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The Effect of Passive Shading Strategies on Cooling Load Reduction in a Three-Story Office Building in West Bandung Regency

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ABSTRACT

Office buildings in humid tropical climates tend to have high energy consumption, with cooling loads representing one of the major components, particularly in existing buildings that were not originally designed with adequate solar radiation control. This study examines the effect of passive shading strategies on reducing cooling loads in an existing office building through a building energy performance simulation approach. The case study focuses on the PT. Sipatamoda Indonesia office building in West Bandung Regency, which accommodates both office and exhibition functions. The building has a total floor area of 1,024.4 m² and is predominantly occupied by daytime activities. The research employed performance-based simulation using the Sefaira plugin by comparing two scenarios, the existing building without passive shading and the building with a combined passive shading strategy incorporating horizontal and vertical elements. The analysis focused on annual cooling energy demand and Energy Use Intensity (EUI). The simulation results indicate that the combined passive shading strategy reduces cooling energy compared with the existing condition, consequently lowering the building's annual EUI. This reduction is associated with decreased solar radiation entering through the openings, thereby reducing the cooling load imposed on the air conditioning system. The findings demonstrate that combined passive shading can provide a measurable contribution to improving the energy efficiency of existing office buildings without requiring structural modifications, making it a suitable nonstructural intervention for office buildings in humid tropical climates.

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1. INTRODUCTION

Office buildings are among the building types with significant energy consumption, particularly in humid tropical regions such as Indonesia. High air temperature and humidity, combined with strong solar exposure throughout the year, make indoor cooling a substantial component of office building operation (Attaufiq & Pratiwi, 2022). In many cases, energy consumption for air conditioning systems exceeds that of lighting and other equipment, affecting the overall energy efficiency of the building. Previous studies have shown that cooling loads are a major contributor to energy consumption in office buildings in tropical climates, particularly where the building design is not adequately responsive to local climatic conditions (Budhyowati, 2021; Fahmi & Mutia, 2022). Solar radiation entering through the building facade and openings can increase internal heat gain, consequently requiring the cooling system to operate at a higher capacity. This condition is commonly observed in office buildings located in industrial areas, where spatial functionality and construction efficiency often receive greater consideration than energy performance.

Passive shading plays an important role in controlling heat transfer from the exterior to the interior. Passive solar control is an effective approach to reducing cooling loads without increasing operational energy consumption (Dewi, 2021). However, implementing passive shading strategies in existing buildings is often constrained by structural conditions and the configuration of the existing building mass. Structural modifications are generally difficult to undertake, therefore adaptive strategies with minimal intervention are needed to improve building energy performance. In this context, evaluating the energy performance of existing buildings through simulation is useful for quantitatively assessing their potential for energy reduction. Building performance simulation software such as Sefaira enables a rapid assessment of how modifications to passive shading elements affect cooling energy consumption and annual *Energy Use Intensity* (EUI), without requiring direct physical intervention (Hanissaa & Paramita, 2021).

In recent years, research on improving building energy efficiency through modifications to building components has increased considerably. Previous studies have demonstrated that solar control can effectively reduce cooling requirements in office buildings located in humid tropical climates (Allamsyah et al., 2023; Dewi, 2021). Solar shading components installed on the exterior or integrated into the building envelope have been shown to reduce solar heat gain while improving thermal performance. Several studies have specifically examined the potential of passive solar shading to reduce building energy consumption. Dewi (2021) reported that the type of shading device substantially affects the amount of solar heat entering a building. Meanwhile, (Fahmi & Mutia, 2022) found that facade improvements, including solar shading components, can contribute to reducing the energy required to cool office buildings. However, most of these studies have focused on new buildings, where greater flexibility is available in determining the design of building components.

In contrast, relatively few studies have focused on evaluating existing office buildings in industrial areas of West Bandung Regency where design modifications are constrained. Previous research has often assumed the effectiveness of passive shading strategies without quantitatively evaluating their performance in buildings that are already operational. Furthermore, building energy simulations are frequently used to compare multiple variables, which can make the research focus less specific and its findings more difficult to translate into practical applications. Accordingly, the contribution of this study lies in its quantitative analysis of the effects of a combined passive solar shading strategy, consisting of horizontal and vertical elements, on cooling load reduction and annual EUI in an existing office building located in an industrial area of West Bandung Regency. The analysis employs Sefaira as a

building performance simulation tool. Rather than proposing a new passive shading concept, this study provides measurable evidence of energy performance based on an actual building that represents conditions commonly encountered in Indonesian office buildings.

Office buildings in industrial areas of West Bandung Regency often lack effective solar control measures to reduce unwanted solar heat gain and energy consumption. Consequently, annual cooling requirements can remain high, resulting in relatively low building energy efficiency. Passive shading is frequently proposed as a suitable strategy, however, its effect on cooling requirements and EUI in existing buildings is often based primarily on assumptions. Quantitative simulation-based evidence within the local context remains limited. Therefore, this study addresses the following research question, how does the implementation of a passive shading strategy reduce cooling requirements and affect the *Energy Use Intensity* (EUI) of an existing office building in an industrial area of West Bandung Regency?

