A Comparative Study on the Impact of Double-Skin Façade Ventilation Mechanisms on Airflow and Natural Ventilation in Hot–Dry and Hot–Humid Climates

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Abstract: —Double-skin façades (DSFs) are widely used to regulate heat transfer and support natural ventilation in warm climates, yet their airflow behaviour differs significantly between hot–dry and hot–humid regions. A clear comparative understanding of how climate-specific drivers influence DSF ventilation is still limited. This study aims to determine how environmental conditions in these two contrasting climates affect airflow dynamics, ventilation rates, and the overall effectiveness of natural ventilation. The research compares quantitative findings from validated Computational Fluid Dynamics (CFD) analyses, full-scale measurements, and numerical–experimental datasets, using a unified analytical framework focused on airflow behaviour, ventilation performance, and climatic responsiveness. Results demonstrate two distinct operating regimes: in hot–dry climates, DSFs operate mainly as buoyancy-driven thermal buffers, achieving modest cavity velocities and enabling winter preheating, with enhanced performance in narrow cavities. In hot–humid climates, suppressed buoyancy shifts ventilation to primarily wind-driven behaviour, producing substantially higher airflow velocities; adaptive louvers and solar-chimney features further improve ventilation intensity and uniformity. The study concludes that DSF ventilation strategies must be climate-specific and cannot be generalized across warm regions. Remaining research gaps include limited large-scale validation, inadequate consideration of life-cycle impacts, and a lack of integrated analyses linking airflow and energy performance.

Key-Words: —Double-skin façade (DSF), Airflow Performance, Natural Ventilation, Hot–Dry Climate, Hot–Humid Climate, Ventilation Performance

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1. Introduction

Building energy consumption continues to rise globally due to rapid urbanization, increasing population, and the widespread use of highly glazed building envelopes, which has intensified the demand for façade systems capable of improving both thermal and environmental performance [1]. Among various façade technologies, double-skin façades (DSFs) have become one of the most influential transparent envelope systems for enhancing indoor comfort, moderating heat transfer, and integrating natural ventilation and daylighting strategies.

A DSF typically consists of an external glazing layer, an intermediate air cavity, and an inner glazing layer, often combined with adjustable shading devices located within the cavity [2, 3]. The cavity may operate under natural, mechanical, or hybrid ventilation, enabling it to function as a dynamic environmental buffer [4]. Through this configuration, DSFs can reduce solar heat gain during cooling periods, decrease heat loss during heating seasons, and enhance daylight utilization while mitigating glare [5, 6]. The width of the air cavity—typically ranging from 200 mm to more than 2 m—plays a crucial role in airflow behaviour and thermal performance [7]. Moreover, different DSF typologies—such as box-window, shaft-box, corridor, and multi-storey configurations—vary significantly in cost, airflow mechanisms, and climatic suitability [8].

The seasonal operation of DSFs is illustrated in Fig. 1, where the façade acts as a ventilated buffer in summer by exhausting heated air through buoyancy-driven ventilation, while in winter the cavity traps solar gains and reduces heat loss through the inner glazing. This schematic highlights how shading position, airflow direction, and glazing configuration collectively influence the thermal and ventilation behaviour of naturally ventilated single-storey DSFs [9].

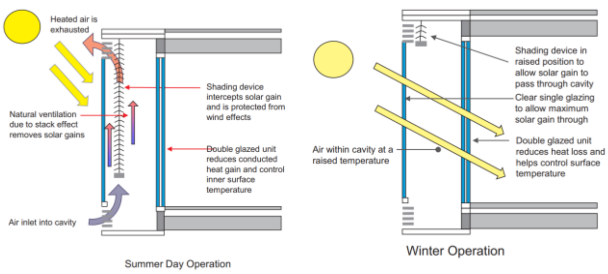

Fig. 1. Double skin facade principle of operation in summer and winter (single storey- naturally ventilated) [9].

In hot–dry and hot–humid climates, where solar loads, overheating risks, and ventilation needs are particularly pronounced, airflow management within DSF cavities becomes a decisive factor. In hot–dry climates, DSFs can help buffer intense solar radiation while enabling buoyancy-driven ventilation to control heat build-up. In hot–humid climates, where moisture and high cooling demands dominate, DSF ventilation strategies must carefully balance heat removal with indoor air quality and energy efficiency objectives. As previous studies highlight, DSF performance is highly climate-dependent, and optimizing airflow control requires detailed knowledge of both façade configuration and local environmental conditions [10].

