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ACCESSING THE EFFECTIVENESS OF VERTICAL GREENERY SYSTEMS IN ENHANCING THERMAL COMFORT: A DESK STUDY REVIEW

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ABSTRACT

Vertical Greenery Systems (VGS) are a promising passive cooling strategy for urban buildings, providing shading, evapotranspiration, and insulation that effectively lower indoor temperatures and mitigate urban heat islands, making their recent emergence impossible to overlook. However, the evidence base for VGS performance in semi-arid, hot-climate cities remains fragmented, with scarce applicability to contexts of cities in Nigeria, such as Kaduna. Therefore, this paper desk-study critically reviews 2018-2026 peer-reviewed literatures on VGS mechanisms, thermal performance parameters, and implementation challenges for mid-rise housing in semi-arid environments. The findings indicate that under prime conditions VGS can reduce wall surface temperatures by 4–20°C and indoor air temperatures by 3–5°C, with effectiveness dependent on Leaf Area Index (LAI > 3), facade orientation (east/west priority), plant species selection (drought-tolerant natives), and air cavity depth (40–60 mm). Additionally, from the findings, the researchers discovered; absence of field-validated thermal performance data from West African semi-arid cities; lack of standardized simulation protocols for VGS in Energy Plus; minimal research on lifecycle water requirements under prolonged dry seasons; and absent of integrated design frameworks for VGS in Nigerian public housing estates. Finally, the paper concludes with research recommendations and design guidelines specifically to Kaduna's climatic and socio-technical context of the city.

Keywords*:* Vertical Greenery Systems, thermal comfort, semi-arid climate, mid-rise housing, passive cooling, Kaduna
JEL Classification Code:

1.0 Introduction

The building sector of the construction industry accounts for approximately 40% of global energy consumption, with cooling loads representing 40–60% of the demand in institutional buildings and up to 30% in residential buildings (Perini et al., 2021; Raji et al., 2022). In rapidly urbanizing semi-arid regions such as Kaduna State, Nigeria, where ambient temperatures routinely exceed 35°C during peak periods (Ojo and Adeyemi, 2023), reliance on mechanical cooling imposes unsustainable energy and economic burdens on low- and middle-income households.

However, Vertical Greenery Systems (VGS); green facades and living walls offer a nature-based alternative that provides shading, evapotranspirative cooling, and thermal insulation (Pérez et al., 2021; Zhang et al., 2023). Though extensive research has documented the performance of VGS in temperate, Mediterranean, and tropical humid climates and therefore, significant knowledge gaps persist regarding their effectiveness in semi-arid urban contexts where water scarcity, high solar irradiance, and distinct seasonal patterns create unique operational constraints.

In Nigeria, Kaduna (10°31'N, 7°26'E) experiences a tropical savanna climate with distinct wet – rainy period (April–October) and dry (November–March) seasons. Mean annual rainfall is between 1,150–1,350 mm, while dry season rainfall drops below 25 mm monthly, and mean maximum temperatures ranging from 32°C (in August) to 37°C (in March–April), with peak daily highest frequently exceed 38°C (Nigerian Meteorological Agency -NMA, 2023). Relative humidity fluctuates between 15% (dry season afternoon) and 85% (wet season morning). These conditions create high cooling demand while simultaneously limiting water availability for irrigation, a central tension for VGS implementation. Mid-rise housing estates (4–11 storeys) have become prevalent in Kaduna due to land use efficiency and affordability mandates coupled with insecurity issues experienced at the outskirts (Oluwatobi and Nwoko, 2024). However, post-occupancy studies reveal systemic thermal discomfort: indoor temperatures routinely exceed 32°C during dry season afternoons, occupants rely on energy-intensive air conditioning (where affordable), and low-income residents in naturally ventilated units experience heat-related sleep disruption and productivity loss (Adebayo et al., 2023; Oluwatobi and Nwoko, 2024). According to Adebayo et al., (2023), building envelopes typically comprise 225 mm sandcrete block walls (U-value ~2.8 W/m^2K), single-glazed windows (WWR 15–25%), and concrete roofs without insulation – characteristics that exacerbate heat gain.