This study investigates how passive shading influences the energy performance of an operational office building. More specifically, it aims to investigate the difference in annual cooling energy demand between an office building without passive shading and one equipped with passive shading, and assess changes in the building's overall *Energy Use Intensity* (EUI) as an indicator of energy efficiency following the implementation of the passive shading strategy.

The study is limited to an existing office building comprising approximately 3.5 floors and located within the PT. Sipatamoda industrial facility in West Bandung Regency. The shading analysis considers two conditions the existing condition without passive shading and a condition incorporating a combined passive shading strategy consisting of horizontal and vertical elements. Building energy performance is evaluated using Sefaira simulation software, with particular emphasis on annual cooling energy demand and *Energy Use Intensity* (EUI).

1.2 Literature Review

1.2.1 Cooling Loads in Office Buildings

The amount of cooling required to maintain indoor thermal comfort is commonly referred to as the cooling load. In office buildings located in humid tropical climates, cooling demand is a major determinant of annual energy consumption. This is largely attributed to high outdoor air temperatures, elevated humidity levels, and intense solar exposure throughout the year (Taslim & Widiastuti, 2024). In general, cooling loads in office buildings are influenced by two main sources of heat gain external and internal loads. External heat gain results from heat transfer through the building envelope due to temperature differences and solar radiation, whereas internal heat gain is generated by occupants, electrical equipment, and artificial lighting (Budhyowati, 2021).

In long operating office buildings, the accumulation of these heat gains directly increases the energy required by air conditioning systems. Previous studies have shown that, in tropical office buildings, solar heat entering through the building envelope and openings can make a substantial contribution to total cooling demand (Fahmi & Mutia, 2022). This suggests that strategies for controlling solar heat gain at the building surface have considerable potential to reduce the energy required for cooling.

Cooling demand in tropical office buildings is affected by several interrelated factors. One of the primary factors is the outdoor climate, particularly ambient air temperature and solar radiation intensity. Intense solar exposure can increase heat transfer through walls, roofs, and openings, especially in buildings with limited facade protection (Allamsyah et al., 2023). Another factor concerns the properties of the building envelope, including wall materials,

glazing type, window to wall ratio, and the presence or absence of solar control devices. An envelope design that is poorly adapted to tropical climatic conditions tends to result in excessive solar heat gain, thereby increasing the cooling load imposed on the air conditioning system (Sabtalistia, 2017).

A third factor is the pattern of space use and the level of activity within the building. In office environments, electronic equipment, artificial lighting, and occupant density also contribute to internal heat gain. However, several studies have found that in buildings exposed to excessive solar radiation, external heat gain more frequently becomes the dominant contributor to increased cooling energy consumption than internal heat gain (Attaufiq & Pratiwi, 2022). In existing buildings, these factors are generally established and difficult to modify fundamentally. Consequently, one practical approach to reducing cooling demand is to control heat transfer from the exterior by optimizing passive shading elements, without requiring major changes to the spatial layout or structural system.

Solar radiation is a primary source of external heat gain and strongly influences the thermal performance of buildings in tropical climates. When solar radiation reaches a building surface, part of it is absorbed, reflected, or transmitted into the building, depending on the properties of the building materials and facade design. The resulting solar heat gain contributes directly to an increase in cooling demand (Ratnasari & Asharhani, 2023). In office buildings, openings and transparent facade components often constitute major pathways for solar radiation to enter the interior. Although glazing is important for daylighting and visual connection with the exterior, it generally provides limited protection against solar heat gain. Without adequate solar control, radiation entering through openings can increase indoor temperatures and consequently require the air conditioning system to operate more intensively (Muhsin et al., 2023).

The building envelope serves as an interface between the outdoor environment and the interior. Its design and the way its components are configured therefore have a substantial influence on the amount of solar heat entering the building. Controlling solar radiation before it reaches the building envelope is generally more effective than relying solely on mechanical cooling systems to remove heat after it has entered the building (Purnama et al., 2024). For existing buildings, incorporating solar control strategies into the building envelope provides a practical means of reducing cooling demand without requiring extensive modifications to established building systems. Understanding the relationship between solar radiation, the building envelope, and cooling demand therefore provides an important theoretical basis for this study, particularly in assessing the effectiveness of passive shading as an energy-performance-oriented strategy for controlling solar heat gain.

1.2.2 Passive Shading Strategies for Existing Buildings

Passive shading strategies are primarily intended to control the amount of solar radiation reaching the building envelope, particularly through openings, before this energy contributes to an increase in indoor temperature. In office buildings located in humid tropical climates, both direct and diffuse solar radiation constitute major sources of solar heat gain, which directly contributes to increased mechanical cooling loads (Budhyowati, 2021).