Despite the extensive body of research on DSF design, thermal behaviour, and ventilation mechanisms a clear gap remains in the comparative understanding of airflow performance in hot–dry versus hot–humid climates. Most existing studies focus on single-case simulations, specific DSF typologies, or isolated climate conditions, leaving limited insight into how ventilation strategies perform across contrasting warm climates with different thermal loads and airflow drivers.

Accordingly, the novelty of this study lies in providing a structured comparative analysis of DSF airflow and natural ventilation performance across hot–dry and hot–humid climates, highlighting how climate-specific environmental drivers influence ventilation efficiency, heat removal, and façade performance. This comparative perspective contributes to a deeper understanding of DSF suitability, design priorities, and optimization potential in diverse warm regions, thereby addressing a research gap that has been largely overlooked in prior DSF literature.

2. Methodology

This study investigates the influence of double-skin façade (DSF) ventilation mechanisms on airflow behaviour and natural ventilation performance in hot–dry and hot–humid climates. The evaluation followed the criteria below:

- To analyse previous studies that report quantitative assessments of airflow, pressure differentials, ventilation rates, or cavity microclimate behaviour
- To include other studies employing Computational Fluid Dynamics (CFD) simulations, experimental measurements, full-scale testbeds, or hybrid evaluation methods relevant to DSF ventilation performance
- To compare DSF typologies that incorporate different ventilation modes, including naturally ventilated, mechanically assisted, hybrid, and climate-responsive configurations

Each selected study was reviewed according to its aim, methodology, climatic profile, DSF configuration, evaluated airflow parameters, and key numerical outcomes. Based on the comparative synthesis of these studies, the research establishes a three-layer analytical framework, structured as follows:

1) Airflow dynamics and cavity pressure behaviour

2) Natural ventilation effectiveness and ventilation rate enhancement

3) Climatic responsiveness of DSF ventilation mechanisms in hot–dry vs. hot–humid conditions

These three analytical layers form the foundation of the Results and Discussion section, where the comparative influence of ventilation mechanisms on DSF airflow performance across the two climatic groups is examined in depth.

3. Airflow and Natural Ventilation Performance of Double-skin Façades in Hot–dry Climates

3.1 Airflow Dynamics and Pressure Behaviour of DSFS in Hot–dry Climates

Across the reviewed studies, airflow behavior in double-skin façades (DSFs) under hot–dry climatic conditions is strongly governed by solar-induced buoyancy, glazing optical properties, and cavity configuration. In the hot–arid climate of Cairo, Hamza and Underwood (2005) demonstrated that solar radiation between 100–700 W/m² generates notable vertical airflow, producing cavity velocities ranging from 0.045–0.84 m/s and mass flow rates of 0.5–0.94 kg/s, with outlet temperatures rising to 41–66 °C. Their coupled CFD – thermal simulations confirmed that increased airflow slightly enhances cooling-load reductions (≈2% reduction), although glazing optical characteristics play a more dominant role in thermal moderation [11].

A subsequent study by Hamza, Gomaa, and Underwood (2007) reinforced the sensitivity of airflow to cavity geometry, showing that continuous vs. obstructed channels produce different ventilation patterns. Air velocity reached 0.4–0.8 m/s in both systems, but the obstructed (corridor-type) DSF generated additional turbulence due to floor-by-floor inlets and outlets, lowering inner-surface temperatures by ≈1.5 ° C. Despite this enhanced airflow mixing, direct solar radiation (~150 W/m²) remained the dominant driver of cavity heat gain, significantly exceeding convective contributions [12].

The influence of glazing configuration on airflow magnitude was further quantified by Pérez-Grande, Meseguer, and Alonso (2005) in Madrid's warm continental (hot–dry) climate. CFD simulations revealed that forced airflow at 6 m/s increased mass flow rate up to 0.8 $kg \cdot s^{-1} \cdot m^{-1}$, halved the cavity temperature rise (from 2.2 K to ≈1.0 K), and reduced total heat gain by a factor of 1.5. Variations in glass transmittance, reflectance, and absorptance modified buoyancy intensity and airflow development, demonstrating that optical properties critically shape natural convection strength in tall vertical cavities [13].

Winter airflow performance in hot–arid regions was examined by Hamza and Qian (2016), who observed that buoyancy-driven ventilation persisted even during cold seasons. Field measurements showed cavity air to be 2–3 °C above ambient at night and 30–35 °C under daytime solar exposure, with air velocities around 0.3 m/s, supporting stable, low-energy ventilation. The validated CFD and IESVE models (±2 °C agreement) indicated that this moderate airflow contributed to a 5% reduction in winter energy demand, highlighting the year-round relevance of airflow-driven thermal buffering in hot–dry climates [14].

