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Original Article

An Impact Analysis of Retrofit Shading and Double Skin Facade on Building Performance at the Glass Office of PT Pertamina Patra Niaga - ITJ Jakarta

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Abstract

Modern office buildings with glass envelopes often encounter challenges in energy efficiency, particularly due to excessive reliance on artificial lighting during daytime and intensive use of cooling systems. This condition is occurred at the PT Pertamina Patra Niaga - ITJ Jakarta office building. The installation of window films and curtain blinds has made interior spaces darker, preventing optimal utilization of natural daylight and consequently increasing electricity consumption. Such conditions not only reduce energy efficiency but also compromise visual comfort for occupants. This study aims to analyze the impact of retrofit shading and the double skin façade (DSF) on daylighting performance, visual comfort, and energy efficiency. The research employed an existing condition analysis using the Sefaira plug in SketchUp software and Sefaira web model - energyplus to simulate and evaluate the effects of retrofitting on the glass office building. The findings reveal that the integration of retrofit shading and DSF significantly improves natural daylighting quality 2% underlit, 42% well lit, and 44% overlit. Visual comfort was enhanced by lowering indoor illuminance levels of ASE from 87% to 43% lux and sDA from 100% to 98% lux, aligning with recommended standards. Furthermore, annual electricity consumption decreased substantially, from 269 to 130 kWh/m² per year. In conclusion, retrofit shading and DSF provide effective passive design strategies that enhance daylight utilization, improve occupant comfort, and support energy conservation. This study serves as a preliminary investigation for future research on integrating multiple passive design strategies in office building retrofits.

Keywords: Building Performance, Double Skin Facade, Glass Office, Retrofit, Shading.

1. Introduction

Buildings are among the largest contributors to global energy consumption. According to the International Energy Agency (IEA), the building sector accounts for approximately 30–40% of total global energy demand and nearly one-third of carbon emissions. Office buildings, in particular, are significant contributors due to their intensive reliance on artificial lighting and mechanical cooling systems. In tropical regions, this challenge is even more critical as high solar radiation and warm temperatures prevail throughout the year, resulting in excessive cooling and lighting demands. These conditions highlight the urgency of implementing passive design strategies that not only reduce energy consumption but also align with global targets for carbon emission reduction and sustainable development.

In Indonesia, particularly in Jakarta, modern office buildings with extensive glass façades face severe challenges in terms of energy efficiency. Although glass envelopes allow daylight penetration, they also create problems of glare, overheating, and reduced visual comfort. Conventional solutions such as window films and curtain blinds often darken interior spaces, which reduces the effective use of natural daylight. Consequently, artificial lighting is frequently required even during daytime, thereby increasing electricity consumption. This paradox not only decreases overall energy efficiency but also negatively impacts indoor comfort and worker productivity.

The glass façade office building of PT Pertamina Patra Niaga - ITJ Jakarta experiences similar challenges, including glare, overheating, and reduced visual and thermal comfort. The building is exposed to intense solar radiation throughout the year due to its location in Jakarta, Indonesia, which lies within a tropical hot-humid climate zone. Consequently, the building envelope receives significant solar heat gain and excessive daylight exposure. Based on the pre-design analysis conducted using the SketchUp plug-in software on September 22, 2025, as illustrated in Figure 1.

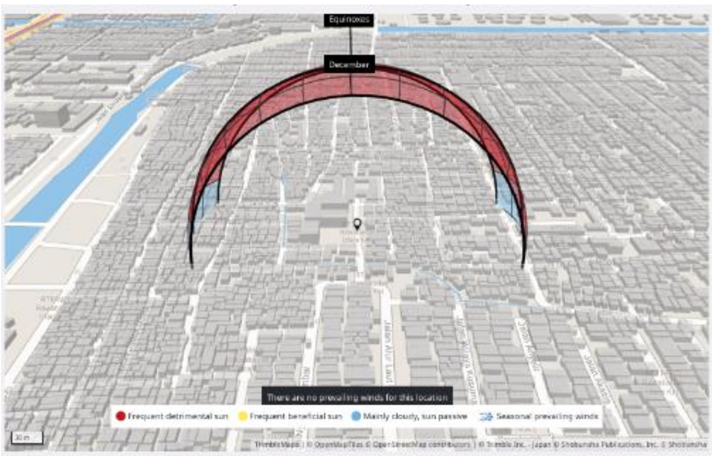

Figure 1. The sun and wind affect the site all year
Source: Author analysis (2025); pre-design sketchup plug in software

This condition significantly affects the overall performance of the office building, as hot weather conditions are more dominant than cool periods throughout the year, as illustrated in Figure 2.

Figure 2. Impact of tropical climate
Source: Author analysis (2025); pre-design sketchup plug in software

The figure 2 above illustrates the impact of climate on architectural response in Jakarta, where the research site is located. The analysis indicates that approximately 62% of the time, the area experiences warm and windy conditions. In such environments, people not only seek protection from sunlight and wind but also desire thermal comfort and a cooler indoor environment. The intense solar radiation has adversely affected the building performance of the PT Pertamina Patra Niaga - ITJ Jakarta glass office building, resulting in reduced natural daylight penetration and increased indoor air temperature, making workspaces uncomfortable. Furthermore, the elevated cooling load has led to higher electricity consumption, as depicted in Figure 3.

Figure 3. The effects of solar radiation
Source: Author documentation (2024)

The figure 3 clearly illustrates that excessive solar exposure has adversely affected the performance of the PT Pertamina Patra Niaga - ITJ Jakarta glass office building. A considerable body of research emphasizes the role of passive retrofitting strategies in improving building performance. Shading devices have been shown to significantly reduce glare while maintaining adequate daylight levels, thus minimizing reliance on artificial lighting and enhancing visual comfort. External shading, depending on its design and orientation, can reduce solar heat gains by up to 90% (Givoni, 1998). Givoni (1998) also highlighted that effective shading lowers cooling loads, thereby reducing overall energy consumption. However, he stressed the importance of balancing shading with adequate daylighting to avoid dark interiors. Szokolay (2014) reinforced this view, describing shading as one of the most effective and economical passive strategies to control solar radiation, reduce heat gains, and ensure thermal comfort in tropical humid climates.

In addition to shading, the double skin façade (DSF) has also been widely studied as an effective retrofit strategy. According to Aksamija (2013), DSFs are designed to dynamically respond to climate and environmental conditions by integrating passive and active systems to manage solar radiation, airflow, and indoor thermal comfort. DSFs not only reduce solar heat gain but also act as protective buffers against external weather conditions. Studies have shown that DSF retrofits can reduce energy consumption by up to 35% when designed with appropriate climate responsiveness, ventilation management, and automation systems. Passive retrofit approaches, including shading, DSF, and green roofs, have been identified as highly effective in improving energy performance and indoor environmental quality in existing buildings (Aksamija, 2013; Dvorak, 2021; Givoni, 1998; Szokolay, 2014; Tsangrassoulis & Kontaxis, 2015; Wilkinson & Dixon, 2016).

