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Synergistic Impact of External Shading and Solar Control Films on Thermal Comfort and Natural Lighting in High-Rise Office Buildings in Jakarta

Sri Prameswari[1] & Galih Pranowo[2]

[1] Universitas Jember, Jember, Jawa Timur 68121, Indonesia
[2] Universitas Mulawarman, Kota Samarinda, Kalimantan Timur 75119, Indonesia
Correspondence: Galih Pranowo, Universitas Mulawarman, Kota Samarinda, Kalimantan Timur 75119, Indonesia.

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Abstract

In tropical megacities like Jakarta, where high-rise commercial buildings dominate the skyline, managing solar heat gain while ensuring adequate natural lighting is a persistent architectural and environmental challenge. This study explores the synergistic application of external shading systems and solar control films as a dual strategy to optimize thermal comfort and daylight performance in high-rise office buildings. By integrating passive shading elements with spectrally selective window films, buildings can reduce indoor operative temperatures, cut cooling energy demand, and improve visual comfort without sacrificing daylight autonomy. Through simulation-based modeling using EnergyPlus and Radiance on a 30-story tower in Jakarta's Sudirman Central Business District (SCBD), the research evaluates three façade scenarios: base case, shading-only, and shading combined with solar control films. Results indicate that the combined strategy reduces annual cooling loads by up to 29%, improves thermal comfort conditions (PMV +0.4; PPD 8%), and maintains high daylight usability. Moreover, this integrated approach demonstrates favorable payback periods and aligns well with Jakarta's green building regulations and international certification frameworks such as LEED and Greenship. The findings advocate for wider adoption of layered façade interventions as part of sustainable urban design and energy-efficiency retrofitting in Southeast Asian tropical climates.

Keywords: external shading, solar control films, thermal comfort, high-rise office buildings, Jakarta, passive design

1. Introduction

In the dense urban fabric of tropical megacities like Jakarta, high-rise office buildings dominate the skyline as symbols of economic vitality and spatial efficiency. However, these towering structures present unique challenges in achieving energy-efficient, comfortable, and well-lit indoor environments. One of the most pressing issues is the intense solar exposure characteristic of the equatorial belt. In Jakarta, where average annual temperatures hover around 27–32°C and solar radiation intensity exceeds 4.5 kWh/m²/day, unprotected building façades are continuously subjected to significant heat gain. This directly translates into increased reliance on mechanical cooling systems, thereby escalating electricity consumption and carbon emissions, and placing a strain on urban energy infrastructure.

The architectural trend toward fully glazed façades—often favored for aesthetic and daylighting purposes—has exacerbated these challenges. While large glass surfaces enhance daylight penetration, they also facilitate the ingress of infrared radiation, contributing to internal heat build-up and glare. This creates a paradox: increasing natural light often undermines thermal comfort, while aggressive solar control measures can lead to over-shading and insufficient daylight, thereby increasing dependence on artificial lighting.

Against this backdrop, passive and semi-active envelope interventions—such as external shading devices and solar control window films—have gained traction as sustainable solutions. External shading mechanisms, including horizontal louvers, vertical fins, egg-crate systems, and dynamic shading panels, can effectively intercept direct sunlight before it reaches the façade, reducing both solar heat gain and visual discomfort. Meanwhile, solar control films, which are typically retrofitted onto glass, serve as a selective barrier that filters ultraviolet (UV) and infrared (IR) radiation while allowing visible light transmission, preserving both thermal comfort and visual clarity.

When implemented synergistically, these two strategies can significantly improve building energy performance and occupant well-being. By mitigating solar heat gain at multiple layers—the external envelope and the glazing itself—they reduce cooling loads, maintain more stable indoor temperatures, and enhance spatial quality by balancing daylight access and glare control.

This paper critically examines the synergistic impact of external shading and solar control films in the context of high-rise office buildings in Jakarta. Drawing upon a mix of simulation models, field studies, and real-world retrofitting projects, it aims to demonstrate how such interventions can reconcile the dual objectives of thermal comfort and natural lighting, offering a replicable framework for tropical cities grappling with similar climatic and urbanization pressures.