Collectively, these studies indicate that in hot–dry climates, DSF airflow is primarily controlled by three factors: (1) solar-induced buoyancy, which consistently generates upward air movement; (2) cavity geometry (continuous vs. obstructed), which governs turbulence and mixing; and (3) glazing optical properties, which significantly influence both the magnitude of temperature stratification and the resulting airflow intensity. Forced ventilation can further enhance airflow rates and cooling performance, but even passive buoyancy alone can sustain meaningful mass flow capable of reducing façade heat gain.

3.2 Natural Ventilation Performance of DSFS in Hot–dry Climates

Natural ventilation in hot–dry climates is shaped by strong solar loads, large diurnal temperature swings, and predominantly wind-driven flow. Nasrollahi and Salehi (2015) used CFD simulations for Isfahan's hot–arid conditions and showed that manipulating wind-driven pressure fields is more effective than cavity subdivision for enhancing ventilation. Their results indicated that dividing the DSF cavity into smaller segments did not improve airflow, whereas adding a vertical air channel on the north façade generated positive pressure, preventing warm air recirculation and significantly increasing exhaust performance. The optimal configurations (A3 at 0° and A5 at 180° wind) achieved ≈2.3 m/s outlet velocity and 2.39 m^3/s volumetric flow, demonstrating that channel-assisted DSFs can effectively mitigate cavity overheating and enhance wind-supported natural ventilation in hot–arid regions [15].

In warm–dry climates, cavity geometry plays a dominant role in shaping ventilation efficiency. Ma'bdeh et al. (2025) performed CFD simulations for an office building in Amman and found that a 0.2 m cavity provided the highest ventilation performance, producing 0.51 kg/s mass flow, ≈1.0 m/s air velocity, and an nQ ratio of 5.3, well above ASHRAE 62 requirements. Larger vent window-to-wall ratios (5 - 15%) resulted in minimal changes, indicating that cavity depth is the principal design parameter for airflow enhancement in semi-arid climates. Their findings emphasize that narrow cavities promote stronger airflow and lower turbulence, leading to improved ventilation uniformity and air quality [16].

Beyond geometric optimization, bio-integrated DSFs offer an alternative strategy for airflow and ventilation improvement in hot–dry environments. Parhizkar, Afghani Khoraskani, and Tahbaz (2019) proposed an Azolla-integrated DSF for Tehran, demonstrating that plant-based CO_2 absorption can offset ventilation demand. Analytical and simulation results showed that 5 m² of Azolla per person reduced required outdoor airflow by ≈30%, while full offset occurred at 16.6 m² per person. The system lowered the air-exchange rate from 9.8 to 8.2 ACH and reduced indoor CO_2 concentrations by 134–176 ppm, enhancing IAQ while reducing mechanical ventilation needs. Additionally, Azolla integration decreased annual sensible cooling demand by ≈ 600 kWh, showing potential for combined natural ventilation and thermal performance gains [17].

In semi-hot–arid climates with high ventilation requirements, Gholampour et al. (2025) demonstrated that DSFs can serve as effective passive ventilation systems for healthcare retrofits. Their combined numerical–experimental study in Shiraz showed that an optimized box-type DSF (Model 4) achieved 9 ACH (139 L/s), meeting ASHRAE and WHO ventilation standards, while maintaining infection probability below 1% for airborne pathogens. The DSF moderated outdoor air by reducing 35 °C air to 28 °C indoors and provided winter preheating from −7 °C to 26 °C. However, western orientations triggered overheating up to 68.7 °C, which could be mitigated through inner shading or low-U outer panes. These results highlight that DSFs can partially or fully replace mechanical AHUs in hot–dry climates, supporting energy-efficient, adaptive natural ventilation strategies for sensitive building types [18].

Overall, natural ventilation studies in hot–dry climates show that: (1) wind-driven airflow is a dominant ventilating force and benefits strongly from channel-assisted DSF geometries; (2) cavity depth plays a critical role, with narrow cavities delivering superior ventilation; (3) bio-integrated façades can reduce ventilation loads through CO_2 absorption; and (4) box-type DSFs can meet high ventilation and infection-control standards, provided overheating risks are mitigated. These findings collectively emphasize the need for climate-adapted DSF configurations that exploit wind pressure, minimize thermal load, and integrate airflow-enhancing mechanisms for arid regions.