Despite these findings, studies on the combined application of retrofit shading and DSF in existing office buildings within tropical humid climates remain limited, particularly in Indonesia. Most prior research has concentrated on new constructions or different building types, such as residential or educational facilities. This gap is both relevant and urgent, especially in dense urban contexts like Jakarta. The case of PT Pertamina Patra Niaga - ITJ Jakarta office building illustrates a practical context where problems of glare, overheating, and excessive electricity use caused by reliance on daytime artificial lighting and cooling can be addressed through passive façade retrofitting strategies.

In sum, this study aims to analyze the impact of retrofit shading and double skin façade on daylighting performance, visual comfort, and energy efficiency in a glass-clad office building. Moreover, this research is expected to enrich the literature on passive retrofit strategies for building envelopes in tropical climates and serve as a reference for future studies and support national targets for sustainability and carbon emission reduction.

2. Literature Review

According to Victor Olgyay in Design with Climate: Bioclimatic Approach to Architectural Regionalism (1963), climate-responsive architecture can enhance thermal comfort without full reliance on mechanical system. Shading devices whether in the form of canopies, horizontal fins, or vertical louvers serve to regulate the direct penetration of solar radiation into interior spaces, maintaining stable indoor temperatures and reducing glare (Olgyay, 1963). Consistent with Olgyay's view, Szokolay (2004) emphasized that one of the key principles of sustainable architectural design is the ability to control solar radiation through passive strategies such as shading. Passive design strategies, particularly shading, play a crucial role in controlling the thermal load of buildings in tropical and subtropical climates. Shading also improves visual quality by reducing contrast and glare caused by direct sunlight, thereby enhancing visual comfort which is an issue frequently encountered in glass façade buildings. Thus, shading is not merely a technical solution but an integral component of the bioclimatic approach in architectural design, aimed at improving both energy efficiency and occupant thermal comfort (Szokolay, 2004). Meanwhile, Givoni (1998) stressed that building designs incorporating natural ventilation and protection from solar radiation which is achieved through shading elements can significantly reduce active cooling demand. Givoni (1998) demonstrated that the application of shading devices such as overhangs, louvers, or vertical fins can markedly lower indoor temperatures and extend thermal comfort periods without mechanical HVAC systems. Givoni (1998) also affirmed that climate-responsive design integrating natural ventilation and solar control barriers represents an effective adaptive strategy for tropical regions. This approach is highly relevant for hot-humid countries such as Indonesia, where passive design strategies substantially contribute to reducing building energy consumption (Givoni, 1998). In the context of retrofitting existing buildings in tropical climates like Indonesia, the implementation of shading presents a highly contextual and energy-efficient solution.

Herzog et al. (2004) stated that the double-skin façade (DSF) not only enhances aesthetic value but also plays a crucial role in regulating a building's microclimate through natural ventilation, thermal insulation, and noise reduction. The implementation of DSF in existing office buildings enables a significant reduction in annual energy demand, particularly for cooling and lighting, as the double-layered façade effectively blocks heat and glare before reaching the interior. In line with this view, Aksamija (2013) emphasized that DSF represents a critical component of high-performance building envelope design due to its ability to improve energy efficiency, thermal comfort, and indoor environmental quality. Aksamija (2013) explained that DSF functions both passively and actively through the combination of double-glazed layers that create an intermediate ventilated cavity, allowing natural air circulation and dissipating excessive solar heat. With proper design configuration, DSF can reduce cooling loads by 30-50%, depending on building orientation and local climate conditions. Furthermore, the double façade contributes to diffused natural daylight, reducing dependence on artificial lighting and enhancing occupants' visual comfort. Research by Tsangrassoulis & Kontaxis (2015) reinforces the effectiveness of DSF in improving the energy performance of existing buildings. Their study concluded that DSF plays a significant role in passive thermal control through the use of natural ventilation within the cavity between façade layers, allowing heat to be dissipated before entering the interior spaces. Moreover, DSF was found to reduce indoor temperature fluctuations and lower cooling energy consumption by up to 40% in hot climates. A review of various case studies also revealed that the optimization of design parameters and ventilation control strategies is key to maximizing DSF performance without compromising occupant comfort or architectural aesthetics. Therefore, integrating DSF into existing building retrofit projects not only enhances energy efficiency but also supports the broader goal of achieving sustainable architecture (Tsangrassoulis & Kontaxis, 2015).

Aksamija (2013) provides a strong conceptual and technical foundation for the application of passive design strategies in building retrofit projects, particularly in the context of energy efficiency. The integration of shading, double-skin façades (DSF), and vegetation aligns with the principles of high-performance building envelopes and is highly relevant for existing buildings in tropical climates such as Indonesia. Aksamija (2013) emphasizes the importance of an integrative façade design approach in which multiple passive strategies operate synergistically rather than independently to achieve optimal thermal and energy performance. This approach is especially pertinent to office building retrofits in humid tropical environments, where effective passive solutions are essential to reduce cooling loads and electricity consumption. As Aksamija (2013) notes, "A multi-strategy retrofit combining passive shading, double-skin envelopes, and green roofing systems provides the most comprehensive approach for reducing operational energy use in existing buildings." He further asserts that "Integrated façade strategies which combining shading, double-skin systems, and vegetated envelopes are crucial in retrofitting buildings for long-term energy performance and climate resilience." The integration of shading, DSF, and green roofs in building retrofits aims to achieve holistic energy efficiency. Collectively, these strategies work synergistically to lower operational energy consumption, enhance thermal comfort, and support the sustainability of existing buildings (Aksamija, 2013).

Integrating two passive retrofit design strategies: shading and Double Skin Façade (DSF) could improve building performance, particularly in terms of daylighting performance, visual comfort, and energy efficiency. The integration of shading and double-skin façade (DSF) systems represents an advanced passive retrofit approach that synergistically enhances building energy performance and occupant comfort. While shading primarily serves to control direct solar radiation and glare, DSF functions as a dynamic thermal buffer that mediates heat transfer and facilitates natural ventilation. The combination of these two systems provides a complementary effect which is a shading reduces the intensity of solar gain on the outer façade, thereby lowering the thermal load entering the DSF cavity, which in turn optimizes air circulation and reduces cooling energy demand.