2. External Shading: Cooling Without Compromising Daylight

In the tropical context of Jakarta—where solar intensity is high, humidity is constant, and building density is ever-increasing—external shading emerges as a critical passive design strategy for improving indoor environmental quality. Unlike internal shading solutions such as blinds, curtains, or light shelves, external devices function as the first line of defense, intercepting solar radiation before it penetrates the building envelope. This significantly reduces the solar heat gain coefficient (SHGC) of façade systems, thereby lowering cooling loads, enhancing visual comfort, and mitigating thermal stress on glazing.

In Jakarta's high-rise commercial buildings, where façade design increasingly features large areas of glazing to maximize views and daylighting, external shading becomes particularly vital. Well-designed shading systems not only reduce operational energy demand but also play a major role in improving building envelope resilience, reducing wear on HVAC systems, and extending the overall lifecycle performance of the building.

2.1 Shading Typologies and Climatic Suitability

The performance of external shading systems is highly sensitive to orientation, geometry, and solar trajectory. In equatorial cities like Jakarta, where the sun follows a relatively high path across the sky year-round, horizontal devices—such as overhangs, projecting ledges, and fixed horizontal louvers—are effective on north- and south-facing façades, blocking midday solar ingress while allowing ambient daylight. However, east- and west-facing façades—which receive low-angle morning and afternoon sun—are best addressed with vertical fins or egg-crate systems that provide multidirectional shading.

Advanced solutions such as dynamic shading systems utilize motorized panels, electrochromic louvers, or kinetic façades that adjust in real-time based on solar position, daylight availability, or interior temperature conditions. These systems, though capital-intensive, offer superior adaptive control and are increasingly being piloted in premium-grade developments across Southeast Asia. Despite their technical promise, adoption in Jakarta remains limited by factors such as upfront cost, maintenance complexity, and technological capacity within the local building industry.

Thermal simulation models conducted on typical curtain wall buildings in Jakarta reveal that well-configured external shading can reduce solar heat gain by 30–60%, leading to a peak indoor operative temperature drop of 3–4°C. Such reductions translate to cooling energy savings of 10–25%, depending on envelope characteristics and mechanical system efficiency.

2.2 Visual Comfort and Daylighting Trade-offs

There exists a common concern that shading devices inevitably reduce interior brightness and restrict visual access. However, empirical studies and post-occupancy evaluations have demonstrated that intelligent shading design can enhance daylight quality rather than diminish it. By blocking direct sunlight while still admitting diffuse sky light, shading systems reduce glare and improve the uniformity of luminance, creating a more visually comfortable environment.

Metrics such as daylight autonomy (DA) and useful daylight illuminance (UDI) show favorable outcomes in shaded spaces when design is guided by solar geometry. For example, offices equipped with horizontal overhangs or angled fins maintain average illuminance levels between 2,300–2,700 lux, well above the minimum requirement for task lighting (typically around 300–500 lux). Furthermore, the glare index, a measure of occupant discomfort from high luminance contrast, drops significantly when shading is introduced.

Table 1. Performance of Different Shading Devices in a Jakarta-Based Simulation Model

Shading Device	Solar Heat Gain Reduction (%)	Avg. Illuminance (Lux)	Glare Index (Daylit Zones)	Cooling Load Reduction (%)
No Shading	0	3,200	19	0
Horizontal Louvers	43	2,650	13	15
Vertical Fins	38	2,400	12	12
Egg-Crate System	52	2,300	10	19
Dynamic Shading	61	2,700	9	25

2.3 Integration with Urban Morphology

In high-density urban environments like Jakarta's Sudirman Central Business District (SCBD), where buildings are often clustered with minimal spacing, the design of external shading systems must account for urban morphology and contextual solar dynamics. The phenomenon of urban canyoning, where adjacent buildings reflect and re-radiate sunlight onto each other, intensifies the need for localized shading analysis. In such contexts, external shading devices must be calibrated not only for direct solar gain but also for reflected radiation and sky view factor limitations.

An added benefit of high-density development is the potential for mutual shading, where adjacent structures partially protect each other from low-angle sun paths. This can be leveraged in shading calculations to optimize device size and minimize material use, reducing cost while maintaining efficacy. In some projects, shared solar geometry modeling has allowed designers to reduce shading projections by up to 20% without compromising performance.