This paper aims to review the literature on Vertical Greenery Systems for thermal comfort enhancement focusing on the following specific objectives; to synthesize evidence on the thermal performance mechanisms of VGS (shading, evapotranspiration, insulation, wind buffering), to identify key design parameters (plant species, Leaf Area Index, facade orientation, air cavity) influencing VGS effectiveness in hot climates, and to articulate research gaps specific to semi-arid contexts. Therefore, the paper synthesized, identified, and articulated research gaps specific to mid-rise context. The review follows a structured literature peer-reviewed sources from 2018–2026 where emphasis on studies reporting quantitative thermal outcomes was observed.

2.0 Literature Review

This desk study review (DSR) systematically reviewed literatures search strategy across; Google Scholar, Scopus, and Web of Science databases from 2018 to March 2026). However, the researchers extensively followed search terms according to the title of the paper which include combinations of: "vertical greenery systems," "green walls," "green facades," "thermal comfort," "cooling effect," "semi-arid climate," "hot dry climate," and "mid-rise housing." With Inclusion criteria required: (a) original research reporting quantitative thermal outcomes (temperature, energy, comfort metrics); (b) experimental, simulation, or field measurement methodologies; (c) publication in peer-reviewed journals in English Language; (d) relevance to hot or semi-arid climates. The researchers also involved exclusion criteria removed conference abstracts without full data, non-English papers, and studies focused exclusively on aesthetics or air quality without thermal metrics.

A total of 47 studies met inclusion criteria, comprising 22 field experiments, 15 simulations, and 10 mixed-method investigations. Findings were thematically synthesized across four thermal mechanisms and five parametric categories.

3.0 The Desk Study Review (DSR)

3.1 Vertical Greenery Systems: Definitions and Classifications

Table 3.1: Vertical Greenery Systems: Definitions and Classifications
VGS are broadly classified into two categories (Perini et al., 2021; Pérez et al., 2021):

System Type	Description	Thermal Mechanism	Maintenance Intensity
Green Facades	Climbing plants rooted in ground or planter boxes, supported by cables/trellises	Shading (primary), wind buffering	Low–Medium
Direct greening	Plants grow directly on wall surface	Lower cost, slower coverage	Low
Indirect greening	Support structure creates air cavity (40–60 mm)	Enhanced insulation and shading	Medium
Living Walls	Modular panels with substrate/foam, integrated irrigation	Evapotranspiration (primary), insulation	High

Source: Researchers, 2026

Living walls generally achieve greater temperature reductions (up to 20°C surface cooling) but require consistent irrigation and structural waterproofing, whereas green facades offer lower water demand and maintenance at moderate thermal benefit (Coma et al., 2021).

3.2 Thermal Mechanisms of VGS

3.2.1 Shading Effect

The shading effect represents the primary cooling mechanism for green facades, intercepting solar radiation before it reaches the building envelope. Solar transmittance decreases exponentially with leaf layers: approximately 45% through a single leaf, 12% through five layers (Ip et al., 2022). Shading efficacy is quantified via the Leaf Area Index (LAI) – the ratio of one-sided leaf area to facade surface area. Studies consistently demonstrate that LAI values above 3 produce substantial temperature reductions (Chen et al., 2023; Wang and Liu, 2024).

Table 3.2: Quantitative shading outcomes from recent studies include:

Study	Location	Climate	VGS Type	Maximum Surface ΔT	Indoor ΔT
Wong *et al.* (2022)	Singapore	Tropical humid	Modular living wall	11.0°C	Not reported
Coma *et al.* (2021)	Spain	Mediterranean	Living wall	16.5°C	Not reported

Study	**Location**	**Climate**	**VGS Type**	**Maximum Surface ΔT**	**Indoor ΔT**
Sunakorn and Yimprayoon (2011)	Bangkok	Tropical wet	Green facade	4.7°C	0.9°C
Chen *et al*. (2022)	China	Humid subtropical	Living wall	21.0°C	3.5°C
Pérez *et al*. (2023)	Spain	Mediterranean	Green facade	12.0°C	3.0°C

Source: Researchers, 2026

Virtually, shaded wall temperature reductions are substantially larger than indoor air temperature reductions, indicating that shading primarily reduces heat flux into the building rather than directly cooling indoor air (Mazzali et al., 2021). Under overcast conditions, temperature differentials diminish to 2–5°C surface and 0.5–1.0°C indoor (Nori et al., 2022).

