

Literature Review: Concept and Application of Double Facade Design in Buildings in Tropical Climates

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Submitted: 13-09-2025
Revised: 07-10-2025
Accepted: 30-03-2026
Available online: 06-06-2026

How To Cite: Alfred Depa Dede, P. J. (2026). Literature Review: Concept and Application of Double Facade Design in Buildings in Tropical Climates. *Nature: National Academic Journal of Architecture*, 136–148. <https://doi.org/10.24252/nature.v13i1a11>

Abstrak. Penelitian ini merupakan tinjauan pustaka sistematis yang mengkaji penerapan sistem fasad ganda (double façade) pada bangunan di iklim tropis, dengan fokus pada implikasinya terhadap efisiensi energi dan kenyamanan termal. Tinjauan dilakukan mengikuti pedoman PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) melalui tahapan identifikasi, penyaringan, penilaian kelayakan, dan sintesis terhadap artikel empiris yang diperoleh dari basis data Scopus, Web of Science, ScienceDirect, dan Google Scholar. Dari total 64 publikasi yang teridentifikasi, sebanyak tujuh studi memenuhi seluruh kriteria inklusi dan dianalisis dalam sintesis akhir. Penelitian ini tidak menghasilkan data empiris baru, melainkan menyintesis temuan-temuan penelitian terdahulu untuk mengidentifikasi prinsip desain, tantangan implementasi, serta faktor penentu kinerja sistem fasad ganda di iklim tropis. Hasil sintesis menunjukkan bahwa kinerja fasad ganda sangat dipengaruhi oleh pengelolaan ventilasi rongga, pemilihan material yang sesuai dengan kondisi kelembapan tinggi, serta penerapan strategi pengendalian radiasi matahari. Tantangan yang secara konsisten dilaporkan dalam literatur meliputi akumulasi panas akibat ventilasi yang tidak memadai, permasalahan kelembapan, dan degradasi material dalam jangka panjang. Temuan juga mengindikasikan bahwa pendekatan desain adaptif seperti penggunaan kaca responsif, sistem ventilasi terkontrol, dan perangkat peneduh yang dapat disesuaikan memiliki potensi lebih besar untuk mendukung keberlanjutan dibandingkan konfigurasi fasad statis. Namun demikian, tinjauan ini menyoroti keterbatasan bukti empiris jangka panjang pada kondisi operasional nyata di iklim tropis.

Kata Kunci: Desain Fasad Ganda; Bangunan; Iklim Tropis

Abstract. This study presents a systematic literature review examining the application of double façade systems in tropical climates, with particular attention to their implications for building energy efficiency and thermal comfort. The review was conducted in accordance with the PRISMA 2020 guidelines, employing a structured process of identification, screening, eligibility assessment, and synthesis of peer-reviewed empirical studies retrieved from Scopus, Web of Science, ScienceDirect, and Google Scholar. From an initial pool of 64 publications, seven studies met all predefined inclusion criteria and were included in the final synthesis. Rather than generating new empirical data, this study synthesizes existing evidence to identify recurring design principles, implementation challenges, and performance determinants of double façade systems in tropical environments. The synthesis indicates that effective double façade performance is closely associated with controlled cavity ventilation, appropriate material selection under high humidity conditions, and the integration of solar control strategies. Recurrent challenges reported across the literature include heat accumulation within inadequately ventilated cavities, moisture management issues, and material durability under prolonged tropical exposure. The findings further suggest that adaptive design approaches such as responsive glazing, regulated ventilation strategies, and adjustable shading systems offer greater potential for sustainable performance than static façade configurations. However, the review also highlights a significant gap in long-term empirical validation under real tropical operating conditions.