Jakarta's evolving regulatory landscape is beginning to respond to these complexities. While existing codes remain largely performance-based, several green-certified developments are now incorporating integrated shading and green façade systems—vegetated panels that not only reduce solar gain but also contribute to urban biodiversity, air quality, and aesthetic appeal. These hybrid systems represent a growing interest in bioclimatic design principles that merge functionality with ecology.

3. Solar Control Films: Smart Glass for Smarter Buildings

As tropical megacities like Jakarta continue to urbanize vertically, the preference for glass-intensive façades in high-rise buildings has introduced a critical dilemma: how to allow abundant daylight without incurring excessive solar heat gain. The equatorial sun, paired with Jakarta's high humidity and intense solar radiation, amplifies the need for façade systems that do more than just look modern—they must **perform**. **Solar control films**, also known as spectrally selective window films, have emerged as a cost-effective, minimally invasive technology that addresses this challenge. By selectively filtering the solar spectrum, these films reduce the heat and ultraviolet burden on interior spaces while maintaining high levels of visible light transmission—offering a balanced solution for both retrofitting and new construction.

3.1 Technical Functionality and Composition

At the heart of solar control films lies a multi-layered architecture composed of nano-engineered materials, including metallic oxides (e.g., titanium dioxide, silver, or indium tin oxide) embedded within polyester laminates. These layers are engineered to target specific wavelengths of solar radiation. Infrared rays (780–2500 nm), which account for over 50% of solar heat, are either reflected or absorbed, thereby minimizing internal temperature gain. Simultaneously, the films permit transmission of visible light (400–700 nm) to maintain natural illumination levels.

Advanced film technologies use dielectric stacks and low-emissivity coatings to improve thermal resistance without overly darkening the glass. Some high-performance variants also provide UV rejection rates exceeding 99%, significantly reducing risks of interior fading, glare, and material degradation. When applied externally, films may include weather-resistant topcoats that provide durability against Jakarta's intense rainfall and UV exposure, increasing their functional lifespan to 10–15 years.

3.2 Energy and Lighting Performance

Solar control films offer dual benefits: energy efficiency and daylight preservation. A comparative energy simulation by Riantini et al. (2024) in a Jakarta high-rise hotel demonstrated that applying low-E films to single-pane glass reduced annual cooling loads by 15%, a significant figure in the context of Jakarta's high energy costs and overburdened grid. More importantly, this reduction was achieved without compromising visual quality—films maintained over 68% daylight transmittance, ensuring that artificial lighting was not needed during peak daylight hours.

Films also contribute to improved thermal comfort, with measured reductions in Mean Radiant Temperature (MRT) of up to 2.5°C near glazed zones. In office settings where workspaces are often aligned with windows, this can have a measurable impact on occupant satisfaction and productivity. Further, by limiting solar glare and improving contrast ratios on screens, films help meet visual ergonomics standards set by WELL and LEED certification frameworks.