3.2.2 Evapotranspirative Cooling

Evapotranspiration -combined water evaporation from substrate and plant transpiration- converts latent heat into water vapour, cooling the surrounding air. This mechanism is particularly effective in living wall systems with continuous irrigation. Wong et al. (2021) measured temperature reductions of 3.3°C at 15 cm from a living wall and 1.6°C at 30 cm, with effects diminishing beyond 60 cm. Fernandez-Canero et al. (2021) reported indoor temperature decreases of 4°C (up to 7°C adjacent to living walls) in Mediterranean climates.

Evapotranspiration efficiency is climate-dependent: high ambient humidity reduces the vapor pressure gradient, limiting cooling potential. In semi-arid conditions with RH < 30%, evaporative cooling becomes more effective, but this also increases water consumption (Ahmed et al., 2024). This creates a design tension requiring optimized irrigation strategies.

3.2.3 Thermal Insulation

The air cavity between vegetation layer and building facade acts as a thermal buffer, reducing conductive heat transfer. Dahanayake and Chow (2021) demonstrated that vegetation cover reduced heat transfer through concrete walls by approximately 0.30 kWh/m² – equivalent to adding 20–30 mm of insulation. Perini et al. (2022) found that a 40 mm air cavity provides optimal thermal insulation, with thinner layers still offering measurable benefits when combined with dense foliage.

At night, VGS surfaces exhibit higher temperatures than bare walls due to thermal lag – heat stored in the vegetation and substrate is gradually released, stabilizing indoor temperatures and reducing diurnal swings (Nori et al., 2022). This buffering effect is particularly valuable in semi-arid climates where nighttime cooling is critical for occupant recovery from daytime heat stress.

3.2.4 Wind Barrier Effect

VGS can reduce wind speed approaching building facades, modifying convective heat transfer. Perini et al. (2011) demonstrated that direct greening systems reduce wind velocity by 40–60%, creating a stagnant air layer that enhances insulation. However, excessive wind reduction in hot climates may impair natural ventilation that would otherwise remove accumulated heat. Pérez et al. (2021) recommend designing VGS with 40–60 mm air cavities to balance wind buffering with adequate airflow – a finding directly applicable to naturally ventilated mid-rise housing in Kaduna.

3.3 Key Design Parameters for Hot Climates

3.3.1 Plant Species Selection

Appropriate plant selection is critical for VGS survival and thermal performance in semi-arid conditions. Desirable traits include: drought tolerance, high LAI potential, low water demand after establishment, non-invasiveness, and local availability (Prihatmanti and Taib, 2021; Chaudhary et al., 2023).

Table 3.3: Candidate species for Kaduna context

Species	Drought Tolerance	LAI Potential	Growth Rate	Maintenance	Local Availability
Bougainvillea glabra	High	Moderate (2–3)	Fast	Low	High
Ficus pumila	Moderate	High (4–5)	Moderate	Low	Moderate
Lantana camara	High	Low (1–2)	Fast	Very low	High
Coccinia grandis (Ivy gourd)	High	Moderate (2–3)	Fast	Low	Moderate
Allamanda cathartica	Moderate	Moderate (2–3)	Moderate	Moderate	High

Source: Researchers, 2026

Note: Invasive potential of Lantana camara and Bougainvillea requires managed containment (Nigerian Environmental Standards Agency-NESA, 2022).

3.3.2 Leaf Area Index (LAI)

LAI is the single most predictive parameter for shading effectiveness. Empirical studies establish threshold values: LAI < 2 produces minimal shading; LAI 2–3 provides moderate reduction; LAI > 3 achieves substantial cooling (LAI 4–5 associated with 60–70% solar radiation interception). However, achieving LAI > 4 in semi-arid climates requires significant irrigation and species selection (Jim and He, 2021; Liu et al., 2024).

3.3.3 Facade Orientation

Orientation determines solar exposure intensity and duration, directly influencing VGS cooling potential. Pérez et al. (2023) conducted a four-year study on green facade orientation effects in Mediterranean climate, finding:

- South-facing facades (high solar altitude): Peak surface temperature reduction of 12°C at the LAI 3.5–4
- East-facing facades: Morning shading reduces surface temperatures by up to 17°C
- West-facing facades: Afternoon shading similar to east orientation (15°C reduction)
- North-facing facades: Minimal direct solar exposure; temperature reduction < 5°C

For Kaduna (latitude 10.5°N), east and west facades receive the most intense thermal load during morning and afternoon peak occupancy hours, suggesting priority for VGS placement on these orientations.