4. Airflow and Natural Ventilation Performance of DSFS in Hot–humid Climates

4.1 Airflow Dynamics and Pressure Behaviour of DSFS in Hot–humid Climates

In humid subtropical and hot–humid climates, airflow behavior within double-skin façades (DSFs) is influenced by strong solar loads, moisture-driven buoyancy suppression, and complex wind–façade interactions. Chan, Chow, Fong, and Lin (2009) reported that in Hong Kong's humid subtropical climate, solar irradiance of 615 W/m² generated cavity airflow speeds of ≈0.6 m/s and an average cavity temperature of 37.9 °C in a 1 m cavity. Their experimental–simulation validation (<2 °C deviation) confirmed that glazing type and placement strongly affect natural convection strength. Reflective outer layers, particularly the s_clr–d_ref configuration, improved airflow-driven thermal reduction by limiting solar penetration while maintaining buoyancy flow, contributing to the observed cooling-energy savings [7].

Wind-driven airflow can exceed buoyancy-driven ventilation in humid coastal climates, especially for tall buildings. Hassanli, Hu, Kwok, and Fletcher (2017) demonstrated that strategically vented DSFs under Hong Kong's urban wind conditions can achieve mean cavity velocities of 6–8 m/s, with turbulence intensities remaining below 20%. Their RANS SST k–ω CFD simulations showed good agreement with wind tunnel measurements (±15%), confirming that central and lateral openings stabilize cavity flow and promote uniform velocity profiles along the outlet. These aerodynamic characteristics create suitable conditions for façade-integrated micro-turbines, with optimal airflow occurring in the mid-cavity region for wind incidence angles between 0°–140° [19].

For naturally ventilated façades dominated by solar buoyancy, Zhao et al. (2025) identified a strong correlation between solar radiation and airflow development in a hot–humid climate. Experimental results from Hefei showed that ventilation rate follows $V = 0.009\ I^{0.41}$ ($R^2 = 0.999$), with airflow increasing by up to 35% as irradiance rose from 300 to 700 W/m². Optimizing inlet and outlet louver angles (θ_o = 90°, θ_i = 90° for ≤500 W/m² and θ_o = 90°, θ_i = 60° for >500 W/m²) enhanced airflow by 33–63% relative to baseline 45° openings. The validated theoretical model (MRE = 11.5%) confirmed that adaptive louver control significantly strengthens buoyancy-driven ventilation in high-humidity environments [20].

Overall, studies in humid climates highlight two dominant airflow regimes: (1) solar-buoyancy-driven flow, which is highly sensitive to glazing properties and dynamic louver geometry; and (2) wind-driven flow, which can far exceed buoyancy velocities in coastal high-rise contexts. The combination of high solar intensity and humid air stratification requires DSFs in these climates to rely on optimized openings and reflective glazing to maintain effective ventilation while mitigating moisture-induced airflow reduction.

4.2 Natural Ventilation Performance of DSFS in Hot–humid Climates

Natural ventilation in hot–humid climates is strongly influenced by high ambient temperatures, weak diurnal variations, and prevalent wind-driven and buoyancy-driven processes. Wong, Prasad, and Behnia (2008) conducted CFD simulations for a high-rise office context in Singapore and demonstrated that narrow cavities (300 mm) provide the strongest natural ventilation benefits, maintaining 26–28 °C operative temperature within ASHRAE 55 80% acceptability for south-facing façades at wind speeds ≥ 1.5 m/s. Wider cavities (up to 1200 mm) weakened airflow intensity, while north-facing façades showed poor performance with temperatures exceeding 30 °C. Their findings emphasize the importance of cavity width and façade orientation, confirming that narrow, south-oriented DSFs are most effective for natural ventilation in hot–humid tropical environments [21].

Similarly, Hien et al. (2005) evaluated naturally ventilated and mechanically ventilated DGFs in Singapore and found that natural ventilation alone enabled substantial extraction of heat from the inner glass layer, lowering surface temperatures to 31–32 °C, compared to 35–36 °C for single façades. This stack-driven ventilation contributed to an annual cooling load reduction of 23.6 MWh (~19%), with mechanical ventilation providing only marginal additional energy savings (~1.3 MWh/year). Thermal comfort improved from PPD 24.5% to ~19%, and nighttime moisture issues were effectively resolved under mechanically assisted ventilation. The naturally ventilated DGF was identified as the optimal system, balancing energy savings, comfort, and operational simplicity for tropical high-rise buildings [22].