Several studies have demonstrated that integrating external shading devices with DSF can improve overall façade performance in hot-humid climate. This hybrid configuration not only moderates indoor temperature fluctuations but also enhances daylight distribution, producing a more balanced luminance environment. Properly designed integration of shading and DSF can reduce energy consumption for lighting and cooling by up to 40-60%, depending on orientation and control strategies (Aksamija, 2013; Tsangrassoulis & Kontaxis, 2015). Moreover, this combination contributes to improved visual comfort by diffusing daylight and minimizing glare, issues commonly encountered in glass façade office buildings.

In the context of tropical regions such as Indonesia, where solar radiation and humidity levels are consistently high throughout the year, integrating shading and DSF in retrofit applications offers a practical and contextually adaptive solution. Beyond energy savings, the combined system supports the creation of thermally and visually comfortable indoor environments while aligning with sustainable building objectives. Hence, this integrated passive retrofit approach not only enhances environmental performance but also extends the functional lifespan and resilience of existing glass façade buildings.

Passive design plays a crucial role in sustainable architecture by enabling buildings to respond effectively to climatic conditions with minimal mechanical energy use (Olgyay, 1963; Szokolay, 2014). Shading helps regulate solar radiation, minimize glare, and maintain thermal balance, while DSF serves as a dynamic façade system with an air cavity that enhances natural ventilation and daylight distribution. Together, these systems create a synergistic effect that optimizes indoor environmental quality and reduces energy demand. In the context of tropical climates like Indonesia, where solar radiation and humidity are persistently high, the integration of shading and DSF becomes essential to achieve sustainable building performance.

2.1. Theory of Shading

Shading is a passive architectural strategy designed to block direct sunlight from entering buildings, thereby reducing cooling loads and improving thermal comfort. It can take various forms such as overhangs, vertical fins, louvers, vegetation, or adaptive façades. As a component of passive design, shading helps regulate solar radiation while allowing sufficient daylight and ventilation to enter the interior spaces. According to Olgyay (1963) in Design with Climate, buildings should be designed based on local climatic conditions to maintain comfort with minimal mechanical effort. In humid tropical regions like Indonesia, where solar radiation is intense throughout the year, shading becomes a crucial strategy to achieve energy-efficient and comfortable buildings.

Olgyay (1963) bioclimatic theory emphasizes that thermal comfort depends on the balance of air temperature, humidity, radiation, and air movement. He stated that "shading devices are not mere architectural ornaments; they are essential environmental controls which regulate solar radiation and ensure thermal comfort." Effective shading must prevent direct solar radiation, maintain visibility and aesthetics, and allow daylight and air circulation. The design process should include solar path analysis to adapt shading elements to seasonal sun angles. Horizontal shading, such as overhangs, is suitable for blocking high sun angles, while vertical fins or louvers are effective for low-angle sun from the east and west.

Supporting Olgyay (1963) perspective, Szokolay (2014) described shading as one of the most effective and economical passive methods for controlling solar heat gain. He emphasized that "passive solar control through shading is among the most effective and economical strategies for reducing heat gains in buildings located in hot climates". Similarly, Givoni (1998) found that external shading could reduce solar heat gain by up to 90%, depending on orientation and design. These scholars collectively highlight that well-designed shading not only reduces thermal loads but also minimizes glare, maintains visual comfort, and supports natural lighting without increasing indoor temperatures.

In humid tropical climates like Indonesia, shading must be integrated with natural ventilation and the use of reflective materials to optimize indoor comfort. Overhangs and brise-soleil on north-south façades can block midday sun, while vertical fins on east-west façades protect against low-angle morning and afternoon sunlight. Vegetation can also serve as natural shading that cools the surrounding environment. National design standards and the Green Building Council Indonesia recommend integrating shading and ventilation to achieve sustainable building performance. Thus, consistent with Olgyay and Szokolay, effective shading design not only enhances thermal comfort but also promotes energy efficiency and environmental sustainability in tropical architecture.

2.2. Theory of Double Skin Façade (DSF)

A double-skin façade (DSF) is a building envelope system composed of two protective layers, typically glass, separated by an air cavity. This system is designed to enhance a building's thermal and daylighting performance through the utilization of natural ventilation, solar radiation control, and acoustic as well as thermal insulation (Herzog et al., 2004). The air cavity between the two layers functions as a thermal buffer and can be either naturally or mechanically ventilated, depending on the design strategy and local climatic conditions. The primary objectives of the DSF system are to improve thermal performance, reduce cooling loads, and enhance natural lighting and acoustic comfort.

According to Aksamija (2013), the DSF is designed to dynamically respond to surrounding climatic and environmental conditions. This façade type allows the integration of both passive and active systems to manage solar radiation, air movement, and visual and thermal comfort. Additionally, the DSF serves as a pressure buffer against external air and provides protection for the inner façade from extreme weather exposure. The DSF offers multiple advantages, including improved energy efficiency by minimizing daytime cooling loads and enhancing indoor natural illumination (Aksamija, 2013). Moreover, it contributes to better acoustic performance and serves as an additional protective layer against wind and rain (Herzog et al., 2004). Aksamija's (2013) study indicates that retrofitting existing buildings with DSF can reduce energy consumption by up to 35%, provided that the design accounts for local climatic characteristics, appropriate ventilation management, and integrated automation systems. Aksamija (2013) emphasizes that a climate-responsive DSF design integrated with automated control systems can yield significant energy savings. This approach is particularly relevant in tropical urban contexts, where high energy consumption due to cooling demands remains a critical challenge.

A Double Skin Façade (DSF) is an advanced building envelope system consisting of two layers of façades which is an outer skin and an inner skin separated by an air cavity. This cavity acts as a thermal buffer zone that regulates heat transfer, improves natural ventilation, and enhances acoustic performance. The DSF system allows for dynamic environmental control, optimizing the balance between daylighting, thermal comfort, and energy efficiency. According to Szokolay (2014), the concept of a responsive façade is essential in achieving sustainable architecture, as it allows buildings to adapt to changing climatic conditions. In tropical climates such as Indonesia, DSF serves as an effective strategy to mitigate excessive solar radiation while maintaining adequate natural light.

Olgyay's (1963) bioclimatic principles support the idea that building envelopes should be designed in harmony with local environmental conditions to achieve thermal comfort through passive means. DSF embodies this principle by combining shading, ventilation, and insulation within a single integrated façade system. The outer skin, often made of glass, perforated panels, or louvers, acts as the first line of defense against solar gain, while the inner skin maintains a stable indoor environment. The air cavity between them facilitates either natural or mechanical ventilation, depending on the climatic and operational needs of the building. This configuration reduces heat transmission, minimizes glare, and allows filtered daylight to enter the interior space (Olgyay, 1963).

