGE BUILDING
$\alpha[U_w \times (1\text{-}WWR) \times TD_{ek}]$	Wall Conductivity		0.00	14.80	18.38	17.61	7.01	14.21	11.90
$+ (U_f \times WWR \times \Delta T)$	Glass Conductivity		0.00	5.73	1.38	2.31	0.00	2.08	1.41
$+ (SC \times WWR \times SF)$	Glass Radiation		0.00	12.47	5.30	9.64	0.00	6.82	4.64
= OTTV or RTTV			0.00	33.01	25.05	29.56	7.01	23.11	17.95
	Baseline	SNI	35.00	35.00	35.00	35.00	10.00	35.00	35.00

RESULT



	Average Wall	Roof	Average Building
SNI	35.00	10.00	26.99
On Buildings	23.11	7.01	17.95

Figure 5. Overall Thermal Transfer Value (OTTV) of Taba Building
Source: Processed Data, 2025

From Figure 5, the calculation of the Overall Thermal Transfer Value (OTTV) reveals that the southern façade exhibits the highest value at 45.49 W/m², which exceeds the Indonesian national standard of 35 W/m² and indicates a substantial risk of increased cooling energy demand. A detailed breakdown shows that wall conduction contributes the largest share at 37.75 W/m² (≈83%), followed by glass radiation at 5.30 W/m² (≈12%), and glass conduction at 2.44 W/m² (≈5%). This high OTTV value results primarily from the large window-to-wall ratio (56%), the relatively high shading coefficient (SC) and solar factor (SF), and the intense solar radiation exposure during midday and afternoon in Surabaya's tropical climate. If this condition persists without intervention, the elevated OTTV will translate into greater heat gain through the building envelope, forcing mechanical cooling systems to operate longer and less efficiently, ultimately leading to higher energy consumption and reduced sustainability performance. Therefore, the southern façade becomes a critical target for design optimization through measures such as shading devices, reduced glazing ratios, improved wall insulation, or low-emissivity glass to mitigate heat gain and align the building with green building energy efficiency standards.

Based on the SNI 03-6389-2011 standard, the maximum allowable Overall Thermal Transfer Value (OTTV) is 35 W/m² for walls and 10 W/m² for roofs. The evaluation results indicate that the average OTTV of the walls is 20.18 W/m², which remains within the prescribed limit. In contrast, the roof records a value of 15.58 W/m², exceeding the permitted threshold of 10 W/m². When combined, the building's overall average OTTV is 15.07 W/m². Although this value is still below the maximum limit of 35 W/m² set by the standard, it clearly reveals that the roof represents a weak point in the building's thermal performance.

NOTIFIED

	Surabaya
ΔT	5

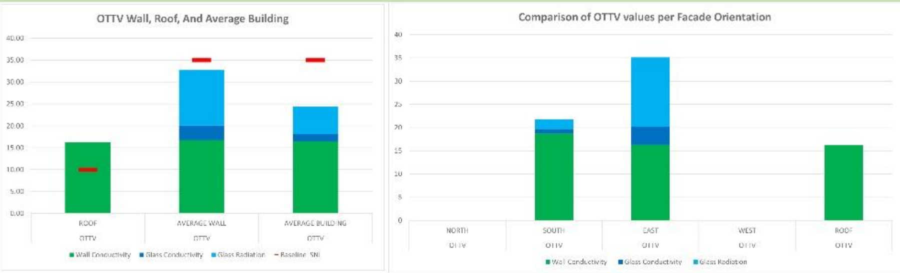
DETERMINED

Orientation		NORTH	SOUTH	EAST	WEST	ROOF
WWR		#DIV/0!	4%	16%	#DIV/0!	0%
Wall	Area	0	90.04	407.2	0	509
	α	0.00	0.47	0.47	0.00	0.70
	U_w	0.00	2.77	2.77	0.00	1.16
	TD_{ek}	15.00	15.00	15.00	15.00	20.00
Fenestration	Area	-	3.60	66.60	0.00	0.00
	U_f	4.75	4.75	4.75	4.75	4.75
	SC	0.47	0.47	0.47	0.47	0.47
	SF	155	110	194	211	470