Field studies in humid subtropical climates underline the significance of hybrid ventilation modes. Xu and Ojima (2007) monitored a residential DSF system in Kitakyushu and reported large cavity temperature rises—8–13 °C in summer and 20 °C above outdoor levels in winter—which enabled 10–15% cooling and 20–30% heating energy reductions. Hybrid ventilation modes during the autumn shoulder season significantly improved thermal comfort (PMV reduced from 1.8 to 0.8) by leveraging buoyancy-driven flow and controlled solar gains. Their results demonstrate that seasonal adaptability—open DSF in summer, closed in winter—provides year-round benefits in hot–humid and mixed climates [23].

The integration of solar chimneys has been shown to strengthen buoyancy-driven airflow under low-wind conditions. Ding, Hasemi, and Yamada (2005) tested DSFs combined with solar chimneys in Tokyo and identified that larger opening areas (≥16 m² per floor) and taller chimneys (2–3 stories) significantly improved stack effect, generating ~20–25 ACH with uniform airflow distribution. Increasing openings beyond 16 m² yielded diminishing returns, while the optimal system balanced airflow efficiency with structural feasibility. CFD deviations below 10% confirmed strong agreement with experimental results. The study highlights that solar chimneys can effectively stabilize DSF ventilation in humid climates with weak wind conditions [3].

Recent work in China's hot–humid climate emphasizes the role of louver geometry and dynamic opening control in optimizing NVDSF airflow. Zhao et al. (2025) showed that increasing inlet louver inclination enhances buoyancy-driven flow, while wider outlet angles introduce resistance. Their optimal configuration—60° inlet and 90° outlet—increased outlet volumetric flow by 56.4% compared to a 45°/45° baseline, with a predictive airflow model achieving 13.1% error [24]. Complementary experiments by Zhao et al. (2024) confirmed that adaptive opening control based on solar irradiance and temperature difference reduced cavity temperature by 6.8 °C and cut energy consumption by 15.3%, generating outlet air velocities up to 0.61 m/s. Their predictive model achieved <10% deviation from measured data [1].

Broader climatic analyses by Tao et al. (2024) revealed the importance of solar incidence angle in governing buoyancy-driven ventilation. Increasing solar angle from 45°→75° amplified multi-reflection heating and buoyancy forces, improving natural ventilation by 9–14%. However, surpassing 75° caused rapid transmissivity losses and reduced airflow enhancement. Their empirical correction equation ($\Delta m/ms = -0.0003A^2 + 0.03A - 0.9$) captured these dynamics, demonstrating that ignoring angular optical effects can underestimate ventilation rates by up to 14%, a major concern for accurate DSF energy modeling [25].

Studies in humid subtropical residential buildings further highlight the benefits of augmented ventilation. Kan and Kato (2015) observed that operating fans in a mechanically ventilated DSF reduced cavity temperature by 2–3 °C and decreased exterior wall temperatures by up to 4 °C under high solar radiation (~2000 W/m²). The system supplied pre-cooled underfloor ventilation air and stabilized indoor temperatures without air-conditioning, underscoring the potential of mechanical–passive hybrid DSF systems for summer performance enhancement [26].

Overall, natural ventilation research in hot–humid climates identifies several controlling parameters: (1) narrow cavity widths with favorable orientations substantially improve ventilation and comfort; (2) stack-driven DGFs reduce cooling load and enhance thermal comfort; (3) hybrid operational strategies yield year-round energy savings; (4) solar chimneys and buoyancy-enhancing geometries effectively boost airflow under low-wind conditions; and (5) adaptive, louver-controlled NVDSFs provide significant airflow amplification and temperature reduction. Collectively, these studies confirm that climate-responsive DSF designs—particularly those leveraging buoyancy, solar geometry, and dynamic control—are critical for achieving effective natural ventilation in hot–humid tropical environments.

5. Discussion

To consolidate the insights obtained from the preceding analyses, the study proceeds to compare the airflow and natural ventilation behavior of double-skin façades across hot–dry and hot–humid climatic conditions. Given the distinct environmental drivers influencing DSF performance in these two regions, a comparative framework was necessary to clarify the differences in airflow mechanisms, thermal responses, and ventilation effectiveness. Accordingly, Table 1 presents a structured comparison of the key parameters governing DSF performance in both climates, highlighting the critical factors that inform climate-responsive façade design.

TABLE I. COMPARATIVE AIRFLOW AND NATURAL VENTILATION CHARACTERISTICS OF DSFS IN HOT–DRY AND HOT–HUMID CLIMATES.