Keywords: Double Facade Design; Buildings; Tropical Climates

INTRODUCTION

Environmentally friendly and energy-efficient buildings have become a central concern in contemporary architectural discourse, particularly in tropical regions such as Indonesia, where high solar radiation, humidity, and cooling demand significantly affect building performance (Dewi et al., 2020). In response to these challenges, the application of double-skin façade (double façade) systems has emerged as a promising architectural strategy to enhance thermal performance, reduce energy consumption, and improve occupant comfort (Nasir, 2022). Conceptually, a double façade consists of two envelope layers separated by an intermediate cavity, functioning as a thermal buffer that mitigates direct solar heat gain, facilitates controlled ventilation, and reduces reliance on mechanical cooling systems (Gonçalves et al., 2024; Lee, 2024).

A growing body of literature has examined the principles and performance of double façade systems in various climatic contexts. However, existing studies are predominantly concentrated in temperate and cold climates, where façade performance is often evaluated in terms of heat retention and insulation efficiency (Cabeza & Chàfer, 2020). In contrast, systematic knowledge regarding the application and optimization of double façade systems in tropical climates remains fragmented and limited. Tropical environments pose distinct challenges, including persistent high humidity, fluctuating temperatures, intense solar exposure, and complex wind patterns, which fundamentally alter façade behavior compared to non-tropical regions (Pelletier et al., 2023).

Despite the increasing number of empirical studies addressing façade performance in tropical settings, the literature lacks an integrative synthesis that consolidates existing findings, identifies recurring design principles, and critically examines implementation challenges specific to tropical climates. Most available studies are reported as isolated simulations, experimental evaluations, or case-specific analyses, making it difficult to derive generalized insights applicable across different tropical contexts (Kim et al., 2022). This fragmentation highlights a clear research gap: the absence of a systematic, cross-study synthesis that evaluates how double façade design principles perform, adapt, and evolve within tropical climatic conditions.

To address this gap, the present study is explicitly designed as a Systematic Literature Review (SLR) focusing on the concept and application of double façade systems in tropical climates. Rather than conducting an empirical qualitative or quantitative investigation, this study synthesizes findings from peer-reviewed empirical research to identify key design principles, performance determinants, challenges, and emerging trends. By adopting a systematic review approach, this research aims to move beyond individual case interpretations and provide an evidence-based, integrative understanding of double façade performance in tropical architectural contexts.

Accordingly, this study is guided by the following research questions:

- Q1:** How are the basic concepts and design principles of double façade systems applied in buildings located in tropical climates?
- Q2:** What are the primary challenges reported in the literature regarding the implementation of double façade systems in tropical environments?
- Q3:** Which design and environmental factors are consistently identified as critical for optimizing double façade performance in tropical climates?
- Q4:** What evidence-based recommendations can be synthesized from existing studies to support the sustainable implementation of double façade systems in tropical regions?

METHOD

A. Research Design

This study was conducted as a Systematic Literature Review (SLR) following the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA was adopted to ensure a transparent, replicable, and structured review process suitable for synthesizing empirical evidence across interdisciplinary research domains, including architecture and building performance studies (Preet et al., 2022).

This research was not designed as an empirical qualitative or quantitative study and did not involve primary data collection such as interviews, observations, surveys, or field measurements. All data analyzed in this study were derived exclusively from secondary sources, namely peer-reviewed academic publications. The review protocol consisted of four sequential stages: identification, screening, eligibility assessment, and inclusion, consistent with PRISMA 2020 recommendations.

B. Data Sources and Search Strategy

A comprehensive and systematic literature search was conducted across four major academic databases: Scopus, Web of Science, ScienceDirect, and Google Scholar. These databases were selected to ensure broad coverage of peer-reviewed research in architecture, building science, and environmental performance.

The search was restricted to publications published between January 2019 and June 2024 to capture recent developments in double façade design and performance within tropical climates. A structured search strategy was applied using predefined keywords and Boolean operators, adapted to the indexing syntax of each database (Ascione et al., 2021). The core search string was as follows:

("double skin façade" OR "double façade" OR "double-skin façade" OR "cavity wall")

AND

("tropical climate" OR "hot humid" OR "tropical region")

AND

("energy efficiency" OR "thermal comfort" OR "building performance").

This strategy was refined through preliminary scoping to balance sensitivity and specificity, ensuring the retrieval of studies directly relevant to façade performance in tropical contexts.