Horizontal shading works by intercepting relatively high solar angles, which typically occur around midday. These elements reduce direct solar radiation incident on facades and openings, particularly during periods of peak solar intensity. In contrast, vertical shading is more responsive to solar radiation at lower angles, which commonly occurs in the morning and afternoon and cannot be effectively controlled by horizontal overhangs alone (Sari & Rauzi, 2021). In existing buildings, combining horizontal and vertical shading provides more adaptive solar protection in response to variations in solar angles throughout the day and

across seasons. This approach is particularly relevant to office buildings with established opening configurations, where modifying the building orientation or massing geometry is no longer feasible (Khalid et al., 2023).

The thermal effectiveness of passive shading is not determined merely by the presence of shading devices, but by their ability to reduce solar heat gain entering the building and, consequently, lower the energy demand of the air conditioning system. Previous studies have shown that reducing solar radiation at openings directly affects indoor surface temperatures and the rate of heat transfer into interior spaces (Ratnasari & Asharhani, 2023). Building performance simulation using software such as Sefaira enables the relationship between shading strategies and annual energy consumption to be assessed quantitatively. Previous studies have indicated that passive shading can reduce cooling energy demand, particularly in office buildings where primary activities occur during the daytime and air conditioning systems operate continuously (Purnama et al., 2024).

Improving the energy performance of existing buildings is often constrained by limitations on structural and geometric modifications. Large scale interventions, such as changes to building orientation, massing, or structural systems, are generally impractical for buildings that are already operational (Octarino & Feriadi, 2021). Under such conditions, passive shading represents a relevant strategy because it can be introduced as an additional building element without modifying the primary structure. As a nonstructural intervention, shading can improve the thermal performance of the building envelope with relatively low technical risk while causing minimal disruption to existing spatial functions (Dewi, 2021).

1.2.3 Building Energy Performance Simulation Using Sefaira

Building energy performance simulation is widely used as an analytical approach for quantitatively assessing the effects of design strategies on energy consumption, particularly in existing buildings where physical modifications are constrained. For office buildings in humid tropical climates, this approach enables the causal relationship between changes in building envelope components and variations in annual cooling loads to be examined without requiring direct intervention in an operational building (Attaufiq & Pratiwi, 2022).

Sefaira is a building performance simulation tool commonly used during the early design stages and for evaluating passive design strategies, including applications to existing buildings. Based on building performance simulation principles, Sefaira is designed to generate energy performance outputs rapidly and facilitate comparative analysis. These characteristics make it suitable for studies that compare multiple design scenarios while deliberately limiting the number of variables under investigation (Hanissaa & Paramita, 2021). In office building energy efficiency research, cooling energy and *Energy Use Intensity* (EUI) are two commonly used indicators for quantitatively assessing building energy performance. Cooling energy represents the energy required by the air-conditioning system to maintain indoor thermal conditions, whereas EUI expresses the total energy consumption of a building relative to its floor area (Santamouris, 2016).

Sefaira can simulate annual cooling energy demand by accounting for local climatic conditions, building envelope characteristics, occupancy patterns, and assumptions regarding building systems. This approach allows changes to facade elements, such as the introduction of passive shading, to be directly associated with variations in cooling loads without modifying other parameters beyond the scope of the study (Hanissaa & Paramita, 2021). In addition, Sefaira provides annual EUI outputs that facilitate comparison of energy performance across different design scenarios. For existing buildings, EUI is a relevant indicator because it can reflect changes in overall building energy efficiency even when design interventions are

limited to specific components, such as openings and the building envelope (Budhyowati, 2021).

2. RESEARCH METHODS

This study adopts a digital simulation approach to develop a virtual model representing both the existing building condition and the proposed intervention. The simulation was conducted using the Sefaira plug in. The baseline geometric model was developed in SketchUp and served as the three-dimensional framework for the subsequent performance analysis (Wibawa et al., 2021).

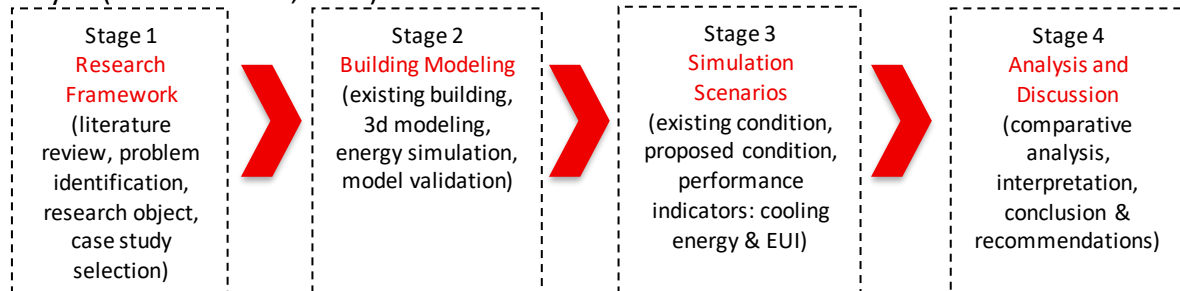


Figure 1. Research Methods and Study Stages
(Source: Author's Illustration, 2026)

2.1 Study Location and Research Object

The study was conducted on an existing office building within the textile industrial complex of PT. Sipatamoda Indonesia. The industrial site covers approximately 18,966.6 m² and is located at Jl. Raya Batujajar No. 3 Km 2, RW 2, Giriasih Village, Batujajar District, West Bandung Regency, West Java, Indonesia. The building is located at 6°53'42.0"S, 107°30'08.9"E. The existing office building was constructed in 2015 on land that had previously been used as a textile warehouse. Based on West Bandung Regency Regional Regulation No. 2 of 2024, industrial activities in the area are subject to a maximum Building Coverage Ratio (BCR) of 60%, equivalent to 11,379.96 m²; a minimum Green Area Ratio (GAR) of 10%, equivalent to 1,896.66 m²; and a maximum Floor Area Ratio (FAR) of 1.2, equivalent to 13,656 m² (Bandung Barat, 2024).