Criteria	Hot–Dry Climate	Hot–Humid Climate	References
Primary airflow driver	Dominantly solar-induced buoyancy, strengthened by strong solar radiation (100–700 W/m²); wind pressure becomes significant in channel-assisted configurations.	Mixed regime: solar-induced buoyancy (suppressed by high humidity) + strong wind-driven flow in coastal high-rise contexts. Solar buoyancy strengthens with optimized louvers and reflective glazing.	[7, 11-15, 19, 20]
Typical airflow velocities	Solar-buoyancy airflow: 0.045–0.84 m/s (Cairo); corridor-type DSF: 0.4–0.8 m/s; winter daytime: ~0.3 m/s; wind-assisted systems: up to 2.3 m/s.	Buoyancy-driven: ≈0.6 m/s (Hong Kong); adaptive louver NVDSF: up to 0.61 m/s; wind-driven DSF: 6–8 m/s; solar chimney hybrids: 20–25 ACH equivalent.	[1, 3, 7, 11, 12, 14-16, 19, 24]
Impact of solar radiation	Strong solar gains cause vertical buoyant flow; solar input (~150 W/m² to 700 W/m²) dominates cavity heating and airflow development.	Strong correlation with airflow ($V = 0.009\ I^{0.41}$); 35% increase when irradiance rises 300→700 W/m²; affects buoyancy formation and louver optimization; multi-reflection heating amplifies airflow up to 14% at higher solar angles.	[11, 12, 14, 20, 25]
Role of glazing optical properties	Transmittance/reflectance/absorptance significantly alter buoyancy strength; improved optical control halves temperature rise and reduces heat gain by factor 1.5.	Reflective outer glazing improves airflow-driven cooling by reducing solar penetration while maintaining buoyancy; transmissivity losses beyond solar angle 75° reduce ventilation efficiency.	[7, 11, 13, 25]
Effect of cavity geometry	Continuous vs. obstructed cavities influence turbulence and mixing; narrower cavities (~0.2 m) substantially improve ventilation efficiency.	Narrow cavities (300 mm) perform best; wider cavities (600–1200 mm) weaken airflow; solar chimneys with ≥16 m² openings and 2–3-story height enhance stack effect; geometries with adaptive louvers increase volumetric flow significantly.	[3, 12, 16, 21, 24]
Wind influence	Wind-driven pressure fields are major enhancers; north-side pressure channels prevent recirculation and drastically increase outlet velocity and exhaust efficiency.	Highly influential in coastal/tropical skyscrapers; well-vented DSFs achieve 6–8 m/s velocities with stable turbulence (<20%); wind incidence 0°–140° optimizes mid-cavity flow for micro-turbine integration.	[15, 19]
Ventilation rate improvements	Channel-assisted DSFs: 2.39 m³/s volume flow; optimized cavities: 0.51 kg/s mass flow; medical retrofits achieve 9 ACH meeting WHO/ASHRAE standards.	Adaptive louvers: +33–63% airflow increase; optimal louver setups: 56.4% rise in outlet flow; solar chimneys: 20–25 ACH; hybrid seasonal NV: 10–15% summer cooling, 20–30% winter heating savings.	[3, 15, 16, 18, 20, 23, 24]
Thermal benefits	Reduced cavity temperature rise, lower heat gain; preheating in winter (−7 → 26 °C) and cooling in summer (35 → 28 °C); annual cooling reduction ~5% or ~600 kWh depending on system.	DSFs maintain 26–28 °C (narrow cavities); inner surface temperature reduced from 35–36 °C → 31–32 °C; energy savings: 19% cooling, 1.3 MWh extra by mechanical assist; cavity temperatures reduced by 6.8 °C with adaptive control; wall temp drops up to 4 °C with hybrid MV systems.	[1, 13, 14, 17, 18, 21, 22, 26]
Overheating risk	High risk under western orientations, reaching up to 68.7 °C; mitigated via shading, glazing upgrades, or modified airflow paths.	Overheating mainly in wide cavities, north-facing façades (>30 °C), and static-louver systems; high humidity suppresses buoyancy, causing stagnation unless openings or chimney effects compensate.	[12, 18, 21, 23]
Innovative / alternative solutions	Bio-integrated (Azolla) DSFs reducing CO_2 by 134–176 ppm and lowering required outdoor airflow by ~30%; channel-assisted or box-type DSFs for enhanced ventilation.	Façade-integrated micro-turbines in high-velocity DSFs; solar chimney–DSF combinations; adaptive, irradiance-responsive NVDSFs; hybrid NV–MV systems improving comfort and reducing cooling demand.	[1, 3, 15, 17-19, 24, 26]
Overall performance characteristics	Strong buoyancy-driven vertical flow, enhanced by cavity geometry and optical control; wind-supported systems deliver highest ventilation; DSFs can replace or support mechanical ventilation when overheating is managed.	Two dominant regimes: solar-buoyancy-driven flow (enhanced by louvers/glazing) and wind-driven flow (dominant in tall coastal buildings). Narrow geometry + dynamic louver control + chimney augmentation deliver highest NV efficiency and year-round comfort.	Full set above