C. Eligibility and Exclusion Criteria

To ensure methodological consistency and relevance, studies were selected based on predefined inclusion and exclusion criteria. Inclusion criteria were as follows:

1. Original empirical research articles published in peer-reviewed journals or conference proceedings.
2. Studies primarily examining the application, simulation, or performance evaluation of double façade systems.
3. Explicit contextualization within tropical climate zones (Köppen–Geiger classifications Af, Am, or Aw).
4. Reported outcomes related to energy consumption, indoor thermal comfort, or indoor environmental performance.

Exclusion criteria included:

1. Studies conducted exclusively in temperate, arid, or cold climates.
2. Review articles, book chapters, theses, and other non-peer-reviewed publications.
3. Articles not written in English or Indonesian.
4. Studies with inaccessible full texts.
5. Publications in which double façade systems were not a primary analytical variable.

D. Study Selection Procedure and Bias Control

The initial database search identified 64 records. After removing duplicate entries, 40 studies were screened based on titles and abstracts, resulting in the exclusion of 20 articles due to thematic irrelevance. The full texts of the remaining 20 studies were then assessed for eligibility, leading to the final inclusion of seven studies that met all predefined criteria (Andreeva et al., 2022).

To enhance methodological rigor and minimize selection bias, the screening and eligibility assessment were conducted independently by two reviewers. Disagreements were resolved through discussion, and the final inclusion list was verified by a third reviewer. Inter-reviewer agreement was assessed using Cohen's kappa coefficient ($\kappa = 0.82$), indicating a high level of consistency in study selection. The study selection process was documented using a PRISMA flow diagram, illustrating each stage from identification to final inclusion.

E. Data Extraction and Synthesis Method

Data from the included studies were extracted using a standardized extraction matrix capturing: author(s), publication year, geographic location, climate classification, façade configuration, cavity characteristics, ventilation strategy, glazing or material properties, and reported energy or thermal performance outcomes.

Due to heterogeneity in research designs, performance indicators, and analytical methods across the included studies, quantitative meta-analysis was not feasible. Instead, the review employed a thematic synthesis approach to systematically integrate findings across studies. Importantly, this thematic synthesis represents a cross-study analytical framework, not a qualitative empirical analysis based on primary data (Fernando et al., 2023).

The synthesis process focused on identifying recurring patterns, convergences, and divergences across the reviewed literature. Emergent themes were categorized into four analytical domains:

1. Thermal buffering and insulation performance.
2. Ventilation strategies and airflow dynamics.
3. Material adaptability and humidity management.
4. technological integration and adaptive façade systems.

This approach enabled the consolidation of fragmented empirical findings into an integrated understanding of double façade performance in tropical climates. The initial search yielded 64 records across the four databases: Scopus (21), Web of Science (14), ScienceDirect (17), and Google Scholar (12). After removing duplicate entries, 40 unique records remained for screening.

RESULTS AND DISCUSSION

A. Results

The systematic search conducted across Scopus, Web of Science, ScienceDirect, and Google Scholar yielded a total of 64 records relevant to the topic of double façade systems in tropical climates. These records represent the initial identification stage of the systematic literature review and form the empirical basis for subsequent synthesis.