CALCULATION

	Orientation		OTTV NORTH	OTTV SOUTH	OTTV EAST	OTTV WEST	OTTV ROOF	OTTV AVERAGE WALL	OTTV AVERAGE BUILDING
$\alpha[U_w \times (1\text{-}WWR) \times TD_{ek}]$	Wall Conductivity			18.73	16.32		16.27	16.75	16.51
$+ (U_f \times WWR \times \Delta T)$	Glass Conductivity			0.95	3.88		0.00	3.35	1.66
+ (SC x WWR x SF)	Glass Radiation			2.07	14.91		0.00	12.59	6.22
= OTTV or RTTV			**0.00**	**21.75**	**35.12**	**0.00**	**16.27**	**32.69**	**24.39**
	Baseline	SNI	**35.00**	**35.00**	**35.00**	**35.00**	**10.00**	**35.00**	**35.00**

RESULT



	Average Wall	Roof	Average Building
SNI	35.00	10.00	22.35
On Buildings	32.69	16.27	24.39

Figure 6. OTTV of Dharma Wanita Building
Source: Processed Data, 2025

The figure 6 presents the results of the Overall Thermal Transfer Value (OTTV) calculation for a building in Surabaya with ΔT = 3. The input table includes data on building orientation (north, south, east, west, roof), Window-to-Wall Ratio (WWR), wall conductivity value (U), glass conductivity (Uf), shading coefficient (SC), and solar factor (SF). The calculation shows that OTTV values vary across orientations, with the largest contribution coming from glass radiation on the east-facing facade. The graph compares the OTTV values of walls, the roof, and the overall building average against the SNI standard. The building's average OTTV value is recorded at 24.39, which is still below the SNI threshold (35 for walls and 10 for roofs), indicating that the building design meets thermal efficiency standards.

4.4.3. Analysis of Existing Lighting

The analysis of existing lighting conditions in the PRKPCK office workspace highlights the importance of evaluating illumination as part of energy efficiency efforts. Based on lux testing, illumination levels in several work areas remain uneven. Some areas are over-illuminated, leading to potential energy waste, while others suffer from insufficient lighting, reducing visual comfort and employee productivity. This condition reveals an imbalance in lighting design, both in terms of artificial lighting use and the potential of natural daylight.

Furthermore, the inconsistency between the measured results and technical standards such as SNI 03-6197-2000 on Energy Conservation for Lighting Systems in Buildings and international references underscores the need for improvements in the existing lighting system. The use of conventional high-power lamps without automatic control systems, along with the underutilization of natural lighting, are the main contributors to high energy consumption.

Therefore, the existing lighting data can serve as the basis for developing improvement strategies, including replacing light sources with more efficient technologies such as LEDs, implementing daylight harvesting, and integrating light sensors with automated control systems. These measures are expected not only to meet the required lux standards but also to enhance energy efficiency while creating a healthy, comfortable, and productive working environment.

Table 3. Field Data of Room Lighting (Lux) in the Main Building

Floor	Room Name	Room Category	Standard (Lux)	Measurement Result (Lux)	Remarks
1	Reception	Reception	100	85	Below standard
1	PPID Meeting Room	Meeting Room	300	115	Below standard
1	Meeting Room	Meeting Room	300	94	Below standard
1	Staff Office	Office	250	104	Below standard
1	Prayer Room (Mushola)	Prayer Room	200	77	Below standard
1	Manager's Office	Office	250	83	Below standard
2	Guest Room (2nd Floor)	Guest Room	120	200	Meets standard
2	Head Office Front Desk	Reception	100	79	Below standard
2	Executive Meeting Room	Meeting Room	300	171	Below standard
2	Executive Guest Room	Guest Room	120	100	Below standard
2	Secretary's Office	Office	250	84	Below standard
2	Subdivision Head Office	Office	250	79	Below standard
2	Staff Office	Office	250	127	Below standard
3	Taru Front Desk	Reception	100	220	Meets standard
3	Staff Office	Office	250	147	Below standard
3	Taru Division Head Office	Office	250	147	Below standard
3	Section Head Office	Office	250	147	Below standard
3	Section Head Office	Office	250	147	Below standard
3	Section Head Office	Office	250	147	Below standard
3	Meeting Room	Meeting Room	300	175	Below standard
3	Podcast Room	Theater	200	54	Below standard
3	Small Office	Office	250	170	Below standard
4	Corridor	Corridor	100	550	Meets standard