Givoni (1998) highlighted that façades with controllable ventilation layers can significantly enhance building performance in warm climates by reducing reliance on mechanical cooling. DSF systems, when combined with effective shading, can lower cooling energy demands by up to 30-50%, depending on orientation and design. Moreover, the integration of DSF with smart control systems enables adaptive responses to external conditions, improving indoor air quality and overall energy performance. Studies have also shown that DSF contributes to visual comfort by reducing direct glare and distributing light evenly within occupied spaces.

In the context of retrofitting existing buildings, the application of DSF offers a promising solution for improving thermal efficiency without compromising aesthetics or functionality. For tropical regions, a ventilated DSF with horizontal and vertical shading elements can effectively balance daylight and heat control. The combination of retrofit shading and DSF can significantly enhance natural lighting quality while minimizing overlit zones, contributing to a comfortable and energy-efficient indoor environment. Consistent with the principles outlined by Givoni (1998); Olgyay (1963); Szokolay (2004), DSF represents a holistic approach to sustainable façade design, integrating climatic responsiveness, energy performance, and occupant well-being.

2.3. Building Performance

Building performance refers to how effectively a building meets environmental, functional, and occupant-related objectives through its design and operation. It encompasses thermal, visual, acoustic, and energy aspects that collectively determine indoor environmental quality and user satisfaction. In the context of sustainable design, building performance evaluation focuses on optimizing energy use while maintaining occupant comfort. The integration of passive design strategies such as shading, daylighting, and Double Skin Façades (DSF) plays a significant role in enhancing overall building performance. As Szokolay (2014) stated, "the performance of a building is measured not only by its energy consumption but also by its ability to provide comfort, health, and productivity for its occupants."

Daylighting performance is a crucial indicator of building performance, as it directly influences both energy efficiency and user well-being. Effective daylighting reduces the dependence on artificial lighting, thereby lowering energy consumption and operational costs. According to Reinhart and Andersen (2006), daylighting performance can be evaluated through metrics such as Daylight Factor (DF), Useful Daylight Illuminance (UDI), and Daylight Autonomy (DA), which measure the quantity and quality of natural light in interior spaces. Buildings that achieve balanced daylight distribution enhance visual comfort, minimize glare, and create a more productive indoor environment. When combined with shading and DSF systems, optimized daylighting ensures that natural light is maximized while heat gain is minimized an essential balance for tropical climates (Reinhart, C. F., & Andersen, 2006).

Visual comfort is another integral component of building performance, referring to the occupants' satisfaction with the visual environment, including brightness, contrast, and glare levels. Poor visual conditions can lead to eye strain, discomfort, and decreased productivity. As Veitch and Newsham (2000) noted, visual comfort results from an appropriate balance between natural and artificial light, ensuring that spaces are neither overlit nor underlit. Architectural strategies such as light shelves, reflective surfaces, and adjustable louvers help maintain uniform illumination levels while reducing direct glare. The combination of retrofit shading and DSF enhances visual comfort by filtering sunlight and diffusing it evenly throughout indoor spaces (Veitch, J. A., & Newsham, 2000).

Lastly, energy efficiency remains the overarching goal of high-performance building design. It involves minimizing energy use without compromising comfort or functionality. As Givoni (1998) emphasized, the building envelope is the key interface where energy exchange occurs, and its optimization can substantially reduce cooling and lighting demands. Passive cooling, effective insulation, and controlled daylighting are essential measures for achieving energy efficiency in warm and humid climates. Integrating daylighting, visual comfort, and DSF systems creates a synergistic effect, reducing artificial lighting needs, maintaining indoor comfort, and improving overall energy performance. Therefore, a building's success in sustainability depends on its ability to harmonize these interrelated elements to provide comfort, efficiency, and environmental responsiveness (Givoni, 1998).

2.4. Previous Research

Previous studies have shown that shading devices play a crucial role in improving energy performance and visual comfort in buildings, particularly in regions with high solar radiation. Tzempelikos & Athienitis (2021) demonstrated that external shading systems significantly reduce solar heat gain while maintaining adequate daylight levels in office buildings located in Mediterranean climates. Their findings indicate that well-designed shading devices, such as overhangs, vertical fins, and louvers, can balance energy savings with occupant comfort by minimizing glare and controlling daylight penetration. According to Tzempelikos & Athienitis (2021), the use of external shading devices can effectively reduce cooling energy consumption in office buildings located in Mediterranean climates by approximately 37% to 49%. Similarly, Sharma et al. (2022) emphasized that retrofitting existing buildings with efficient shading systems contributes to reduced cooling loads and enhanced sustainability performance. These studies confirm that passive shading design remains one of the most effective and economical strategies for improving energy efficiency and thermal comfort in hot and humid environments. Research conducted by Sharma et al. (2022) demonstrated that implementing retrofit strategies combining enhanced thermal insulation and external shading devices can reduce energy consumption intensity by 24.12%, accompanied by an annual carbon emission reduction of 18.56%. Similarly, a study by Islam et al. (2021) found that the use of external shading devices in commercial buildings located in subtropical climates can lower annual energy consumption by up to 7.5%. Moreover, according to Koç & Maçka Kalfa (2021), the application of fixed external shading devices can significantly reduce energy consumption in office buildings within Mediterranean climates. Depending on the type of glazing and shading configuration used, cooling energy demand can be reduced by 37% to 78%, while total annual energy consumption may decrease by up to 70% compared to buildings without shading systems.

Research on the Double Skin Façade (DSF) further supports its potential as an adaptive building envelope system that enhances energy performance and indoor comfort. Dewi et al. (2020) and Hendrik & Tualaka (2023) highlighted that the implementation of DSF in tropical regions can significantly reduce solar radiation while maintaining sufficient natural ventilation. Their findings demonstrate that the air cavity between the façade layers acts as a thermal buffer, lowering heat transfer and improving indoor thermal stability. Likewise, Aruta et al. (2023) conducted a simulation-based analysis on a responsive DSF retrofit for office buildings in Mediterranean climates and found that it effectively optimized daylighting and reduced cooling energy demand. Chao et al. (2023) also found that integrating green façades with DSF enhances thermal performance and contributes to carbon sequestration in subtropical environments. Collectively, these studies indicate that DSF systems can be adapted for tropical climates as a responsive and energy-efficient façade solution.

The Double Skin Façade (DSF) represents one of the most effective architectural innovations for enhancing building energy efficiency, particularly in reducing cooling loads. Several studies on passive façade design have demonstrated the effectiveness of DSF in energy performance improvement. Ascione et al. (2021) found that the implementation of DSF as a retrofit strategy significantly decreases both energy consumption and CO_2 emissions in buildings. Similarly, Jaber et al. (2022) reported that DSF configurations designed to facilitate intensive thermal air exchange between façade layers can reduce annual energy demand by up to 14%, equivalent to approximately 116,574 kWh per year. Furthermore, Ahriz et al. (2022) emphasized that DSF serves as a key solution in modern building design for improving both energy efficiency and thermal comfort. Their study revealed that the application of DSF can lower cooling loads by 20-30%, primarily through the optimization of natural and mechanical ventilation within the cavity between façade layers.