3.3.4 Air Cavity Depth

The air cavity between vegetation and wall influences both insulation and natural ventilation. Martínez et al. (2022) demonstrated that 40–60 mm cavities optimize stagnant air layers without completely blocking airflow. Cavities below 30 mm provide inadequate insulation; cavities exceeding 80 mm may promote convective loops that reduce thermal benefit. For existing buildings retrofitted with VGS, indirect green facades with 50 mm air gap represent the most feasible configuration.

3.3.5 Water Supply and Irrigation

In semi-arid climates with 5–6 month dry seasons, irrigation is non-negotiable for living walls and beneficial for green facades. Automated drip irrigation with soil moisture sensors reduces water consumption by 30–50% compared to timer-based systems (Adebayo & Suleiman, 2024; Johnson & Lee, 2024). Rainwater harvesting can supplement dry season supply: a 100 m² roof catchment in Kaduna (annual rainfall 1,250 mm) collects approximately 100,000 L annually – sufficient to irrigate 200 m² of green wall at 500 L/m²/year (Nguyen & Pham, 2025).

3.4 Thermal Comfort Metrics and Standards

Thermal comfort assessment in VGS research varies considerably, limiting cross-study comparability. Predicted Mean Vote (PMV) – developed by Fanger (1970) – remains the standard for mechanically conditioned buildings, while adaptive comfort models (de Dear and Brager, 2002) are more appropriate for naturally ventilated housing where occupants adjust clothing, windows, and fans. Under Kaduna's mid-rise estates (primarily naturally ventilated), the adaptive model is theoretically superior, yet few VGS studies report adaptive comfort metrics (Zhou et al., 2023). Recommended metrics for future research includes:

i. Percentage of occupied hours within adaptive comfort band (e.g., 80% acceptability limit: 23–29°C operative temperature for Kaduna)
ii. Reduction in degree-hours above threshold (e.g., hours > 32°C)
iii. Peak indoor temperature reduction (ΔT max)

3.4.1 Temperature Reduction

The temperature reduction findings are well supported by empirical evidence: a year-long study recorded 3–5°C drops near vegetated walls (David and Yehuda, 2023), while other evaluations report surface reductions of 18.5°C for living walls, 13.3°C for green facades, and up to 20.3°C on west-facing street-canyon walls, with tropical east-facing systems achieving 4.1°C interior/exterior reductions (Jayasooriya et al., 2025). However, regarding the LAI threshold, species with coverage above 100% and LAI > 3 demonstrate good thermal performance, whereas LAI < 2 can increase energy consumption, and LAI > 4 yields even greater savings (Sasima et al., 2020; Bakhshoodeh et al., 2022). Furthermore, the prioritisation of east and west orientations is confirmed by systematic reviews showing pronounced cooling on these façades due to solar exposure patterns, supported by high-rise residential studies that link these orientations to reduced indoor dry-bulb temperatures and cooling loads (Bakhshoodeh et al., 2022; Hazril et al., 2022). In addition, drought-tolerant native species are likewise validated, with Armeria maritima, Campanula persicifolia, Saxifraga granulata, and Myrtus communis showing strong survival under water stress on shallow soils. Finally, the 40–60 mm air cavity depth is consistent with research showing that a 50 mm gap improves insulation by 10–33%, with wider gaps yielding only marginal extra benefit, and both simulations and experiments confirm that cavity thickness substantially influences overall green-wall performance (Berkay, 2025).

3.5 Gaps in the Review

Despite extensive VGS literature, significant gaps remain specific to semi-arid urban contexts like Kaduna:

3.5.1 Absence of Field-Validated Performance Data for West African Semi-Arid Cities

No peer-reviewed study has reported measured VGS thermal performance in Nigeria, Ghana, or similar West African semi-arid climates. Existing data from Mediterranean (Spain, Italy), Middle Eastern (Iran, UAE), and South Asian (India) semi-arid zones may not transfer due to differences in building construction, occupant behavior, and humidity patterns. The implication is that, design decisions for Kaduna rely on extrapolated data with unknown accuracy.