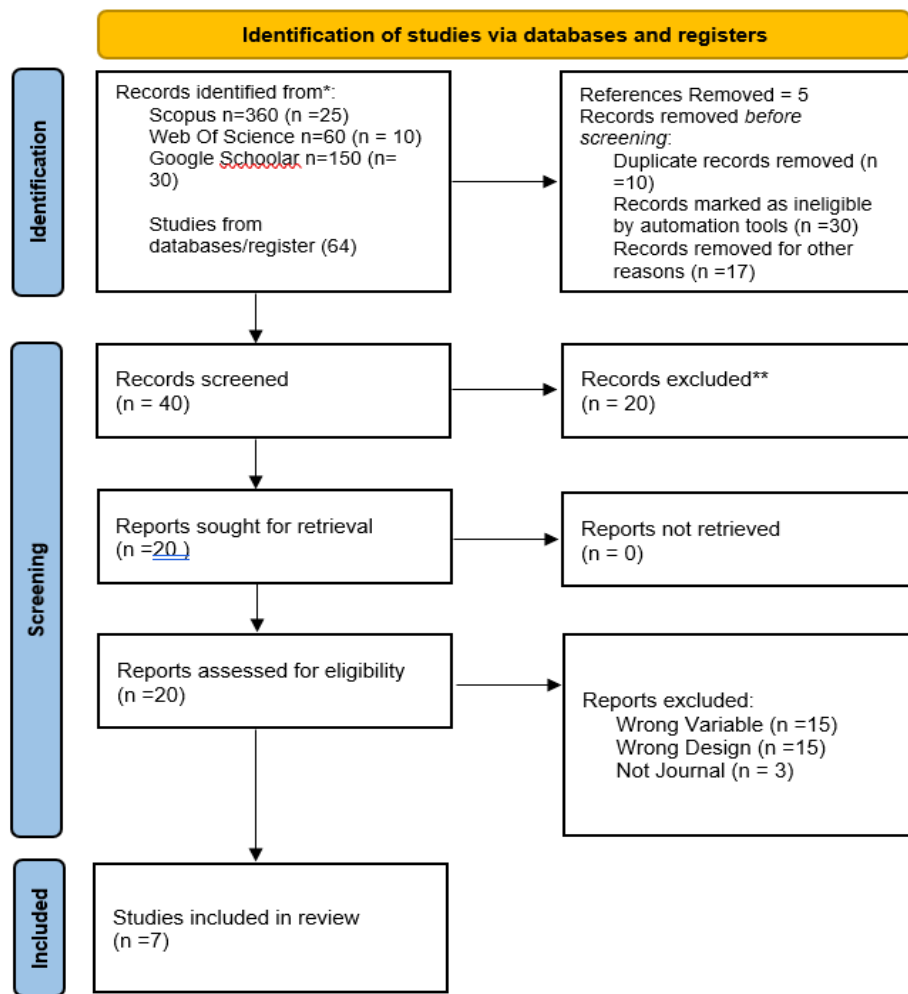


Figure 1. Prism Diagram

Following the removal of duplicate publications, 40 records were retained and subjected to title and abstract screening. At this stage, 20 studies were excluded due to a lack of thematic relevance, insufficient focus on double façade systems, or absence of a clear tropical climate context. The remaining 20 full-text articles were then assessed for eligibility based on the predefined inclusion and exclusion criteria.

The eligibility assessment resulted in the exclusion of 18 studies, primarily due to misalignment of research variables, inappropriate climatic settings, or publication type inconsistencies. Consequently, seven studies satisfied all methodological and thematic criteria and were included in the final synthesis. The study selection process is summarized in the PRISMA flow diagram (Figure 1), which illustrates each stage from identification to inclusion.

Importantly, the limited number of eligible studies does not indicate a lack of research interest, but rather reflects the stringent selection criteria applied to ensure analytical consistency and contextual relevance. This outcome underscores the fragmented nature of existing research on double façade systems in tropical climates, where many studies address façade performance in isolation or within non-tropical contexts (Gupta & Deb, 2023; Lionar et al., 2024; Liu et al., 2023).

From a systematic review perspective, the inclusion of seven high-relevance empirical studies provides a focused and credible evidence base for cross-study synthesis. Rather than interpreting these studies as individual cases, the analysis emphasizes recurring patterns, convergent findings, and thematic relationships across the selected literature. This approach enables the identification of

dominant performance factors, implementation challenges, and design strategies associated with double façade systems in tropical environments.

B. Discussion

The analysis results of 7 articles were used as data (*data can be seen in the Appendix file included with this article*). It is known that:

1. Application of Double Façade Design Principles in Tropical Climates (Q1)

Across the reviewed literature, double façade design is consistently conceptualized as a climate-responsive building envelope system that mediates thermal exchange between outdoor and indoor environments through an intermediate cavity. Rather than functioning solely as an additional insulating layer, the façade is understood as a dynamic interface whose performance depends on the interaction between cavity configuration, ventilation strategy, and climatic context (Lim & Rodzi, 2022; Vassiliades et al., 2022).