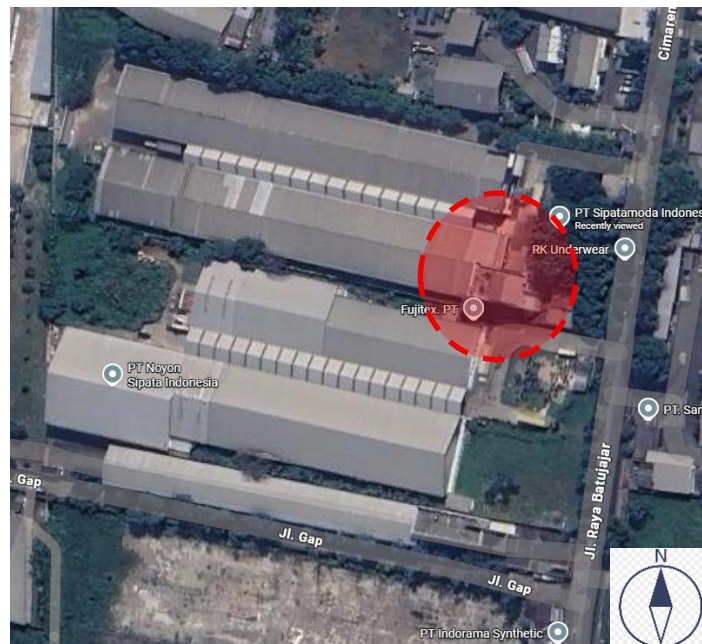


Figure 2. Location of the Research Object
(Source: Adapted from Google Maps, 2026)



Figure 3. Floor Plans of the Research Object
(Source: Author's Illustration, 2026)

As a building that combines office and exhibition functions, thermal comfort is an important consideration. Most activities take place during the daytime, resulting in a high dependence on air conditioning systems. The selection of the PT. Sipatamoda Indonesia office building as the research object was based on several methodological considerations. First, the building is already operational therefore, substantial modifications to its massing, orientation, or primary structural system would be relatively difficult to implement. Second, the existing facade openings provide an opportunity to introduce a passive strategy through the addition of shading elements without directly disrupting the existing spatial functions. Third, the combination of office and exhibition functions represents a medium scale office building typology commonly found in industrial areas. The findings may therefore have broader contextual relevance to similar existing office buildings (Octarino & Feriadi, 2021; Saleh, 2025).



Figure 4. Exterior Perspective of the Research Object
(Source: Author's Illustration, 2026)



Figure 5. Photograph of the Research Object
(Source: Adapted from Google Maps, 2026)

Climatologically, the study area is characterized by a humid tropical climate, relatively high solar radiation throughout the year, moderately stable daily air temperatures, and high humidity levels. These climatic conditions directly influence the building's cooling load, particularly in office buildings that operate primarily during the daytime and rely on mechanical air conditioning systems to maintain indoor thermal comfort (Budhyowati, 2021; Santamouris, 2016). Considering the local climatic conditions, building functions, and patterns of space use, the PT. Sipatamoda Indonesia office building provides a relevant case for examining the effects of passive shading on cooling load reduction and annual *Energy Use Intensity* (EUI) through a building energy performance simulation using Sefaira (Attaufiq & Pratiwi, 2022; Notodipuro & Mandala, 2022).