Floor	Room Name	Room Category	Standard (Lux)	Measurement Result (Lux)	Remarks
4	Conference Room	Conference Room	200	127	Below standard
4	Conference Room	Conference Room	200	127	Below standard
4	Conference Stage	Conference Room	200	127	Below standard

Source: Processed Data, 2025

From the table 3 of lighting measurement results at the PRKPCK office, it is evident that most workspaces, meeting rooms, and service areas have illumination levels below the SNI standard. Only a few areas, such as the 2nd Floor Guest Room, Taru Front Desk, and the Corridor, meet the required standard. This condition indicates an imbalance in the lighting system design, where several rooms suffer from insufficient lighting that may reduce comfort and work productivity, while certain areas receive excessive lighting, potentially leading to energy waste.

Table 4. Field Data of Room Lighting (Lux) in the Taba Building

Floor	Room Name	Room Category	Standard (Lux)	Measurement Result (Lux)	Remarks
1	Service Room	Office	250	150	Below standard
1	Corridor	Corridor	100	470	Meets standard
1	Division Head Office	Division Head Office	200	105	Below standard
1	Toilet	Toilet	200	210	Meets standard
1	Staff Office	Staff Office	250	180	Below standard
1	Meeting Room	Meeting Room	300	250	Below standard
1	Prayer Room (Mushola)	Prayer Room	200	180	Below standard
1	Guest Room	Guest Room	250	250	Meets standard
1	Section Head Office (Jakon)	Section Head Office	250	250	Meets standard
1	Staff Office	Staff Office	250	80	Below standard
2	Guest Room	Guest Room	300	155	Below standard
2	Service Room	Service Room	300	155	Below standard
2	Section Head Office (Taba Int)	Section Head Office	140	140	Below standard
2	Section Head Office (Taba Eks)	Section Head Office	250	50	Below standard
2	Staff Office	Staff Office	250	80	Below standard

Floor	Room Name	Room Category	Standard (Lux)	Measurement Result (Lux)	Remarks
2	Prayer Room (Mushola)	Prayer Room	200	180	Below standard
2	Treasurer's Office	Treasurer's Office	250	81	Below standard
2	Meeting Room	Meeting Room	300	205	Below standard
2	Prayer Room (Mushola)	Prayer Room	200	180	Below standard
2	Ablution Area (Wudhu)	Ablution Area	200	150	Below standard

Source: Processed Data, 2025

Table 4. The lighting measurement results on the 1st and 2nd floors show that most rooms are still below the required lux standard, particularly staff offices, service areas, the prayer room, meeting rooms, and several executive offices. This condition may reduce visual comfort and work productivity. Only a few spaces meet the standard, such as corridors, toilets, the guest room, and the Head of Jakon's office, while other rooms such as the Head of Taba Eks office, the treasurer's office, and staff rooms have lighting levels far below the requirements. These findings indicate the need for a reorganization of the lighting system, either by optimizing natural daylight or replacing lamps with more efficient alternatives, in order to achieve a more even lighting distribution in line with building energy conservation standards.

Table 5. On-Site Measurement of Indoor Lighting Levels (Lux) in the Dharmawanita Building

Fl	Room Name	Room Category	Standard (Lux)	Measurement Result (Lux)	Remarks
1	Service Room	Office Space	250	259	Meets Standard
1	Corridor	Corridor	100	470	Meets Standard
1	Toilet	Toilet	200	49	Below Standard
1	Record Room	Theater	200	209	Meets Standard
1	Record Room	Theater	200	524	Meets Standard
1	Dharmawanita Room	Meeting Room	300	39	Below Standard
1	Dharmawanita Room	Meeting Room	300	230	Below Standard
1	Canteen	Food Stall	250	80	Below Standard
2	Podcast Meeting Room	Meeting Room	300	130	Below Standard
2	Podcast Meeting Room	Meeting Room	300	155	Below Standard
2	Office Room	Office Space	250	140	Below Standard
2	Left-Side Podcast Office Room	Office Space	250	50	Below Standard