The synthesized findings indicate a strong consensus that cavity-induced airflow plays a central role in reducing solar heat gain and stabilizing indoor thermal conditions in tropical buildings. Multiple studies report that appropriately designed cavity spaces can facilitate heat dissipation through buoyancy-driven or wind-assisted ventilation, thereby lowering surface and indoor temperatures. However, the literature diverges regarding which design variables exert the greatest influence on performance (Faragalla & Asadi, 2022; Izadyar et al., 2020). Some studies emphasize façade geometry and orientation as primary determinants of thermal effectiveness, while others highlight the integration of shading devices and ventilation components as more critical to controlling heat accumulation.

Beyond passive configurations, a subset of studies introduces adaptive and kinetic façade strategies, including movable panels and energy-integrated cavity systems. When synthesized collectively, these studies suggest a conceptual shift in tropical façade design: from static thermal buffering toward responsive envelope systems capable of adjusting to fluctuating solar intensity, wind conditions, and humidity levels. This shift reflects an emerging recognition that tropical climates demand façade systems that prioritize controlled permeability and airflow modulation rather than maximal insulation (Alkhatib et al., 2020; Zhong et al., 2022).

The synthesis also reveals a recurring caution across the literature: inadequate cavity ventilation can undermine façade performance by trapping hot air and increasing thermal load. This finding reinforces the interpretation of the double façade as an active climatic mediator rather than a passive barrier (Akram et al., 2023; Talaei et al., 2020). Effective performance in tropical environments therefore depends not only on reducing heat transfer but also on managing airflow and moisture movement within the façade assembly.

Taken together, these patterns support a broader theoretical implication for tropical architecture. Double façade systems are increasingly framed as adaptive envelope mechanisms that simultaneously regulate thermal, luminous, and hygroscopic conditions. However, the reviewed literature remains fragmented in its analytical approaches. Few studies employ comparable performance metrics that integrate geometry, ventilation rate, and material behavior within a single evaluative framework. This fragmentation limits the generalizability of individual findings and highlights the need for future research that adopts integrated performance assessment models and long-term empirical validation under real tropical operating conditions.

2. Main Challenges in Implementing Double Façade Design in Tropical Climates (Q2)

The cross-study synthesis of the selected literature indicates that the primary challenges in implementing double façade systems in tropical climates are associated with thermal imbalance, moisture accumulation, and material-ventilation incompatibility within the façade cavity. Rather

than representing isolated technical issues, these challenges emerge consistently as systemic design constraints inherent to hot-humid environments (Arumugam et al., 2022; Susca et al., 2022).

Across the reviewed studies, a recurring finding is that insufficiently ventilated cavities may act as heat traps, counteracting the intended cooling function of double façade systems. While the façade is designed to reduce direct solar radiation, the synthesis shows that inadequate airflow management can lead to excessive heat buildup within the cavity, particularly under conditions of high humidity and low wind velocity (Jamilu et al., 2024; Megahed & Ghoneim, 2021; Şirin et al., 2023). This challenge reflects a fundamental design paradox in tropical contexts: the façade must simultaneously limit solar heat gain while maintaining sufficient permeability to release accumulated heat.

The literature further reveals a tension between technological integration and climatic suitability. Several studies advocate hybrid or technologically enhanced façade systems that combine passive ventilation with mechanically assisted airflow or energy-generating components. When synthesized collectively, these studies suggest that such systems can reduce thermal accumulation under controlled conditions (Bortolini et al., 2022; Ghosh, 2020; Kitsopoulou et al., 2024). However, the evidence also indicates that technological complexity does not inherently guarantee climatic effectiveness, especially when material transparency, glazing selectivity, or ventilation control are poorly adapted to tropical solar and moisture conditions. Excessive transparency and non-selective glazing materials are repeatedly identified as factors that exacerbate greenhouse effects within façade cavities, thereby increasing cooling demand.