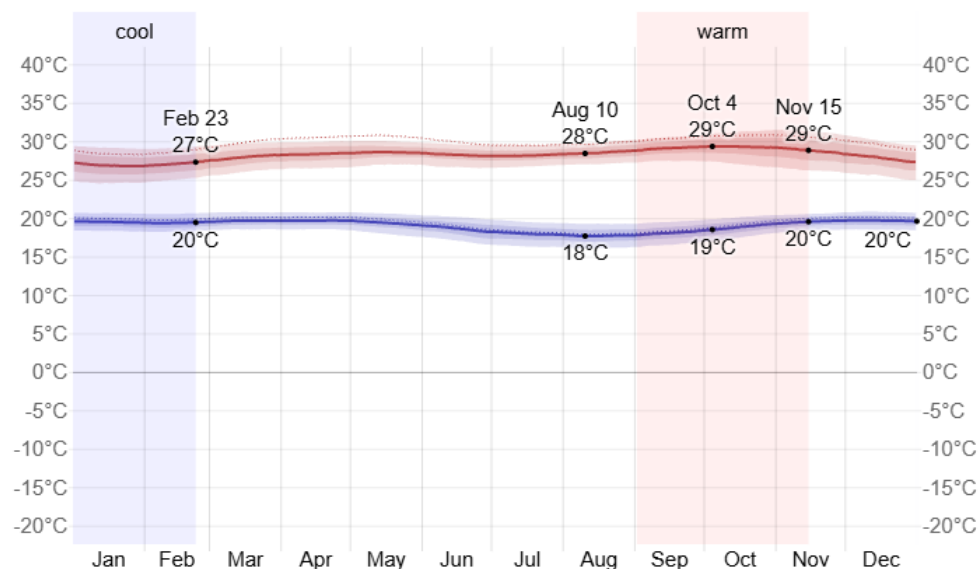


Figure 6. Average Temperature in Bandung
(Source: WeatherSpark, 2026)

2.2 Building Model, Simulation Scenarios, and Analysis Parameters

The building model developed in this study was reconstructed to represent the existing condition of the PT. Sipatamoda Indonesia office building as constructed on site. The model was developed using SketchUp and subsequently integrated with the Sefaira plug in. The building massing, number of floors, floor areas, and proportions of openings were therefore based on the actual building configuration (Winandari et al., 2023). This approach was adopted to ensure that the simulation results were not merely hypothetical but reflected the building's energy performance under its actual operating conditions (Nabilah et al., 2021). Accordingly, changes in energy performance observed in the simulation results can be directly attributed to the research variable, namely the implementation of a passive shading strategy (Satrioprato et al., 2024).

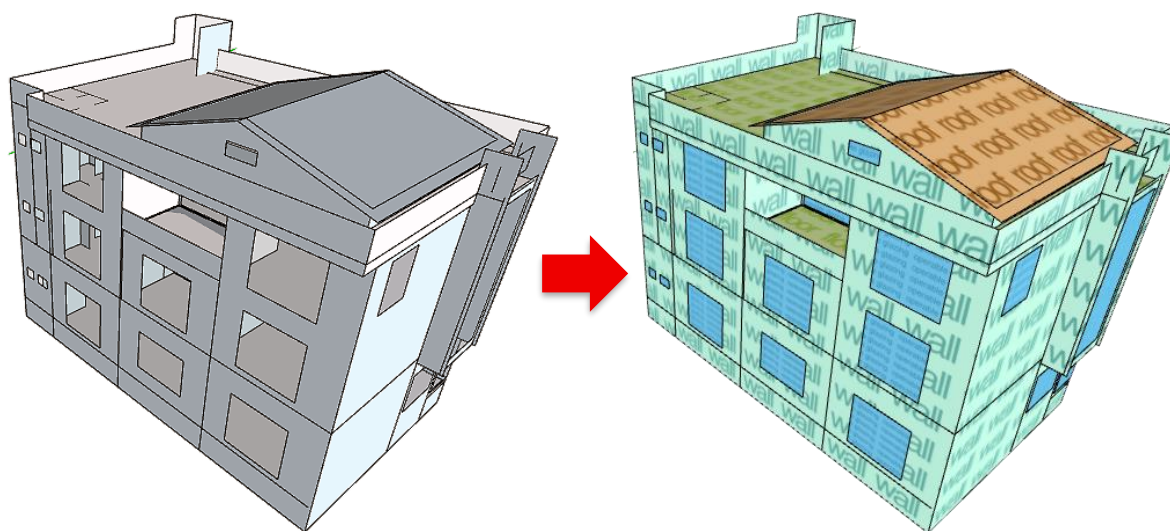


Figure 7. Existing Building Model (Without Shading)
(Source: Author's Illustration, 2026)

The first scenario represents the existing building condition, with no additional shading elements applied to the openings. This scenario serves as the baseline for assessing the building's energy performance, particularly its annual cooling energy demand and EUI under the current building envelope configuration (Budhyowati, 2021). The second scenario was

developed from the existing condition by introducing a combined passive shading strategy consisting of horizontal and vertical elements at the building openings. The combination of horizontal and vertical shading was selected based on its ability to respond to variations in solar angles throughout the day, including both high and low solar angles, without requiring structural modifications to the existing building (Hanissaa & Paramita, 2021).