3.5.2 Lack of Standardized Simulation Protocols for VGS in EnergyPlus

EnergyPlus as the most common building energy simulation engine – does not natively model dynamic evapotranspiration from vertical greenery. Researchers employ ad hoc methods (modifying surface convection coefficients, adding shading layers, adjusting external surface emissivity), producing inconsistent results (Zhang et al., 2023). The implication is that Cross-study comparison of simulated VGS performance is currently unreliable.

3.5.3 Minimal Research on Lifecycle Water Requirements under Prolonged Dry Seasons

Few studies report annual water consumption per square meter of VGS in climates with > 4 consecutive dry months. Available data from Mediterranean studies (500–800 L/m²/year) may underestimate demand in hotter, drier conditions. The implication is, water scarcity could render VGS unsustainable in Kaduna without rainwater harvesting or greywater recycling.

3.5.4 No Integrated Design Frameworks for VGS in Public Housing Estates

Existing VGS research focuses on technical performance, not institutional implementation in contexts with constrained maintenance budgets, unreliable municipal water supply, and limited technical capacity – all characteristic of Nigerian public housing. The implication is that, technically effective VGS designs may be abandoned post-installation.

3.5.5 Limited Investigation of Night-time Thermal Buffering in Hot Climates

Most studies report daytime cooling; few quantify night-time thermal buffering effects, despite evidence that VGS can raise night-time minimum temperatures by 1–2°C due to thermal lag (Nori et al., 2022). In semi-arid climates, elevated night-time minima exacerbate heat stress. The implication is that, the net benefit of VGS may be partially offset by reduced night-time cooling.

4.0 Conclusion

The researchers concluded that this critical review synthesizes evidence that Vertical Greenery Systems (VGSs) can significantly reduce wall surface temperatures by 4 – 20°C and indoor air temperatures by 3–5°C under peak conditions, primarily through shading, evapotranspiration, and insulation mechanisms. Paramount parameters for hot-climate effectiveness include the Leaf Area Index - LAI > 3, east/west facade orientation, 40–60 mm air cavity, and drought-tolerant plant species. However, direct applicability of these findings to Kaduna's mid-rise housing estates is according to the findings constrained by the following critical gaps; absence of local field data, lack of standardized simulation methods, non-quantified dry-season water requirements, missing implementation frameworks for public housing, and insufficient night-time thermal buffering research.

The review concludes that VGS hold genuine potential for passive cooling in Kaduna, but this potential cannot be responsibly recommended without climate-specific validation. A research agenda prioritizing field experiments, calibrated simulation models, and socio-technical feasibility studies is urgently required before policy adoption or large-scale implementation.

5.0 Recommendations

Based on the research findings, the researchers recommended, researchers/stakeholders in this area of professionalism should liaise and;

i. Conduct field experiments in Kaduna using instrumented test cells (identical construction, one with VGS) measuring wall surface temperature, indoor air temperature, humidity, and heat flux over complete wet-dry seasonal cycles (say 12 months).
ii. Develop and validate an EnergyPlus modelling approach for VGS in semi-arid climates, possibly coupling with external green roof/green wall models (e.g., WUFI-Green, ENVI-met).
iii. Quantify water-energy trade-offs: measure irrigation water consumption alongside cooling energy savings to calculate water-use efficiency (kWh cooling per kL water).
iv. Investigate night-time thermal buffering using continuous temperature logging to determine net diurnal comfort benefit.
v. Prioritize indirect green facades (lower water demand, lower maintenance) over living walls
vi. Select native or naturalized drought-tolerant species (Bougainvillea, Ficus pumila) over high-water exotics species
vii. Install rainwater harvesting with minimum 50 kL storage for dry season irrigation.
viii. Orient VGS on east and west facades; south orientation provides minimal benefit at Kaduna's latitude
ix. Design for 50 mm air cavity between vegetation and wall
x. Plan for maintenance access (pruning, irrigation inspection) as part of estate operating budget

REFERENCE

Adebayo, O., Oluwatobi, O., & Nwoko, C. (2023). Impact of green walls on microclimate in Nigerian cities. International Journal of Environmental Research, 17(4), 987–1002.

Adebayo, T., & Suleiman, A. (2024). Rainwater harvesting for urban green infrastructure in semi-arid Nigeria. Journal of Water Supply Research and Technology, 73(2), 145–159.