Fl	Room Name	Room Category	Standard (Lux)	Measurement Result (Lux)	Remarks
2	Left-Side Podcast Office Room	Office Space	250	80	Below Standard
2	Prayer Room (Mushola)	Prayer Room	200	140	Below Standard
2	Office Room	Office Space	250	81	Below Standard
2	Meeting Room	Meeting Room	300	205	Below Standard

Source: Processed Data, 2025

The lighting measurement results show that only a small number of rooms meet the standards, namely the service room, corridor, and record room on the 1st floor, while most other rooms such as toilets, Dharmawanita room, canteen, podcast meeting room, work room, prayer room, and meeting room on the 2nd floor are still below the required lighting standards. This finding confirms the need for lighting improvements, both by optimizing natural lighting and adding artificial lights, so that all rooms can meet occupational comfort and health standards.

4.4.4. Energy Efficiency Parameters in the Context of Green Building

The energy efficiency parameters in this study were developed based on national regulations through SE PUPR No. 01/SE/M/2022 on Technical Guidelines for Green Building (BGH) and the Greenship Rating Tools from the Green Building Council Indonesia (GBCI). Both instruments are the main reference in assessing the extent to which a building meets the principles of sustainability, especially in the energy sector which is the largest component in the resource consumption of government buildings. The research focuses on the performance of the building envelope, and lighting and energy management systems, parameters that directly affect the operational efficiency, thermal comfort and carbon emissions of the building.

In addition to technical achievements, energy efficiency assessment at BGH also emphasizes the importance of continuous evaluation and monitoring. Instruments such as Overall Thermal Transfer Value (OTTV), energy consumption intensity per building area (kWh/m²/year), mechanical-electrical equipment efficiency, to the application of sub-metering and IoT-based digital systems, are quantitative indicators that must be met. Thus, energy efficiency parameters not only serve as a measuring tool, but also as an implementation guideline in planning, retrofitting, and building operations. The study of existing field data is the first step to formulate an optimization strategy that is able to reduce the energy burden while supporting the realization of the Green Building concept in a sustainable manner.

4.5. Discussion

The assessment of green building implementation in government buildings indicates that energy efficiency performance remains inconsistent and often falls short of national standards. Field measurements (Tables 3 and 4) show that most working spaces, meeting rooms, prayer rooms, and several executive offices are below the required lighting standards, whereas corridors, toilets, and selected reception areas meet SNI-regulated lux levels. This imbalance suggests that current lighting system designs have not fully incorporated green building principles, resulting in visual discomfort, reduced productivity, and unnecessary energy consumption. These findings highlight the need for targeted retrofitting interventions, including optimizing natural daylighting with improved window placement and shading devices, upgrading conventional lighting to energy-efficient LEDs, and implementing occupancy-based lighting controls. In addition, cooling and thermal comfort can be enhanced through high-efficiency HVAC systems, improved wall and roof insulation, reflective coatings or green roofs, and automated ventilation and shading systems.

A limitation of this study is its cross-sectional nature, which captures performance at a single point in time, and it does not fully consider variations in occupant behavior that affect energy use. Despite these constraints, the results provide actionable insights for policymakers and facility managers in Indonesia by explicitly linking measured inefficiencies to practical interventions. By demonstrating how targeted retrofits can improve lighting and cooling performance, this study extends current knowledge and offers policy-relevant guidance for advancing green building practices in government buildings, reinforcing their role as models for sustainable development and low-carbon public infrastructure.

Cooling loads present another critical challenge. The case study in Surabaya demonstrates that air conditioners were operated at 18 °C, significantly lower than the recommended 26 °C in the national Green Building Guidelines (SE PUPR No. 01/SE/M/2022). Such practices substantially increase electricity consumption, particularly during normal operational periods when staff occupancy is at full capacity. Together with inefficient lighting, this situation explains the higher-than-expected Energy Use Intensity (EUI) observed in these government buildings. These findings support Kusumastuti et al. (2025), who emphasized that cooling and lighting are dominant factors influencing EUI in tropical office buildings.