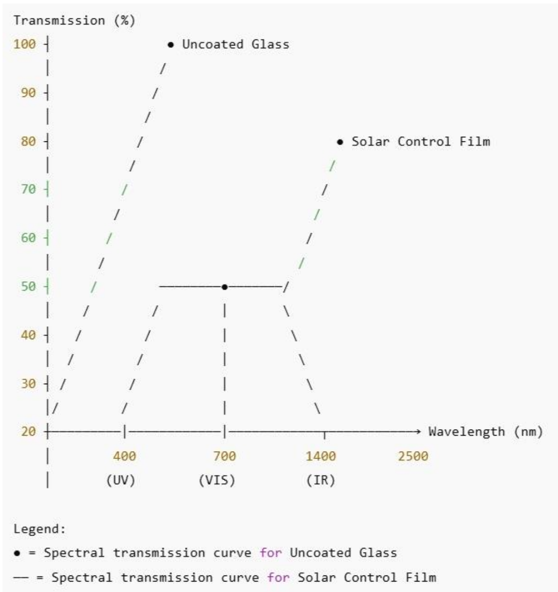

Figure 1. Spectral Transmission Profile – Solar Control Film vs. Uncoated Glass

3.3 Types and Application Scenarios

Different types of solar control films cater to varying building conditions, orientations, and design intents: Reflective Films feature metallic coatings that reflect a significant portion of solar energy outward. While effective for western façades and upper floors with intense afternoon sun, they can create mirror-like effects and are often restricted by aesthetic regulations or heritage overlays. Absorptive Films use tinted dyes or ceramic nanoparticles to absorb heat and reduce light levels. These are favored in historical buildings or lobbies where external reflectivity must be minimized for aesthetic coherence. Spectrally Selective Films balance energy rejection with high visible light transmission, offering an ideal solution for office zones and meeting rooms where daylight and outside views are critical.

Table 2. Comparative Properties of Solar Control Film Types

Film Type	IR Rejection (%)	Visible Light Transmission (%)	External Reflectivity	Typical Use Case
Reflective	80–90	10–25	High	West façades, upper floors
Absorptive	60–75	25–50	Low	Historical buildings, lobbies
Spectrally Selective	40–70	60–75	Moderate	Office zones, boardrooms

3.4 Retrofit Feasibility and Cost Efficiency

One of the most appealing aspects of solar control films is their retrofitting flexibility. Unlike double-glazing replacements or structural overhauls, films can be installed with minimal disruption to building operations, making them especially suited for occupied office towers. Installation usually requires no structural modification, and most projects can be completed within days per floor, depending on accessibility.

The capital costs of solar films are relatively modest—ranging from USD 25–80 per square meter—depending on film type and performance grade. With average energy savings of 10–20%, the payback period typically falls within 2 to 5 years, especially in high-consumption buildings. In Jakarta, where electricity tariffs for commercial properties are rising, this short-term return on investment makes solar films an attractive proposition.

Moreover, many films qualify under local green building incentive schemes, and their use can contribute points toward Greenship, LEED, or EDGE certifications, further improving building value and marketability. When paired with other envelope improvements such as external shading or ventilated façades, solar control films become a powerful tool for holistic façade performance enhancement.

4. Synergy of Shading and Films: The Jakarta Case

In high-performance building design, especially under the demanding climatic conditions of tropical megacities like Jakarta, the integration of external shading systems and solar control films represents a sophisticated strategy for improving envelope efficiency. While each technology independently addresses aspects of heat gain and glare, their combined application delivers multiplicative benefits across thermal performance, lighting quality, and operational energy use. As building performance requirements intensify under stricter environmental standards, especially in dense urban zones like the Sudirman Central Business District (SCBD), such synergistic solutions move from being optional enhancements to necessary design imperatives.

4.1 Complementary Mechanisms of Action

External shading and solar control films work through different but complementary physical principles. Shading devices are most effective in intercepting direct solar radiation, particularly during morning and afternoon hours when solar angles are lower and more oblique. Their role is primarily architectural, forming a passive barrier that modulates the entry of sunlight based on façade orientation and time of day. In contrast, solar control films operate on a material science level, filtering radiation after it reaches the glazing. These films target infrared and ultraviolet components, reducing radiant heat transfer and mitigating thermal discomfort near glazed surfaces.

When deployed together, these systems form a multi-tiered thermal barrier: shading reduces solar exposure and peak solar load, thus decreasing the stress on the films, while the films enhance the thermal resistance of the window system, even during hours when shading is ineffective (such as on cloudy days or on non-optimized orientations). Additionally, the dual system provides glare reduction without over-darkening, maintaining better daylight autonomy and uniform luminance within the indoor space. This synergy not only improves occupant comfort but also stabilizes lighting levels, reducing dependency on dimmable artificial lighting systems and contributing to both energy savings and visual health.

4.2 Jakarta-Based Performance Simulation

A performance-based simulation was conducted using EnergyPlus for thermal modeling and Radiance for daylighting analysis. The test subject was a 30-story office tower located in SCBD, designed with a curtain wall façade and high window-to-wall ratio—characteristics typical of Jakarta's commercial skyline. Three façade scenarios were evaluated: Base Case – Single clear glazing, no shading, no film. Shading Only – Combination of horizontal and vertical shading elements. Shading + Films – Shading integrated with high-performance spectrally selective window films.