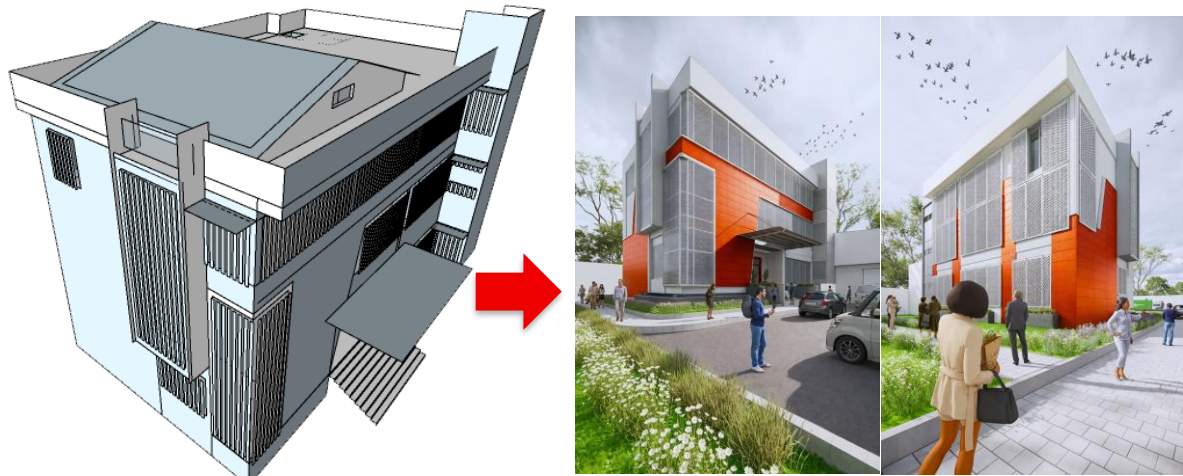


Figure 8. Proposed Building Model with Passive Shading
(Source: Author's Illustration, 2026)

The analysis was limited to energy performance indicators that directly reflect the building's response to solar radiation and its implications for energy consumption (Vakumoro et al., 2023). Two primary parameters were examined: annual cooling energy (kWh/year) and annual *Energy Use Intensity* (EUI) (kWh/m²/year). In office buildings located in humid tropical climates, cooling loads commonly account for a substantial proportion of total energy consumption, particularly in buildings that operate primarily during the daytime and have a relatively high proportion of glazed or open facade areas (Demami & Rizal, 2022). In this study, EUI was used to assess whether the implementation of combined passive shading contributed to an improvement in the building's overall energy efficiency (Attaufiq & Pratiwi, 2022).

3. RESULTS AND DISCUSSION

3.1 Simulation Results: Differences in Cooling Energy and Energy Use Intensity (EUI)

The building energy performance simulation conducted using Sefaira shows a difference in annual cooling energy between the existing building condition without shading and the condition with a combined passive shading strategy.

In the existing building scenario (Scenario 1), which does not incorporate additional shading, the annual cooling energy demand was higher at 28,146 kWh/year. In contrast, the scenario incorporating combined passive shading consisting of horizontal and vertical elements (Scenario 2) recorded a lower annual cooling energy demand of 26,152 kWh/year. This reduction occurred across all building floors and contributed cumulatively to a decrease in the building's total annual energy consumption, from 119,190 kWh/year to 112,810 kWh/year.

Annual Energy Use

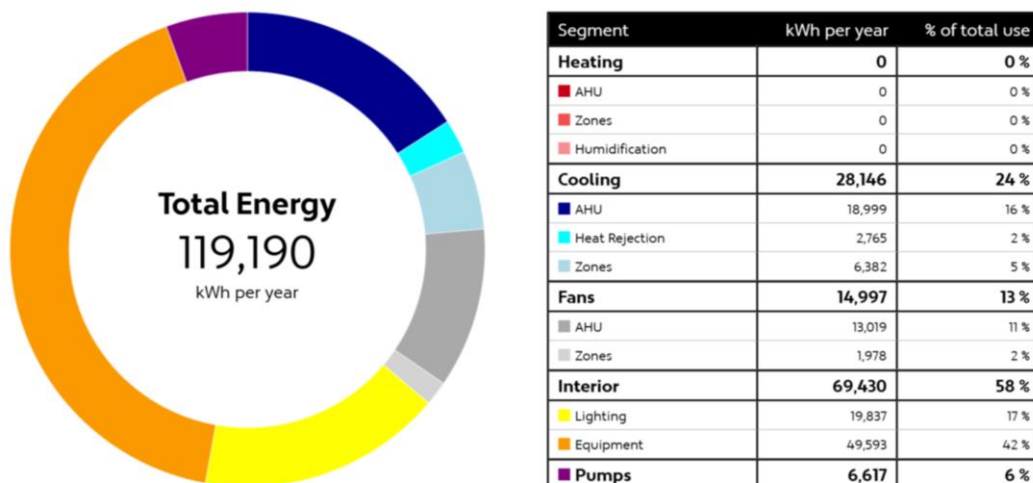


Figure 9. Total Energy Scenario 1
(Source: Sefaira Analysis, 2026)