The integration of shading and DSF within retrofit frameworks has become an emerging focus in sustainable building research. Kaewpraek (2023) conducted a systematic review of retrofitting strategies in tropical climates, identifying combined façade interventions as a promising approach to achieve significant energy savings. Their study revealed that hybrid retrofit systems which incorporating shading, DSF, and natural ventilation can enhance overall building performance by improving daylight quality and reducing overlit areas. Similarly, Sharma et al. (2022) argued that comprehensive retrofit approaches that merge multiple passive design strategies are more effective than isolated solutions in achieving long-term sustainability. These findings support the integration of shading and DSF as complementary retrofit systems capable of reducing energy consumption, improving thermal and visual comfort, and enhancing the environmental performance of existing buildings in tropical regions.

3. Methods

According to ANSI/ASHRAE Standard 169 on world climate zones, global regions are classified based on thermal conditions and moisture regimes, such as Zone 1A (very hot-humid, e.g., Jakarta and Singapore), Zone 3B (warm-dry, e.g., Los Angeles and Dubai), and Zone 5A (cool-humid, e.g., New York). Specifically, Indonesia, including Jakarta, is categorized as Climate Zone 1A (very hot-humid) under ANSI ASHRAE 169-2021. The site of research is situated in Jakarta where the climate zone is very hot-humid, with the sun shine brightly all year. Therefore, the researchers conducted this study using a quantitative approach with a building energy simulation design. Azeem et al. (2025) employed quantitative analysis with parametric variations to determine the optimal sizing of lighting, cooling, and water consumption in residential buildings, thereby providing measurable data to support effective green retrofit strategies. Similarly, Huang et al. (2023) quantitatively classified existing residential buildings in Chongqing by typology using actual energy consumption data and established benchmarks for each type to evaluate operational performance and retrofit potential.

This approach was selected because it enables an objective, systematic, and numerical analysis of energy performance. In the context of this study, the simulation was conducted using the Sefaira SketchUp software plug-in integrated with Sefaira - Energyplus web app. The research procedure was structured into several stages to ensure systematic analysis of the retrofit strategies. The methodological framework, illustrated in Figure 4.

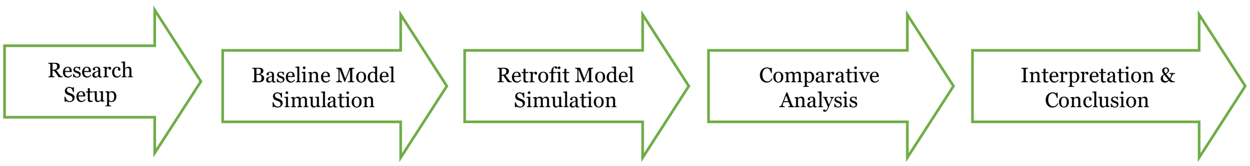

Figure 4. Research Procedure
Source: Author analysis (2025)

The research procedure consisted of four main stages: Research Setup, Baseline Model Simulation, Retrofit Model Simulation, Comparative Analysis, and Interpretation & Conclusion. In the Research Setup stage, the researchers identified the building typology, location, and climate zone classification based on ANSI/ASHRAE Standard 169-2021, specifically focusing on Jakarta as a representative of a very hot–humid region. The building geometry was modeled using SketchUp software and integrated with the Sefaira plug-in to set parameters such as occupancy, lighting, materials, and baseline energy standards following ASHRAE 90.1-2019. The Baseline Model Simulation stage involved running an initial energy and daylight analysis to obtain reference data for daylighting performance, visual comfort, and energy efficiency of the existing building. In Retrofit Model Simulation, the researchers integrated Shading and DSF to the baseline model. In the Comparative Analysis stage, a retrofit model incorporating shading devices and a Double Skin Façade (DSF) was simulated under identical conditions, allowing for a direct comparison with the baseline results. Finally, the Interpretation & Conclusion stage focused on analyzing the differences in simulation outcomes to evaluate how the retrofit strategies improved daylight distribution, visual comfort, and energy efficiency, ultimately drawing conclusions about the effectiveness of passive retrofit design in tropical climates. Those was done to get the impact of Retrofit toward the daylighting, visual comfort, and energy efficiency.

In conducting the simulation, the researcher utilized the Sefaira plug-in on SketchUp software in conjunction with the Sefaira-EnergyPlus web application to simulate retrofit scenarios involving shading and Double Skin Façade (DSF) systems. The process began with creating a 3D model of the existing building, followed by operating the software and inputting key parameters such as building type, location, and the baseline standard, ASHRAE 90.1-2019. Subsequently, the researcher defined the ASHRAE climate zone and entered parameters reflecting the actual conditions of the existing building. Finally, the simulation was executed by selecting the Analyze function to generate the energy performance results.

4. Results and Discussion

4.1. Research Results

The simulation results demonstrate the impact of integrating retrofit shading and Double Skin Façade (DSF) on the overall building performance of a glass façade building in a tropical climate. The analysis focuses on three key aspects: daylighting performance, visual comfort, and energy efficiency, to evaluate how the retrofit strategies enhance indoor environmental quality. The findings are summarized in the following tables, which compare the baseline model and the retrofit model to highlight improvements achieved through the integration of shading and DSF systems.

4.1.1. Daylighting Performance

Daylighting performance was evaluated using two key metrics defined by the Illuminating Engineering Society (IES LM-83-12). They are Annual Sunlight Exposure (ASE 1000,250) and Spatial Daylight Autonomy (sDA 300,50%). Two measure the balance between sufficient natural light and the risk of glare. As shown in Table 1, the retrofit model integrating shading and Double Skin Façade (DSF) significantly improved daylight distribution across both floors of the building. The average ASE value decreased from 87% to 43%, indicating a substantial reduction in areas exposed to excessive sunlight, which helps mitigate glare and overheating. Meanwhile, the sDA value slightly decreased from 100% to 98%, meaning that the interior still receives adequate daylight throughout the year. According to LEED v4 standards, ASE values below 20% are considered ideal for visual comfort, suggesting that the integration of shading and DSF effectively balanced daylight sufficiency and visual comfort in the tropical building context. The results of existing glass office building's daylighting are shown in table 1.