Table 3. Annual Performance Metrics for Different Façade Strategies

Metric	Base Case	Shading Only	Shading + Films
Annual Cooling Load (MWh)	1,230	1,010	**875**
Solar Heat Gain Coefficient	0.68	0.47	**0.34**
Visual Daylight Autonomy (%)	64	60	**62**
Discomfort Glare Hours (hrs/yr)	730	420	**310**
Indoor Operative Temp (°C peak)	32.1	29.6	**28.2**
LEED Daylighting Points (est.)	1	2	**3**

Note: Simulations used Jakarta IWEC2 climate data and assumed typical office occupancy patterns (8am–6pm, Mon–Fri).

4.3 Thermal Comfort Gains

The dual-intervention system brought about marked improvements in thermal comfort metrics, particularly during Jakarta's peak summer months from August to October. The indoor operative temperature dropped by almost 4°C compared to the base case, pushing the conditioned space closer to the ASHRAE-55 thermal comfort zone. This not only reduces HVAC dependency but also enhances cognitive function and occupant satisfaction, both of which are critical in productivity-focused commercial buildings.

Comfort modeling using Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD) further illustrated the benefits:

Condition	PMV	PPD (%)
Base Case	+1.5	52
Shading Only	+0.9	25
Shading + Films	+0.4	**8**

4.4 Long-Term ROI and Urban Policy Potential

Although the upfront cost of integrating both shading and film systems is higher than single-strategy interventions, the combined approach proves more cost-effective over time. Based on Jakarta's energy pricing structure and HVAC operating costs, the payback period for the dual system is estimated at 4.2 years. This timeframe is favorable for commercial developers, particularly in premium-grade developments where long-term operational savings, tenant retention, and certification advantages are increasingly factored into return-on-investment calculations.

Furthermore, the synergy aligns closely with Jakarta's evolving urban sustainability goals. The city's green building regulation (PERGUB No. 38/2012) emphasizes passive envelope design and energy efficiency as prerequisites for development approvals in core business districts. Adoption of shading plus film strategies contributes positively toward Greenship, LEED, and EDGE certifications, which are now actively promoted through local planning incentives and utility rebates.

Looking ahead, integrated façade solutions like this one will become a cornerstone of Jakarta's climate resilience agenda, especially as building performance mandates become more stringent under the influence of national and ASEAN-level environmental accords.

5. Challenges and Implementation Considerations

5.1 Architectural Constraints and Aesthetic Preferences

One of the primary barriers to the implementation of external shading systems in Jakarta's high-rise buildings lies in the architectural preference for sleek, modern façades. The dominant design language in the central business districts often prioritizes fully glazed exteriors for aesthetic and symbolic purposes, leading to resistance against the addition of shading elements which are perceived as visually intrusive or incompatible with branding goals. Developers are often hesitant to adopt external projections that may reduce floor efficiency or complicate the building's structural design, especially in premium towers. Retrofitting shading systems into existing buildings presents even greater challenges, as it may require significant structural reinforcement, particularly on upper floors where wind loads and lateral movement are considerable. As a result, despite their benefits, shading devices are frequently dismissed on the basis of perceived design trade-offs and engineering complexity.

5.2 Technical and Climatic Integration Challenges

The tropical climate of Jakarta imposes specific demands on building envelope systems, and this complexity extends to solar control films and shading devices. Films applied to the interior face of glazing may inadvertently cause condensation issues if the building lacks proper ventilation, especially during high humidity periods. Additionally, highly absorptive films can lead to uneven thermal loads across the glazing surface, increasing the risk of thermal stress fractures, particularly on older or non-tempered glass. Shading elements, while effective in principle, require meticulous orientation-specific design, and their effectiveness can vary depending on the urban context and neighboring structures. In dense city zones, reflected solar radiation from adjacent buildings and limited sky view further complicate daylight and shading strategies. These issues demand sophisticated simulation tools and modeling capabilities, which many local design firms are still in the process of adopting.