Annual Energy Use

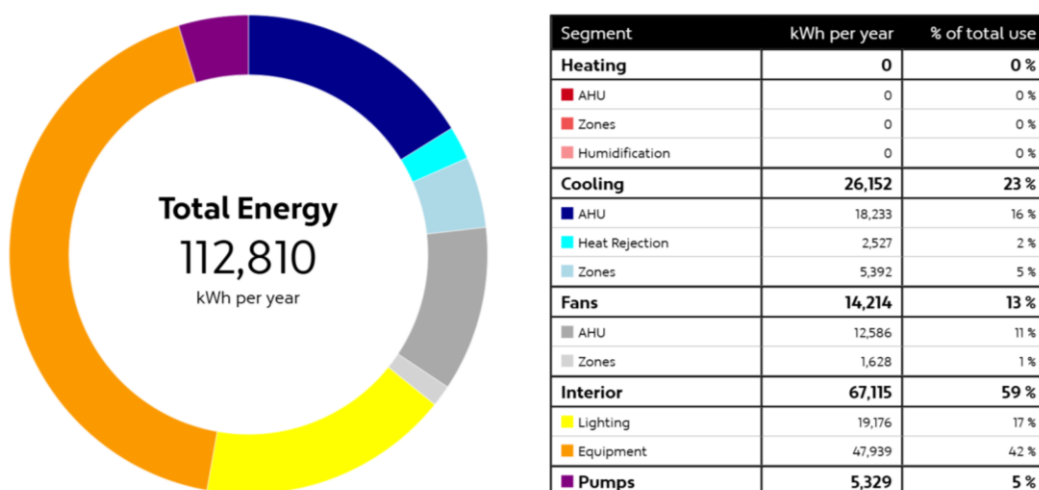


Figure 10. Total Energy Scenario 2
(Source: Sefaira Analysis, 2026)

Table 1. Comparison of Annual Cooling Energy

Simulation Scenario	Cooling Energy (kWh/year)	% of Total Energy Use
Existing without shading	28,146	24
Combined passive shading	26,152	23

Source: Sefaira Analysis, 2026

In addition to cooling energy, the simulation results indicate a difference in annual Energy Use Intensity (EUI) between the two scenarios. UI was used to characterize building energy performance in relation to the total floor area of 1,024.4 m², allowing the energy performance of the two conditions to be compared using a standardized metric (Widiastuti, 2022).

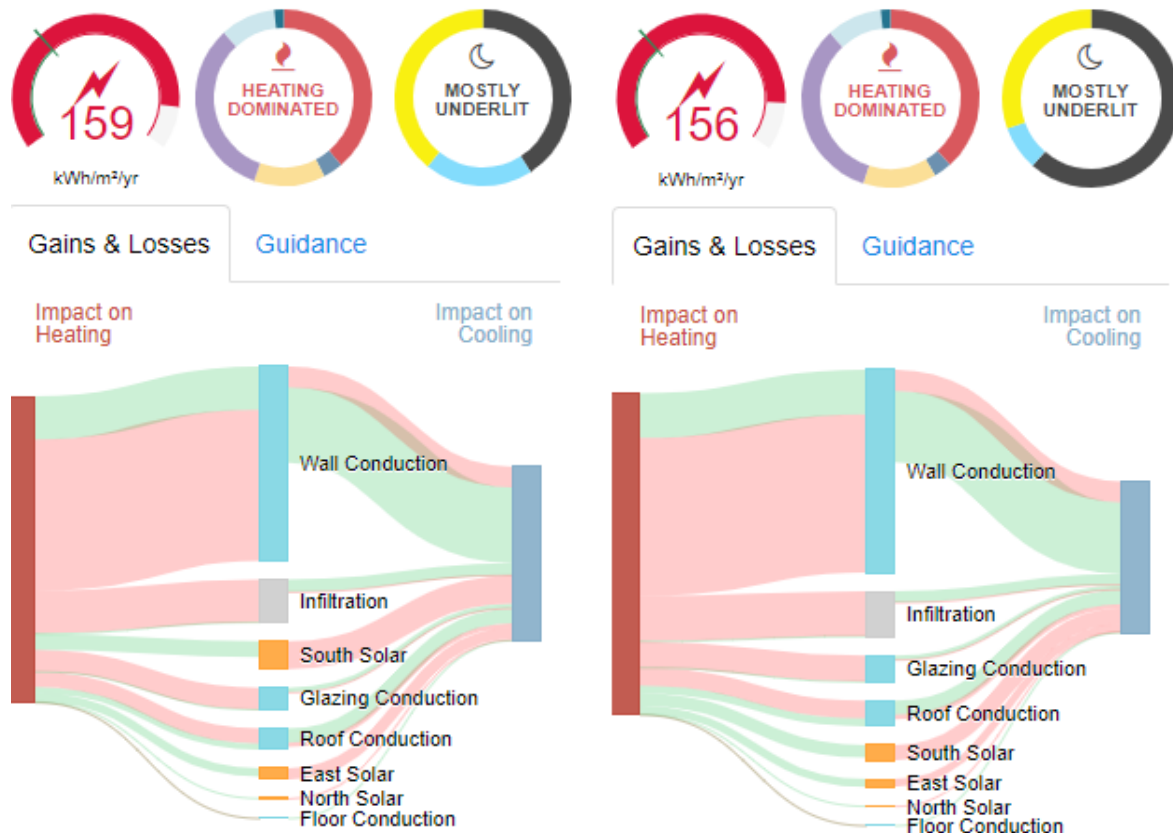


Figure 11. EUI Value Scenario 1
(Source: Sefaira Analysis, 2026)

Figure 12. EUI Value Scenario 2
(Source: Sefaira Analysis, 2026)

For the existing building without shading (Scenario 1), the annual EUI was 159 kWh/m²/year, which was higher than the 156 kWh/m²/year recorded for the building with combined passive shading (Scenario 2). The implementation of the combined passive shading strategy therefore resulted in a lower annual EUI than the existing condition. This reduction corresponds with the lower cooling energy demand identified in the simulation results. The difference in EUI between the two scenarios indicates an improvement in the building's energy efficiency following the implementation of the passive shading strategy, while the cooling system and building operational patterns remained unchanged.