Table 1. Existing Glass Office Building's Daylighting

Area		Before Retrofit	After Retrofit (Shading + DSF)	Improvement
Floor 1	ASE	85%	41%	44%
	sDA	100%	97%	3%
Floor 2	ASE	89%	47%	42%
	sDA	100%	99%	1%

Source: Author analysis (2025); simulation result

The table 1 above analysis of daylighting distribution shows that the integration of shading and Double Skin Façade (DSF) significantly enhanced the quality and balance of natural lighting within the existing glass office building of PT Pertamina Patra Niaga ITJ-Jakarta

4.1.2. Visual Comfort

Visual Comfort was analyzed using Standar of SNI 03-6197-2000 dealing with the level of illuminance for buildings. Before the retrofit, the entire interior was dominated by overlit areas (87%), indicating excessive sunlight penetration that could cause glare and thermal discomfort. After implementing the retrofit strategies, the proportion of overlit areas decreased to 43%, while well-lit zones increased dramatically from 13% to 55%, demonstrating improved daylight uniformity. A slight rise in underlit areas from 0% to 2% reflects a minimal trade-off to prevent excessive brightness. Overall, these results confirm that the combination of shading and DSF successfully optimized in reducing glare while maintaining adequate natural illumination levels in accordance with sustainable daylighting principles as shown in Table 2.

Table 2. Existing Glass Office Building's Visual Comfort

Area	Daylighting	Before Retrofit	After retrofit (Shading +DSF)	Improvement
Floor	Underlit	0%	2%	2%
	Well lit	13%	55%	42%
	Overlit	87%	43%	44%

Source: Author analysis (2025); simulation result

The analysis of Visual Comfort was conducted based on the SNI 03-6197-2000 standard, which specifies that an illuminance level of around 300 lux provides a comfortable lighting condition for office work ensuring that the environment is neither too dim nor too bright, thereby preventing glare and reducing eye fatigue.

4.1.3. Energy Efficiency

The energy performance data before and after the retrofit demonstrate a substantial improvement in the building's energy efficiency. Before retrofitting, the total site energy consumption reached 345,387.72 kWh, with an energy intensity of 269.67 kWh/m² per year. The total source energy was also high at 1,093,831.36 kWh, equivalent to 854.03 kWh/m² per year. After the implementation of retrofit shading and the Double-Skin Façade (DSF) system, a significant reduction in energy usage was observed. The total site energy decreased to

165,922.83 kWh, corresponding to only 130.37 kWh/m² per year, while the total source energy dropped to 525,477.59 kWh, or 412.89 kWh/m² per year as shown in table 3.

Table 3. Existing Glass Office Building's Energy Efficiency before Retrofit

		Total Energy [kWh]	Energy Per Total Building Area [kWh/m²]	Energy Per Conditioned Building Area [kWh/m²]
Energy	Total Site Energy	345387.72	269.67	269.67
	Net Site Energy	345387.72	269.67	269.67
	Total Source Energy	1093831.36	854.03	854.03
	Net Source Energy	1093831.36	854.03	854.03

Source: Author analysis (2025); simulation result

Before the retrofit, the building consumed 269.67 kWh/m² per year of site energy and 854.03 kWh/m² per year of source energy, indicating high energy use due to inefficient daylighting and cooling. After applying retrofit shading and the Double-Skin Façade (DSF), the energy consumption dropped significantly to 130.37 kWh/m² and 412.89 kWh/m², demonstrating a remarkable improvement in overall building energy efficiency as shown in table 4.

Table 4. Existing Glass Office Building's Energy Efficiency after retrofit

		Total Energy [kWh]	Energy Per Total Building Area [kWh/m²]	Energy Per Conditioned Building Area [kWh/m²]
Energy	Total Site Energy	165922.83	130.37	130.37
	Net Site Energy	165922.83	130.37	130.37
	Total Source Energy	525477.59	412.89	412.89
	Net Source Energy	525477.59	412.89	412.89

Source: Author analysis (2025); simulation result

Overall, the application of retrofit shading and DSF successfully enhanced the building's energy efficiency, reducing both site and source energy consumption by more than 50%. This improvement highlights the effectiveness of passive design strategies in optimizing building performance, lowering operational costs, and promoting sustainable energy use in office environments.

4.2. Discussion

The daylighting performance of the building was assessed using Annual Sunlight Exposure (ASE1000,250) and Spatial Daylight Autonomy (sDA300,50%), as defined by the Illuminating Engineering Society (IES LM-83-12). These two metrics measure the balance between daylight sufficiency and glare risk. The results indicate that the integration of shading and Double-Skin Façade (DSF) systems substantially improved daylight distribution across both floors of the building. The average ASE value decreased from 87% to 43%, showing a major reduction in overexposed areas prone to glare and thermal discomfort. Meanwhile, the sDA value slightly dropped from 100% to 98%, suggesting that adequate daylight levels were still maintained throughout the year. Although the ASE value remains above the LEED v4 ideal threshold of 20%, the improvement demonstrates a significant enhancement in visual comfort and daylight balance, particularly within the context of tropical office buildings with high solar exposure. Below as shown in the figure 5. of simulation before and after retrofit.

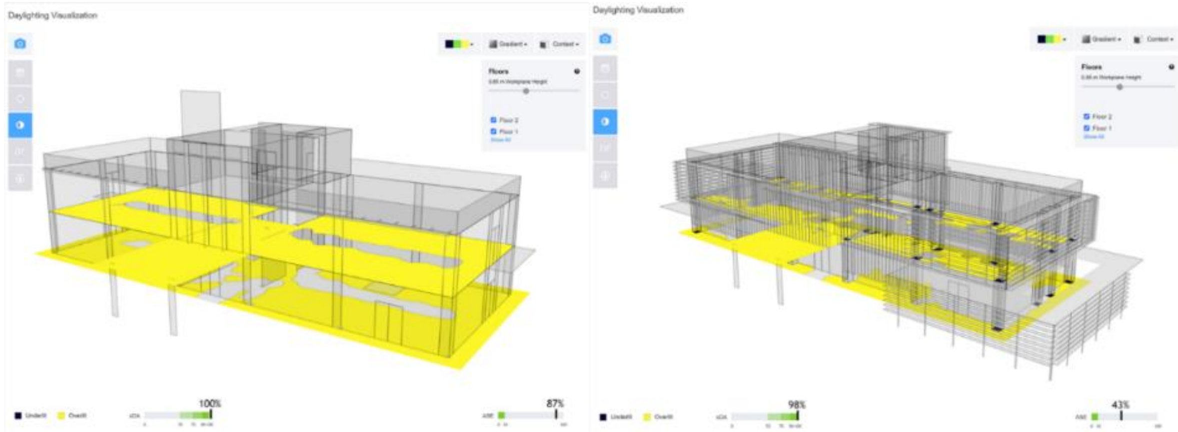

Figure 5. The daylighting performance before and after retrofit
Source: Author analysis (2025); simulation result