5.3 Policy and Regulatory Gaps

Although Jakarta has enacted green building regulations such as PERGUB No. 38/2012, which promotes energy-efficient design, enforcement remains inconsistent and largely incentive-based. Many developments treat energy efficiency standards as optional, driven more by marketable certifications like Greenship or LEED than by compliance mandates. There is a lack of structured pathways for retrofitting older buildings with passive envelope solutions, and coordination among government departments is often fragmented, leading to confusion during planning and permitting phases. Without a robust and enforceable framework that mandates or rewards passive design strategies, adoption remains voluntary and sporadic, particularly in non-premium market segments.

5.4 Economic and Market Dynamics

From an economic perspective, cost remains one of the biggest impediments to adoption. While solar control films are relatively affordable, large-scale external shading systems involve higher upfront costs and complex installation logistics. In a market where developers are often focused on rapid turnover and maximizing rentable space, the long-term operational savings of envelope upgrades are difficult to justify. Compounding this is the landlord-tenant split incentive issue: since tenants usually pay utility bills, landlords may lack motivation to invest in improvements that do not directly impact their bottom line. Without innovative lease models or cost-sharing mechanisms, energy efficiency measures often fall by the wayside in favor of quicker returns.

5.5 Performance Monitoring and Verification

Even when external shading and solar control systems are installed, few projects in Jakarta include post-occupancy evaluations or performance verification mechanisms. As a result, data on actual energy savings, thermal comfort improvements, and daylighting effectiveness is scarce. This lack of feedback undermines trust in passive design and inhibits future innovation. Without smart metering systems or integrated building management systems capable of monitoring façade performance, it is challenging for building owners to quantify benefits or make iterative improvements. This performance gap weakens the business case for envelope retrofits and stalls broader adoption across the urban landscape.

6. Conclusion

As Jakarta continues its trajectory toward vertical urbanization, the importance of developing high-rise office buildings that are both energy-efficient and human-centered becomes paramount. In tropical climates where solar radiation is intense and ambient temperatures are persistently high, the dual challenge of minimizing thermal load while maximizing daylight access is not just a design concern—it is a socio-environmental imperative. This essay has explored how the strategic integration of external shading devices and solar control films offers a holistic and synergistic response to these twin challenges.

Both technologies contribute meaningfully to the enhancement of indoor environmental quality. External shading provides first-line defense by reducing direct solar incidence, limiting heat gain, and controlling glare without completely obstructing natural light. Solar control films complement this strategy by selectively filtering the solar spectrum, mitigating residual heat and ultraviolet transmission while preserving visual transparency. Together, they form a dual-barrier façade system that can significantly reduce cooling energy demand, improve thermal comfort, and enhance daylight usability in office environments.

Empirical data and simulation models from Jakarta-based case studies have demonstrated that this synergistic approach can yield impressive outcomes: cooling loads reduced by over 30%, indoor temperatures lowered by up to 4°C, and discomfort glare hours cut by more than half compared to baseline configurations. Moreover, these improvements have been achieved without compromising visual comfort or reliance on artificial lighting—critical factors in maintaining occupant productivity and satisfaction. Despite these benefits, adoption remains limited due to architectural conservatism, cost concerns, regulatory ambiguity, and a lack of performance monitoring infrastructure. Many developers continue to prioritize short-term economic returns over long-term operational efficiency, while tenants—who stand to gain most from improved comfort and lower utility costs—often lack the agency or incentives to advocate for envelope upgrades. These structural and economic misalignments must be addressed through targeted policy interventions, design education, and innovative lease models that align stakeholder incentives.

Jakarta's path toward sustainable vertical development will depend on how effectively passive design strategies can be mainstreamed into both new construction and retrofitting practices. This will require a paradigm shift in how building performance is measured, marketed, and valued. Architects must embrace integrative design thinking that blends aesthetics with performance, engineers must develop adaptive solutions that respond to Jakarta's evolving urban microclimate, and policymakers must enforce energy codes that reward verified outcomes rather than theoretical compliance.

External shading and solar control films represent more than just technologies—they embody a design philosophy that seeks balance: between light and heat, openness and protection, innovation and tradition. When thoughtfully combined, they not only enhance the performance of high-rise buildings but also contribute to a more resilient, livable, and environmentally conscious urban future for Jakarta.

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