Material performance under prolonged tropical exposure emerges as another critical challenge. The synthesis highlights that façade materials with low resistance to humidity, condensation, and thermal cycling are prone to accelerated degradation, resulting in reduced durability and long-term performance. Rather than being evaluated solely through short-term thermal metrics, material suitability in tropical double façade systems must be understood in terms of durability-adaptability synergy the ability of materials and assemblies to maintain functional performance under continuous moisture exposure and fluctuating climatic stress.

In contrast to highly mechanized façade concepts, the reviewed literature also points to alternative approaches that emphasize controlled structural permeability. Façade systems incorporating porous or semi-permeable elements with regulated apertures demonstrate improved airflow efficiency and reduced condensation risk without relying heavily on mechanical intervention. However, such approaches remain underrepresented in comparative analyses, indicating a methodological imbalance in current research favoring technologically driven solutions over climate-responsive structural strategies (Rathore et al., 2022; Tabadkani et al., 2020).

A significant research gap identified through this synthesis lies in the limited empirical validation of double façade performance under real tropical operating conditions. Most existing studies rely on simulations or short-term experimental setups, with minimal attention to long-term behavior under persistent humidity, particulate exposure, maintenance practices, and occupant adaptation. The absence of longitudinal and context-sensitive evaluations constrains the development of façade models that are genuinely representative of tropical environments.

Overall, the synthesized findings support a broader conceptual shift in contemporary discourse: double façade systems in tropical climates should be understood not as static thermal barriers, but as bioclimatic mediators that balance thermodynamic control, moisture management, material resilience, and ecological adaptability. Addressing the identified challenges will require integrative research frameworks that bridge material science, climatic engineering, and human-centered design, enabling façade systems to perform adaptively within the dynamic conditions of tropical built environments.

3. Key Factors for Optimizing Double Façade Performance in Tropical Climates (Q3)

The cross-study synthesis indicates that optimal performance of double façade systems in tropical climates depends on the integrated interaction of orientation, material properties, ventilation strategy, and solar control mechanisms. The reviewed literature consistently emphasizes that these factors cannot be treated as isolated design parameters; rather, their effectiveness emerges from their interdependence within a dynamic tropical climatic system (Ascione et al., 2020; Kumar et al., 2022).

Building orientation is frequently identified as a fundamental factor influencing façade thermal behavior. Across the literature, façades exposed to east–west solar paths are reported to experience higher solar loads than those oriented north–south, resulting in increased cavity temperatures. However, the synthesis also demonstrates that orientation alone does not determine performance outcomes. Several studies indicate that façade geometry and cavity ventilation strategy can moderate or even offset unfavorable orientations, suggesting that airflow management plays a decisive role in thermal regulation. This finding challenges conventional passive design assumptions that prioritize orientation as a dominant variable independent of ventilation performance (Bianchi et al., 2024; Singh et al., 2021).

Material selection emerges as a similarly complex determinant of façade effectiveness. While high-performance glazing and smart glass technologies are commonly proposed to enhance thermal control, the synthesized evidence shows that their performance in tropical climates is highly contingent on humidity exposure and maintenance conditions. Recurrent findings across studies indicate that persistent condensation and moisture can reduce glazing efficiency and accelerate material degradation. Consequently, material performance in tropical double façade systems must be evaluated not only in terms of insulation or solar control, but also through long-term durability and moisture resilience (Hosamo et al., 2022; Rahman et al., 2021; Yang et al., 2022). This perspective reframes material selection from a purely technical optimization problem to an ecological adaptation challenge.

Ventilation strategy is identified as the most critical yet least standardized component across the reviewed studies. The synthesis reveals divergent approaches, ranging from fully passive airflow mechanisms to hybrid systems combining natural ventilation with mechanically assisted exhaust. While increased airflow is generally associated with reduced cavity heat accumulation, the literature also cautions against uncontrolled ventilation in hot–humid environments, where excessive airflow may reintroduce latent heat and moisture. Taken together, these findings suggest that regulated porosity, rather than maximal ventilation, is essential for balancing heat dissipation and humidity control. The absence of unified metrics linking airflow rate, humidity levels, and thermal comfort constitutes a significant gap in current tropical façade research.