Compared to previous studies, this research provides a more contextualized understanding of green building practices in the public sector. While Kajjoba et al. (2025) highlighted thermal comfort and material selection in low-income tropical housing, and Lendra et al. (2025) noted that most studies in Indonesia remain focused on the operational phase of green buildings, this study underscores that government buildings represent a strategic category. They are not only operational facilities but also symbols of state commitment to sustainability. Unlike global studies such as Chiradeja & Ngaopitakkul (2019) and Su et al. (2024), which predominantly discuss low-carbon materials and design innovations, the present findings demonstrate that government buildings can serve as policy instruments showcasing exemplary practices that are replicable in other public infrastructure. This positioning becomes increasingly relevant when connected to broader technological advances in smart energy management.

Recent studies have shown how artificial intelligence and digital technologies can significantly enhance building sustainability. This paper reviews the work in the areas of machine learning applications for energy management in smart buildings, 5G technology's role in smart energy management, and the use of machine learning algorithms in microgrid energy management systems. The first area focuses on the adaptability of building-integrated energy systems to unpredictable changes through AI-initiated learning processes and digital twins. The second area explores the impact of 5G technology, particularly in Singapore, emphasizing its role in facilitating high-class services and efficient functionalities. The third area delves into the application of various machine learning algorithms, such as supervised and unsupervised learning, in managing and monitoring microgrids. These broad areas collectively offer a comprehensive understanding of how machine learning can revolutionize energy management systems in smart buildings, making them more efficient, adaptable, and sustainable (Singh et al., 2024). By integrating these technological perspectives, this study not only situates green government buildings within sustainability discourses but also highlights their potential to become active nodes in smart energy networks, positioning public buildings as drivers of innovation and energy transition in the built environment.

The practical implications of this assessment call for targeted retrofit strategies in government buildings, including improvements in thermal insulation, systematic redesign of lighting systems, and the adoption of smart cooling technologies. Beyond reducing operational costs and carbon emissions, such measures carry symbolic weight, demonstrating the government's leadership in the transition toward sustainable development. Academically, this study opens new discourse on the integration of technical performance and governance within energy efficiency, stressing that success depends not only on technology adoption but also on compliance with regulations and behavioral patterns of building users. Future research should adopt longitudinal approaches and integrate behavioral studies to capture the dynamic interaction between human practices and energy systems, thereby strengthening the effectiveness of green building implementation in the public sector.

5. Conclusion

This study highlights that government buildings in Indonesia face significant challenges in energy efficiency, particularly in managing cooling loads, lighting, and building envelope performance. Unlike prior studies that are largely descriptive or focus broadly on tropical buildings, this research contributes novelty by positioning government buildings as both strategic energy consumers and models for public policy replication across other facilities. The findings demonstrate that applying Green Building principles in the public sector not only reduces operational costs and carbon emissions but also strengthens the government's role as a pioneer in sustainable development, providing practical guidance for regulation, retrofit strategies, and energy efficiency implementation. From an academic perspective, this study expands the discourse on energy efficiency from a purely technical concern to a policy instrument that can accelerate the transition toward low-carbon development. Limitations include the cross-sectional nature of the analysis and the limited examination of user behavior, suggesting that future research should incorporate longitudinal monitoring, behavioral studies, and integration of digital and smart building technologies to ensure more comprehensive and sustainable energy efficiency strategies in government buildings.

6. References

Adamson, S., & Medeiros, A. S. (2023). The greenlight for government buildings: strategies for a low-carbon building portfolio. *FACETS*, *8*, 1–10. https://doi.org/10.1139/facets-2022-0193

Adhiwibowo, S., Ischak, M., & Pratiwi, S. N. (2021). Penerapan Konsep Arsitektur Hijau Pada Apartemen Jaticempaka. *Prosiding Seminar Intelektual Muda*, *3*(1). https://doi.org/10.25105/psia.v3i1.13075

Balaji, N. C., Mani, M., & Venkatarama Reddy, B. V. (2019). Dynamic thermal performance of conventional and alternative building wall envelopes. *Journal of Building Engineering*, *21*, 373–395. https://doi.org/10.1016/j.jobe.2018.11.002

Cao, X., Liu, J., Cao, X., Li, Q., Hu, E., & Fan, F. (2015). Study of the thermal insulation properties of the glass fiber board used for interior building envelope. *Energy and Buildings*, *107*, 49–58. https://doi.org/10.1016/j.enbuild.2015.08.007