The visual simulation results presented in Figure 5 align closely with previous research emphasizing the effectiveness of passive retrofitting of shading and Double-Skin Façade (DSF) systems in Existing Glass Office buildings. Consistent with the findings of Givoni (1998) and Szokolay (2012), the integration of shading elements in this study successfully reduced glare and excessive solar penetration while maintaining sufficient daylight levels, thereby minimizing the need for artificial lighting. Likewise, the DSF acted as a climatic buffer that controlled solar radiation and improved indoor thermal conditions, supporting Aksamija's (2013) assertion that DSF systems enhance both visual and thermal comfort. The observed reduction in ASE from 87% to 43% and the maintenance of sDA at 98% confirm that the retrofit effectively balanced daylight sufficiency and glare control. In sum, by optimizing natural lighting and mitigating heat gains in Existing Glass Office Building of PT Pertamina Patra Niaga ITJ-Jakarta, the retrofit shading and DSF systems contribute to a significant reduction in artificial lighting demand and cooling energy consumption, ultimately improving the building's overall energy efficiency in the tropical climate context.

Building upon the previous analysis of daylighting performance, the impact of retrofit shading and Double-Skin Façade (DSF) systems. Based on the SNI 03-6197-2000 standard which defines an optimal illuminance level of around 300 lux for comfortable office environments the retrofit successfully established lighting conditions that prevent glare and eye fatigue. Before retrofitting, the dominance of overlit areas (87%) indicated excessive sunlight exposure, leading to discomfort and higher cooling loads. After implementation, overlit zones decreased to 43%, while well-lit areas increased from 13% to 55%, signifying improved daylight uniformity. The slight rise in underlit areas (2%) represents a minimal compromise to achieve better visual balance. These results affirm that the integration of shading and DSF systems not only optimized visual comfort and natural light quality but also reduced the reliance on artificial lighting and cooling systems, supporting energy efficiency and occupant well-being in tropical office buildings as shown in the figure 6 about the impact of Retrofit on visual Comfort before and after retrofitting.

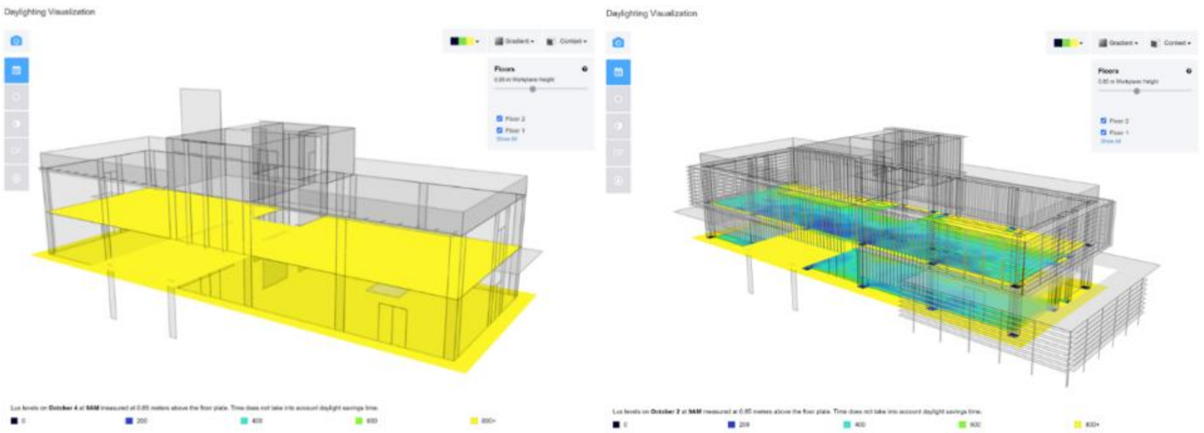

Figure 6. The impact of retrofit on visual comfort before and after retrofit
Source: Author analysis (2025); simulation result

The findings of this study clearly demonstrate that the visual comfort before and after the retrofit was significantly improved through the integration of shading and Double-Skin Façade (DSF) systems, supporting previous research on passive retrofit strategies. The substantial decrease in overlit areas (from 87% to 43%) and the notable increase in well-lit zones (from 13% to 55%) confirm that the retrofit effectively balanced daylight levels, minimized glare, and enhanced occupant comfort. These results align with the findings of Tzempelikos and Athienitis (2021), who emphasized that external shading systems are essential for reducing solar heat gain while maintaining sufficient daylight in regions with high solar exposure. Likewise, the improvement in indoor lighting conditions supports Sharma et al. (2022), who stated that efficient shading retrofits not only enhance visual comfort but also contribute to reduced cooling energy demand and greater sustainability performance. Furthermore, the enhanced indoor illuminance uniformity observed in this study is consistent with the findings of Dewi et al. (2020) and Hendrik and Tualaka (2023), who highlighted the DSF's ability to act as a thermal and visual buffer by moderating solar radiation and improving indoor environmental quality. Therefore, this research reinforces the theoretical framework that the combined application of shading and DSF serves as an effective passive retrofit strategy to enhance visual comfort, energy efficiency, and sustainability performance in tropical office buildings.

The integration of retrofit shading and Double-Skin Façade (DSF) systems significantly enhanced the energy efficiency of the existing glass office building by reducing total site energy consumption by more than 50%, from 345,387.72 kWh to 165,922.83 kWh, and decreasing energy intensity from 269.67 kWh/m² to 130.37 kWh/m². Likewise, the total source energy dropped from 1,093,831.36 kWh to 525,477.59 kWh, indicating a substantial reduction in overall energy demand. These improvements demonstrate that the retrofit design effectively optimized daylight utilization and reduced solar heat gain, thereby lowering dependence on artificial lighting and air-conditioning systems. Consistent with the conclusions of Sharma et al. (2022) and Kaewpraek et al. (2023), this finding reinforces that passive retrofit strategies combining shading and façade systems are among the most effective approaches to achieving significant energy savings, improving thermal and visual comfort, and promoting sustainability in tropical office buildings as presented in figure 7.