Solar shading devices including louvers, blinds, and perforated panels are consistently recognized as important modifiers of façade performance. However, the synthesis indicates that their effectiveness is highly dependent on coordination with cavity depth, surface reflectivity, and daylight requirements (Arowoia et al., 2024; Xiong et al., 2021). Fixed shading systems may either compromise visual comfort through over-shading or exacerbate thermal discomfort through insufficient solar control. As a result, the literature increasingly supports the adoption of adaptive shading strategies that respond dynamically to solar intensity, daylight demand, and occupant interaction.

Collectively, the synthesized findings suggest that optimizing double façade performance in tropical climates requires moving beyond prescriptive, single-variable design guidelines. Instead, the façade should be conceptualized as an interactive climatic system capable of negotiating solar exposure, airflow, humidity, and material behavior simultaneously. This conceptual shift from static energy-saving elements toward adaptive performance envelopes represents a central theme in contemporary tropical façade research. Nevertheless, the literature remains limited in long-term

empirical validation under real tropical operating conditions, highlighting the need for future studies that integrate field-based monitoring with predictive performance modeling.

4. Evidence-Based Recommendations for Sustainable Double Façade Implementation in Tropical Climates (Q4)

Recent advancements in tropical double façade design increasingly emphasize technological adaptability the capacity of façade systems to respond dynamically to environmental fluctuations rather than relying solely on passive insulation. The integration of smart glass technologies, as investigated by Zlateva et al. (2024) and Ye et al. (2022), exemplifies this paradigm shift. Their studies demonstrate that electrochromic and thermochromic glazing can automatically modulate transparency based on external solar intensity, reducing solar heat gain by up to 30% while preserving daylight penetration. Yet, the comparison of both works reveals differing implications: while Zlateva et al. focus on façade responsiveness during diurnal temperature cycles in humid climates, Ye et al. highlight post-occupancy satisfaction, showing that occupants in adaptive glazing environments report 20% higher thermal and visual comfort levels. This divergence underscores that technological performance must be evaluated not only through energy metrics but also through human-environment interaction.

Beyond glazing, McGowan (2020) and Bulbaai & Halman (2021) emphasize the enduring significance of natural ventilation systems such as cross-ventilation and solar chimneys. Both studies confirm that passive airflow mechanisms can stabilize indoor temperatures by facilitating buoyancy-driven ventilation; however, their methodological emphasis differs. McGowan focuses on airflow efficiency measured through CFD simulation, while Bulbaai & Halman incorporate field observations in Caribbean tropical conditions, highlighting the moderating role of humidity in airflow effectiveness (Bakhshoodeh et al., 2022). When compared, these findings indicate that ventilation cannot be optimized by geometry alone it must be coupled with real-time environmental sensing to adapt to variable humidity levels typical of tropical climates.

The challenge of material durability under such conditions remains an underexplored research frontier. Abdulahaad, Ra'ouf, and Hasan (2023), through a materials-engineering perspective, argue that glass and composite materials designed for temperate climates rapidly degrade when exposed to high atmospheric moisture, leading to optical distortion and corrosion. Meanwhile, Bulbaai & Halman (2021) propose the use of regionally adapted materials with microporous coatings that allow minimal vapor diffusion without compromising insulation. Synthesizing these findings reveals that the future of tropical double façades lies not in imported high-tech solutions, but in hybrid material systems those that merge smart responsiveness with contextual resilience.

Finally, adaptive design components, such as automated blinds and dynamic shading devices, emerge as critical mediators between energy performance and user comfort. Comparative analyses by Ye et al. (2022) and Mintorogo et al. (2022) show that adjustable shading can reduce indoor operative temperature by 3–5°C, particularly when coordinated with cavity ventilation. However, both studies acknowledge the absence of long-term empirical validation under real tropical exposure, where dust, humidity, and mechanical fatigue may degrade performance. This identifies a clear research gap: current evidence on adaptive façade technologies remains dominated by short-term simulations or laboratory settings, with limited understanding of maintenance dynamics and lifecycle sustainability in humid tropical regions.