6. Conclusion

This comparative analysis examined airflow dynamics and natural ventilation performance of double-skin façades (DSFs) in hot–dry and hot–humid climates, synthesizing quantitative evidence from prior CFD simulations, field measurements, and hybrid experimental–numerical studies. Results show that in hot–dry climates, airflow is predominantly governed by solar-induced buoyancy, with cavity velocities typically ranging between 0.04–0.84 m/s, and outlet temperatures rising to 41–66 °C under peak solar radiation. Cavity geometry—especially narrow gaps (≈0.2 m)—and glazing optical properties were identified as major determinants of ventilation strength and thermal moderation. Natural ventilation performance was further improved through channel-assisted configurations, which achieved exhaust velocities of ≈2.3 m/s, while bio-integrated DSFs demonstrated the potential to reduce ventilation demand by up to 30% through CO_2 absorption. By contrast, in hot–humid climates, buoyancy-driven airflow remained comparatively weak due to limited indoor–outdoor temperature differentials. Airflow was instead dominated by wind-driven regimes, achieving velocities of 6–8 m/s in vented façades exposed to coastal winds. Reflective glazing and adaptive louvers enhanced buoyancy-driven performance, increasing airflow by 33–63%, while solar chimney–integrated systems provided moderate improvements. Overall, DSF performance in humid conditions was highly sensitive to façade porosity, opening geometry, and alignment with prevailing winds.

Based on the comparative evaluation, the study concludes that DSF ventilation mechanisms exhibit fundamentally different operating regimes in hot–dry versus hot–humid climates, and therefore require climate-specific design strategies:

- In hot–dry climates, DSFs operate most effectively as buoyancy-driven thermal buffers, where narrow cavity depths, optimized glazing optics, and continuous vertical channels enhance natural upward airflow and reduce façade heat gain. These systems can deliver modest but consistent cooling-load reductions and reliable natural ventilation even during winter.
- In hot–humid climates, DSFs function primarily as wind-driven ventilation channels, with performance largely dependent on external wind exposure, vent placement, and louver geometry. Buoyancy alone is insufficient for effective ventilation, making wind-guiding design strategies essential for maintaining cavity airflow and preventing moisture accumulation.

Overall, the findings emphasize that a "one-size-fits-all" DSF ventilation strategy is not feasible, and design optimization must be explicitly aligned with climate-driven airflow behavior. The comparative insights from this study provide a foundation for developing climate-responsive DSF configurations that balance airflow, thermal performance, and energy efficiency across different building contexts.

The comparison is based on previously published simulation and field studies, which vary in their modelling assumptions, façade geometries, cavity dimensions, and boundary conditions. Moreover, most experiments investigate isolated parameters (e.g., cavity depth, glazing type) rather than holistic DSF systems. Cross-study variability in climate data, wind profiles, and solar intensities may also limit generalizability. Finally, few studies have combined both airflow and energy performance within the same DSF model, restricting the ability to assess integrated façade behavior.

Several research gaps were identified that warrant future investigation:

- Bio-integrated and vegetation-assisted DSFs, which remain conceptually promising but lack large-scale experimental validation.
- Life-cycle and economic assessments, especially in hot–dry climates where DSFs show strong thermal potential but uncertain cost-effectiveness.
- Comparative multi-objective optimization across climates to determine optimal DSF configurations for airflow, cooling-load reduction, daylighting, and occupant comfort.

References

[1] Zhao, X., et al., Controlling naturally ventilated double-skin façade to reduce energy consumption in buildings. Renewable and Sustainable Energy Reviews, 2024. 202.

[2] Wong, P.C.J., Natural ventilation in double-skin façade design for office buildings in hot and humid climate. 2008, UNSW Sydney.

[3] Ding, W., Y. Hasemi, and T. Yamada, Natural ventilation performance of a double-skin façade with a solar chimney. Energy and Buildings, 2005. 37(4): p. 411–418.