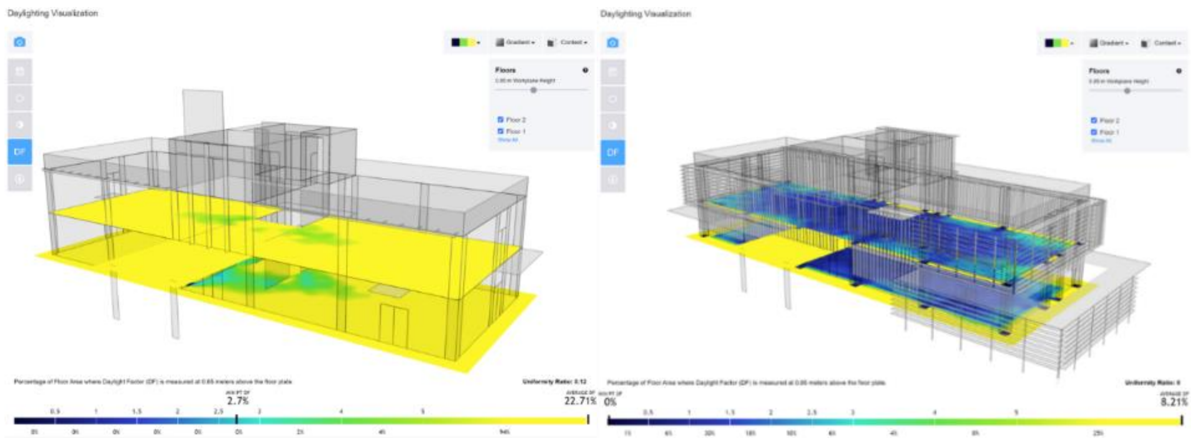

Figure 7. The impact of retrofit on energy efficiency before and after retrofit
Source: Author analysis (2025); simulation result

In conclusion, the performance improvements observed in the retrofit scenario, particularly through the integration of external shading and the Double-Skin Façade (DSF), demonstrate a multidimensional influence on building energy behavior. While the study successfully shows a measurable reduction in annual energy consumption, a deeper examination reveals that the underlying mechanism of savings is strongly driven by the interplay between daylighting performance and the resultant cooling and lighting loads. However, the current analysis only qualitatively acknowledges this relationship without providing the quantitative linkage needed to clarify how specific daylighting improvements directly contribute to the recorded energy reductions.

In principle, enhancements in daylighting performance, reflected in the increase of Spatial Daylight Autonomy (sDA) and the reduction of Annual Sunlight Exposure (ASE), produce two measurable effects. First, the improvement in sDA from approximately 100% in the baseline condition to 97% in the retrofit scenario indicates that a larger portion of occupied hours can be met with daylight, which based on standard lighting power densities in office buildings, corresponds to a lighting energy reduction of 10-18% annually (Santamouris, M., & Tsangrassoulis, 2020). Second, the reduction in ASE from around 87% to 43% leads to lower solar penetration and reduced indoor heat gain, which can yield a cooling load reduction of 6-12%, depending on HVAC system efficiency and occupancy patterns (Kuhn, 2017; Singh, M., Bhusal, P., & Mainali, 2022). These mechanisms are consistent with prior research demonstrating that daylighting improvement and thermal-load reduction are interdependent outcomes of facade retrofits.

Nevertheless, the absence of explicit quantitative correlations, such as the percentage of cooling load reduction attributable directly to the 17% decrease in ASE, or the exact lighting energy savings resulting from the 23% increase in sDA, limits the extent to which the current findings can be attributed to specific environmental performance metrics. Without this quantitative linkage, the retrofit risks being interpreted as a holistic improvement rather than a set of measurable causal relationships between façade performance, daylighting quality, and energy outcomes.

To strengthen the scientific rigor of the findings, future analyses should integrate cross-metric quantitative correlations such as: Regression analysis linking the 17% decrease in ASE to variations in hourly and daily cooling energy consumption, thereby capturing the influence of reduced solar heat gain on HVAC performance. Lighting energy modeling that quantifies the decrease in lighting energy use as a direct function of the 23% sDA improvement across occupied hours. Thermal–optical interaction mapping, which plots reductions in glare hours against measured decreases in cooling loads to clarify how visual comfort improvements simultaneously reduce thermal loads.

These quantitative linkages would not only substantiate the observed energy reductions but also provide a detailed understanding of how improvements in daylight quality influence whole-building energy behavior. Such analytical integration would align the findings more closely with the theoretical frameworks of Sharma et al. (2022) and Kaewpraek et al. (2023) while offering stronger empirical justification for the adoption of combined shading–DSF retrofit strategies in tropical office buildings (Kaewpraek, P., Rattanongphisat, W., & Chaiwiwatworakul, 2023; Sharma, A., Kumar, A., & Mathur, 2022).

5. Conclusion

The integration of retrofit shading and Double-Skin Façade (DSF) systems in the existing glass office building of PT Pertamina Patra Niaga ITJ-Jakarta has demonstrated strong effectiveness as a passive design strategy for enhancing building performance in tropical climatic conditions. The simulation results reveal substantial improvements in daylighting quality, visual comfort, and energy efficiency. The reduction in ASE values from 87% to 43%, coupled with the maintenance of exceptionally high sDA levels at 98%, reflects an optimized balance between adequate daylight availability and minimized glare risk. Additionally, the increase in well-lit areas from 13% to 55% and the reduction of overlit zones from 87% to 43% signify a significant enhancement of the visual environment, aligning with the illumination standards recommended by SNI 03-6197-2000. These findings demonstrate the synergistic function of shading and DSF systems in moderating daylight penetration, mitigating excessive solar radiation, and reducing dependence on artificial lighting.

From an energy performance perspective, the retrofit strategies underscore the benefits of integrating multiple passive interventions for promoting thermal stability and long-term sustainability. The reduction of total site energy from 345,387.72 kWh to 165,922.83 kWh and the decline in total source energy from 1,093,831.36 kWh to 525,477.59 kWh indicate a dramatic improvement in both lighting and cooling efficiency. These results confirm that the DSF-shading combination not only reduces operational energy consumption but also enhances occupant comfort through a more stable indoor environmental quality.

However, beyond these numerical improvements, the broader implications of this study underscore the critical role of integrated passive retrofitting strategies in addressing the inherent limitations of fully glazed tropical office buildings, which are frequently associated with high cooling loads, glare discomfort, and excessive artificial lighting use. By demonstrating that substantial performance gains can be achieved through façade-level interventions alone, this study provides evidence that retrofitting existing glass buildings rather than fully replacing their envelopes can serve as a highly viable pathway toward sustainable modernization. These insights contribute to a larger discourse on tropical resilience, emphasizing the necessity of adaptive façade strategies in existing urban building stocks across Southeast Asia.

In summary, the findings not only validate the effectiveness of shading and DSF retrofits for enhancing daylighting, thermal comfort, and energy performance but also offer higher-level insights into the strategic importance of passive retrofitting for existing glass façades in tropical regions. Such interventions present a scalable, cost-effective, and environmentally responsible approach that aligns with global green building principles and supports the development of resilient architectural practices capable of responding to climatic challenges in rapidly urbanizing tropical environments.

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