Chen, L., Hu, Y., Wang, R., Li, X., Chen, Z., Hua, J., Osman, A. I., Farghali, M., Huang, L., Li, J., Dong, L., Rooney, D. W., & Yap, P.-S. (2024). Green building practices to integrate renewable energy in the construction sector: a review. *Environmental Chemistry Letters*, *22*(2), 751–784. https://doi.org/10.1007/s10311-023-01675-2

Chiradeja, P., & Ngaopitakkul, A. (2019). Energy and Economic Analysis of Tropical Building Envelope Material in Compliance with Thailand's Building Energy Code. *Sustainability*, *11*(23), 6872. https://doi.org/10.3390/su11236872

Cuce, E., & Cuce, P. M. (2016). Vacuum glazing for highly insulating windows: Recent developments and future prospects. *Renewable and Sustainable Energy Reviews*, *54*, 1345–1357. https://doi.org/10.1016/j.rser.2015.10.134

Edyas, A., Daming, T., & Syarif, E. (2017). Konsep Arsitektur Tropis pada Green Building sebagai Solusi Hemat Biaya (Low Cost). *Temu Ilmiah Ikatan Peneliti Lingkungan Binaan Indonesia 6*, 33–40. https://doi.org/10.32315/ti.6.h033

El-Darwish, I., & Gomaa, M. (2017). Retrofitting strategy for building envelopes to achieve energy efficiency. *Alexandria Engineering Journal*, *56*(4), 579–589. https://doi.org/10.1016/j.aej.2017.05.011

Fang, Y., & Arya, F. (2019). Evacuated glazing with tempered glass. *Solar Energy*, *183*, 240–247. https://doi.org/10.1016/j.solener.2019.03.021

Favoino, F., Jin, Q., & Overend, M. (2017). Design and control optimisation of adaptive insulation systems for office buildings. Part 1: Adaptive technologies and simulation framework. *Energy*, *127*, 301–309. https://doi.org/10.1016/j.energy.2017.03.083

GBCI. (2013). *Greenship Rating Tools New Building*. Green Building Council Indonesia. https://gbcindonesia.org/greens/new

GGGI. (2024). *Low Carbon Buildings to Achieve Indonesia's Climate Ambitions*. Global Green Growth Institute. https://gggi.org/low-carbon-buildings-to-achieve-indonesias-climate-ambitions/

IEA. (2022). *Global Status Report for Buildings and Construction*. International Energy Agency (IEA). https://www.iea.org/Reports/Global-Status-Report-for-Buildings-and-Construction-2022

Jin, Q., Favoino, F., & Overend, M. (2017). Design and control optimisation of adaptive insulation systems for office buildings. Part 2: A parametric study for a temperate climate. *Energy*, *127*, 634–649. https://doi.org/10.1016/j.energy.2017.03.096

Kadek, B. W., Kumara, I., & Sari Hartati, R. (2021). Studi Literatur Perkembangan Green Building di Indonesia. *Jurnal SPEKTRUM*, *8*(2), 37. https://doi.org/10.24843/SPEKTRUM.2021.v08.i02.p5

Kajjoba, D., Wesonga, R., Lwanyaga, J. D., Kasedde, H., Olupot, P. W., & Kirabira, J. B. (2025). Assessment of thermal comfort and its potential for energy efficiency in low-income tropical buildings: a review. *Sustainable Energy Research*, *12*(1), 25. https://doi.org/10.1186/s40807-025-00169-9

Karamoozian, M., & Zhang, H. (2025). Obstacles to green building accreditation during operating phases: identifying Challenges and solutions for sustainable development. *Journal of Asian Architecture and Building Engineering*, *24*(1), 350–366. https://doi.org/10.1080/13467581.2023.2280697

Kevin, G., Anggalimanto, I., Chandra, H. P., & Ratnawidjaja, S. (2016). Analisis tantangan dan manfaat bangunan hijau. *Jurnal Dimensi Pratama Teknik Sipil*, *5*(2).