[4] Safer, N., M. Woloszyn, and J.J. Roux, Three-dimensional simulation with a CFD tool of the airflow phenomena in single floor double-skin facade equipped with a venetian blind. Solar Energy, 2005. 79(2): p. 193–203.

[5] Roth, K., T. Lawrence, and J. Brodrick, Double-Skin Façades. ASHRAE Journal, 2007. 49.

[6] Kim, S.Y. and K.D. Song, Determining Photosensor Conditions of a Daylight Dimming Control System Using Different Double-skin Envelope Configurations. Indoor and Built Environment, 2007. 16(5): p. 411–425.

[7] Chan, A.L.S., et al., Investigation on energy performance of double skin façade in Hong Kong. Energy and Buildings, 2009. 41(11): p. 1135–1142.

[8] Li, Y., et al., Seasonal thermal performance of a macro-encapsulated phase change material blind integrated double skin façade system: An experimental study. Energy and Buildings, 2024. 325.

[9] Kilaire, A. and M. Stacey, Design of a prefabricated passive and active double skin façade system for UK offices. Journal of Building Engineering, 2017. 12: p. 161–170.

[10] Su, Z., X. Li, and F. Xue, Double-skin façade optimization design for different climate zones in China. Solar Energy, 2017. 155: p. 281–290.

[11] Hamza, N. and C. Underwood. CFD supported modelling of double skin facades in hot arid climates. in Proceedings of 9th International Building Performance Simulation Association Conference (IBPSA). 2005. Montreal, Canada.

[12] Hamza, N., A. Gomaa, and C. Underwood. Daylighting and thermal analysis of an obstructed double skin façade in hot arid areas. in Proceedings of Wellbeing Indoors, CLIMA. 2007. Helsinki, Finland.

[13] Pérez-Grande, I., J. Meseguer, and G. Alonso, Influence of glass properties on the performance of double-glazed facades. Applied Thermal Engineering, 2005. 25(17-18): p. 3163–3175.

[14] Hamza, N. and Q. Zi. Validating the performance of a Double Skin Facade in winter in an hot arid climate. in Passsive and Low Energy Architecture (PLEA2016): Cities, Buildings, People: Towards Regenerative Environments. 2016. Los Angles-USA.

[15] Nasrollahi, N. and M. Salehi, Performance enhancement of double skin facades in hot and dry climates using wind parameters. Renewable Energy, 2015. 83: p. 1–12.

[16] Ma'bdeh, S.N., et al., Optimizing airflow in double-skin facades: Influence of vents design and cavity depth. Cleaner Engineering and Technology, 2025. 26.

[17] Parhizkar, H., R.A. Khoraskani, and M. Tahbaz, Double skin façade with Azolla; ventilation, Indoor Air Quality and Thermal Performance Assessment. Journal of Cleaner Production, 2020. 249.

[18] Gholampour, M., et al., Retrofitting of building with double skin façade to improve indoor air quality, thermal comfort, and infection control in inpatient wards of a hospital in a semi-hot-arid climate. Energy and Buildings, 2025. 332.

[19] Hassanli, S., et al., Utilizing cavity flow within double skin façade for wind energy harvesting in buildings. Journal of Wind Engineering and Industrial Aerodynamics, 2017. 167: p. 114–127.

[20] Zhao, X., et al., Solar radiation-controllable double-skin façades to enhance natural ventilation for green buildings. Renewable Energy, 2025. 255.

[21] Wong, P.C., D. Prasad, and M. Behnia, A new type of double-skin façade configuration for the hot and humid climate. Energy and Buildings, 2008. 40(10): p. 1941–1945.

[22] Hien, W.N., et al., Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. Energy and Buildings, 2005. 37(6): p. 563–572.

[23] Xu, L. and T. Ojima, Field experiments on natural energy utilization in a residential house with a double skin façade system. Building and Environment, 2007. 42(5): p. 2014–2023.

[24] Zhao, X., et al., Controlling double-skin façades with inclined louvers for natural ventilation: An experimental and theoretical study. Applied Energy, 2025. 377.

[25] Tao, Y., et al., Solar radiation on naturally ventilated double skin facade in real climates: The impact of solar incidence angle. Renewable Energy, 2024. 232.

[26] Lin, K. and S. Kato, Field Experiments on Mechanical Double-skin System of Room-Side Air Gap in a Residential House. Energy Procedia, 2015. 78: p. 543–548.