Table 2. Comparison of Annual Energy Use Intensity (EUI)

Simulation Scenario	EUI (kWh/m ² /year)	Change (%)
Existing without shading	159	-
Combined passive shading	156	1.89

Source: Sefaira Analysis, 2026

3.2 Influence of Passive Shading on Cooling Load Reduction

The simulation results show that implementing combined passive shading in the PT. Sipatamoda Indonesia office building contributed to a reduction in annual cooling energy demand. This change is primarily associated with the ability of shading elements to control solar radiation entering through facade openings, which in the existing condition were not equipped with passive solar protection. Without shading, solar radiation enters the interior and increases solar heat gain within the building. With the introduction of passive shading elements, part of the incoming solar radiation is intercepted before reaching the glazing, thereby reducing the amount of heat transferred into the occupied space. The combination of horizontal and vertical shading elements allows the building facade to respond to variations in solar altitude and incidence angles throughout the day.

Accordingly, the reduction in cooling energy observed in the simulation can be understood as a consequence of the lower amount of solar heat penetrating the building envelope. The findings indicate that passive shading operates at the building envelope level, intercepting solar radiation before the resulting heat gain becomes a cooling load that must be handled by the air conditioning system.

3.3 Implications for the Energy Efficiency of Existing Buildings

The reduction in cooling energy demand resulting from the implementation of combined passive shading has implications for the overall energy efficiency of the existing building, as reflected in the decrease in annual Energy Use Intensity (EUI) from 159 kWh/m²/year to 156 kWh/m²/year. Office buildings that are primarily occupied during the daytime and rely heavily on air conditioning may benefit from passive shading strategies. This approach is particularly relevant to existing buildings that are already in operation and face various constraints on physical modification. Passive shading offers a practical intervention because it can be implemented without altering the existing spatial functions or disrupting established building systems (A'yun & Yun, 2015).

The findings also reinforce the role of passive shading within a bioclimatic design approach for existing buildings. Although the intervention is relatively simple, its effect on annual energy efficiency can still be quantified through building performance simulation. Hence, passive shading can be considered an initial intervention strategy before more extensive measures are introduced, such as improving HVAC system performance or integrating renewable energy technologies (Attafiq & Pratiwi, 2022; Budhyowati, 2021).

3.4 Research Limitations

First, the analysis relies entirely on building energy performance simulations conducted using the Sefaira plug in. The results therefore represent idealized conditions based on the assumptions incorporated into the simulation model. Second, this study does not parametrically explore variations in the dimensions and configurations of the passive shading elements. Accordingly, the analysis focuses on comparing the existing condition with the proposed intervention rather than on comprehensive optimization of the shading design.

Nevertheless, the study provides a relevant academic contribution by demonstrating the potential of passive shading as an energy efficiency strategy for existing office buildings in humid tropical climates. These limitations also provide opportunities for further research through the development of more diverse design scenarios, field-based validation using measured building performance data, and more comprehensive economic assessments.

4. CONCLUSION

The simulation results show that the addition of combined passive shading, consisting of horizontal and vertical elements at the facade openings of the PT. Sipatamoda Indonesia

office building, reduced annual cooling energy demand from 28,146 kWh/year to 26,152 kWh/year. This reduction is associated with the lower amount of solar radiation penetrating the building envelope, which consequently reduces solar heat gain within the occupied spaces and the cooling demand placed on the air conditioning system compared with the existing condition without passive protection.

The reduction in cooling energy demand is also reflected in the building's annual Energy Use Intensity (EUI), which decreased from 159 kWh/m²/year to 156 kWh/m²/year under the combined passive shading scenario. Although the overall composition of the building's energy consumption did not change substantially, the shading intervention produced a measurable improvement in energy efficiency. These findings indicate that combined passive shading can serve as a relevant and applicable nonstructural intervention for existing office buildings, particularly where modifications to building form, orientation, or mechanical systems are constrained.

The main finding of this study is that a relatively simple facade intervention can produce measurable reductions in cooling energy demand without altering the building's existing functions or mechanical systems. In this context, passive shading provides a feasible approach for improving the energy performance of existing office buildings in humid tropical climates, where solar heat gain contributes to cooling demand. The study therefore recommends considering passive shading as part of incremental energy efficiency improvements for existing buildings before more extensive interventions are undertaken.

Further research should investigate variations in shading dimensions, depth, spacing, and configuration through parametric simulation to identify more effective design combinations. Future studies should also incorporate field measurements to validate simulation results and assess the effects of shading under actual operating conditions. A broader assessment that includes construction costs, payback periods, and lifecycle performance would further clarify the feasibility of passive shading as a retrofit strategy for existing buildings in humid tropical climates.

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