Kusumastuti, D., Setyowati, E., Sari, S., & Dwiyanto, A. (2025). Analysis of Energy Use Intensity (EUI) Factors in Government Office Buildings in Tropical Climate: A Case Study in the Ministerial Office Building and the Directorate General of Water Resources Building of The Ministry of Public Works. *TEKNIK*, *46*(3), 209–217. https://doi.org/10.14710/teknik.v46i3.72798

Lendra, L., Jesica, J., Agung Wibowo, M., Hatmoko, J. U. D., & Andi, A. (2025). Green building assessment tools in Indonesia: A systematic literature review and comparative analysis. *E3S Web of Conferences*, *605*, 03023. https://doi.org/10.1051/e3sconf/202560503023

Liu, G. (2025). The Application and Energy-Saving Effect Analysis of Intelligent LED Lighting

Systems in Commercial Buildings. *Studies in Art and Architecture*, *4*(3), 30–37. https://doi.org/10.56397/SAA.2025.06.04

Maqbool, R., Thompson, C., & Ashfaq, S. (2023). LEED and BREEAM Green Building Certification Systems as Possible Game Changers in Attaining Low-Cost Energy-Efficient Urban Housing Projects. *Journal of Urban Planning and Development*, *149*(3). https://doi.org/10.1061/JUPDDM.UPENG-4292

Ministry of Public Works and Housing. (2022). *Petunjuk Teknis Penilaian Kinerja Bangunan Gedung Hijau*. Ministry of Public Works and Housing. https://jdih.pu.go.id/detail-dokumen/SEMenteriPUPR-nomor-01-tahun-2022-Petunjuk-Teknis-Penilaian-Kinerja-Bangunan-Gedung-Hijau

Olabi, A. G., Shehata, N., Issa, U. H., Mohamed, O. A., Mahmoud, M., Abdelkareem, M. A., & Abdelzaher, M. A. (2025). The role of green buildings in achieving the sustainable development goals. *International Journal of Thermofluids*, *25*, 101002. https://doi.org/10.1016/j.ijft.2024.101002

Periyannan, E., Ramachandra, T., & Geekiyanage, D. (2023). Assessment of costs and benefits of green retrofit technologies: Case study of hotel buildings in Sri Lanka. *Journal of Building Engineering*, *78*, 107631. https://doi.org/10.1016/j.jobe.2023.107631

Pezeshki, Z., Soleimani, A., Darabi, A., & Mazinani, S. M. (2018). Thermal transport in: Building materials. *Construction and Building Materials*, *181*, 238–252. https://doi.org/10.1016/j.conbuildmat.2018.05.230

Praptomo, N. E. (2024). Penerapan Konsep Bangunan Gedung Hijau (BGH) pada Rumah Susun Tenaga Pendidik UGM. *Prosiding (SIAR) Seminar Ilmiah Arsitektur*. https://proceedings.ums.ac.id/siar/article/view/4241

Sari, D. P., Maidina, Sumarno, A., Prasetyo, A. M., & Ngeljaratan, L. (2024). The application of Indonesia green building rating system for sustainable buildings. *AIP Conference Proceedings*. https://doi.org/10.1063/5.0184511

Su, Y., Jin, Q., Zhang, S., & He, S. (2024). A review on the energy in buildings: Current research focus and future development direction. *Heliyon*, *10*(12), e32869. https://doi.org/10.1016/j.heliyon.2024.e32869

Sun, Y., Wilson, R., & Wu, Y. (2018). A Review of Transparent Insulation Material (TIM) for building energy saving and daylight comfort. *Applied Energy*, *226*, 713–729. https://doi.org/10.1016/j.apenergy.2018.05.094

Trgala, K., Pavelek, M., & Wimmer, R. (2019). Energy performance of five different building envelope structures using a modified Guarded Hot Box apparatus—Comparative analysis. *Energy and Buildings*, *195*, 116–125. https://doi.org/10.1016/j.enbuild.2019.04.036

Zacki, A., & Pathirana, S. (2025). Effect of green building features on energy efficiency of university buildings in tropical climate. *Sustainable Futures*, *10*, 101069. https://doi.org/10.1016/j.sftr.2025.101069

Zhang, T., & Yang, H. (2019). Heat transfer pattern judgment and thermal performance enhancement of insulation air layers in building envelopes. *Applied Energy*, *250*, 834–845. https://doi.org/10.1016/j.apenergy.2019.05.070