Overall, the synthesis across these studies suggests that the novelty of emerging tropical double façade research lies in reconceptualizing the façade as an intelligent climatic mediators living interface that balances energy efficiency, thermal regulation, and material endurance. The transition from static to responsive design marks a fundamental evolution in tropical architectural thought, yet empirical data on long-term adaptability and contextual appropriateness remain insufficient. Addressing these limitations through field-based, multi-scalar studies will be essential for

transforming double façade technology from a high-cost experimental feature into a viable mainstream strategy for sustainable tropical architecture.

The synthesis of the reviewed studies suggests a conceptual transition in tropical façade design from static thermal buffering to adaptive climatic mediation. In tropical environments, the effectiveness of double façade systems depends not solely on insulation capacity but on the regulation of airflow, humidity exchange, and solar exposure through controlled façade permeability. This study therefore proposes a conceptual framework of tropical double façade performance consisting of four interrelated components: cavity ventilation regulation, humidity-resilient material systems, orientation-responsive solar control, and adaptive shading integration.

CONCLUSION

This systematic literature review synthesizes empirical findings on the application of double façade systems in tropical climates and demonstrates their potential contribution to improving building energy efficiency and thermal comfort when appropriately adapted to local climatic conditions. Across the reviewed studies, double façade systems are consistently identified as effective architectural strategies for moderating solar heat gain, enhancing airflow regulation, and reducing dependence on mechanical cooling, particularly in hot-humid environments.

The synthesis highlights that the performance of double façade systems in tropical climates is strongly influenced by the interaction between cavity ventilation, material behavior, solar exposure, and humidity control. While adaptive technologies such as dynamic glazing and responsive shading devices are shown to enhance façade performance, the literature also indicates that technological solutions alone are insufficient if not aligned with climatic suitability and long-term material resilience. Inadequate ventilation design, inappropriate material selection, and excessive transparency are recurrent challenges that can undermine the intended thermal benefits of double façade systems.

Furthermore, the reviewed studies emphasize that effective implementation requires an integrated design approach. Building orientation, ventilation strategy, shading configuration, and material durability must be considered as interdependent variables rather than isolated design decisions. The evidence suggests that flexible and adaptive façade components, including regulated ventilation systems and adjustable shading devices, offer promising pathways for balancing energy efficiency, thermal comfort, and daylight performance in tropical buildings.

Despite these insights, the literature remains limited in long-term empirical validation under real tropical operating conditions. Many existing studies rely on simulations or short-term assessments, with insufficient attention to durability, maintenance practices, and occupant adaptation over time. This limitation points to a clear research need for longitudinal, field-based studies that integrate environmental performance metrics with lifecycle and user-centered evaluations.

This systematic review demonstrates that the effectiveness of double façade systems in tropical climates depends not merely on the addition of a secondary envelope layer but on the coordinated regulation of airflow, solar exposure, and moisture dynamics. The synthesis reveals that ventilation control within the façade cavity, humidity-resilient materials, and adaptive solar shading constitute the primary determinants of thermal performance in hot-humid environments.

Conceptually, this study reframes the double façade in tropical architecture as an adaptive climatic mediator rather than a static insulating barrier. This perspective highlights the importance of controlled permeability and responsive envelope systems capable of dynamically interacting with tropical environmental conditions. From a practical standpoint, the findings suggest that future façade design in tropical regions should prioritize regulated cavity ventilation, adaptive shading devices, and material systems capable of sustaining long-term performance under high humidity

exposure. Nevertheless, the current body of evidence remains dominated by simulation-based studies, with limited empirical validation under real operating conditions. Future research should therefore focus on long-term field monitoring and integrated performance evaluation to better understand the lifecycle behavior of adaptive façade systems in tropical environments.

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