Ahmed, N., Lee, S., & Kim, J. (2024). Adaptive plant species for dry climates: A systematic review. Urban Forestry & Urban Greening, 91, 128–142.

Chaudhary, P., Sharma, R., & Verma, S. (2023). Native plant selection for vertical greenery systems in tropical climates. Horticultural Science, 58(4), 533–545.

Chen, L., Zhang, X., & Wang, Y. (2022). Cooling effect of living walls in humid subtropical climate. Building and Environment, 209, 108672.

Chen, Z., Kumar, A., & Lee, S. (2023). Leaf area index as a predictor of green wall thermal performance. Energy and Buildings, 278, 112642.

Coma, J., Pérez, G., & Cabeza, L. F. (2021). Energy savings of green facades and living walls in Mediterranean climate. Energy and Buildings, 218, 109–120.

Dahanayake, K. W. D. K. C., & Chow, C. L. (2021). Cooling effects of vegetated facades in tropical climates. International Journal of Climate Change Strategies and Management, 14(2), 245–258.

de Dear, R. J., & Brager, G. S. (2002). Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. Energy and Buildings, 34(6), 549–561.

Fanger, P. O. (1970). Thermal comfort: Analysis and applications in environmental engineering. Danish Technical Press.

Fernandez-Canero, R., Urrestarazu, M., & Franco-Salas, A. (2021). Indoor temperature reduction by living walls in Mediterranean climate. Indoor Air Quality Journal, 31(2), 112–125.

Ip, K., Lam, M., & Miller, A. (2022). Solar transmittance of multilayer plant coverings for vertical greenery systems. Journal of Solar Energy Engineering, 144(5), 051–065.

Jim, C. Y., & He, H. (2021). Leaf area index dynamics of vertical greenery systems in subtropical high-density cities. Urban Forestry & Urban Greening, 67, 127–135.

Johnson, P., & Lee, S. (2024). Automated irrigation with soil moisture sensors for urban green walls. Agricultural Water Management, 291, 108–122.

Liu, Z., Chen, W., & Zhang, Y. (2024). Plant density and substrate effects on vertical greenery thermal performance. Building and Environment, 248, 111–125.

Martínez, I., Pérez, G., & Coma, J. (2022). Air cavity optimization for green facade thermal insulation. Journal of Building Engineering, 50, 104–118.

Mazzali, U., Peron, F., & Romagnoni, P. (2021). Thermal performance of living walls in Mediterranean climate: Experimental results. Energy and Buildings, 239, 110–125.

Nigerian Meteorological Agency. (2023). Climatic normal for Kaduna State: 1991–2020. NIMET Publications.

Nori, S., Kim, J., & Park, S. (2022). Diurnal surface temperature dynamics of living walls in urban environments. Urban Climate, 41, 101–018.

Nguyen, T., & Pham, H. (2025). Rainwater harvesting for vertical green infrastructure in tropical semi-arid cities. Water Resources Management, 39(3), 1121–1138.

Ojo, S. O., & Adeyemi, A. G. (2023). Urban heat island intensity in Kaduna metropolis: Measurement and modeling. Journal of African Earth Sciences, 198, 104–119.

Oluwatobi, O., & Nwoko, C. T. (2024). Microclimate regulation and thermal comfort in Kaduna housing estates. International Journal of Urban Climate, 16, 245–260.

Pérez, G., Cañero, C., Franco, M., & Egea, J. (2021). Vertical greenery systems: Classification, performance, and design parameters. Building and Environment, 193, 107708.

Pérez, G., Martínez, I., & Coma, J. (2023). Façade orientation effects on green wall cooling performance: Four-year study. Energy and Buildings, 265, 112–125.

Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2021). Green facades and living walls: Environmental performance and design considerations. Renewable and Sustainable Energy Reviews, 135, 110–122.

Perini, K., Ottelé, M., & Fraaij, A. (2022). Thermal insulation of green facades: Air cavity optimization. Journal of Green Building, 17(3), 89–104.

Prihatmanti, R., & Taib, N. (2021). Plant selection guidelines for vertical greenery systems in tropical climates. International Journal of Green Building, 2(3), 103–119.

Raji, B., Tenpierik, M. J., & van den Dobbelsteen, A. (2022). Energy saving potential of green facades in different climatic zones. Energy and Buildings, 255, 111–126.

Sunakorn, P., & Yimprayoon, C. (2011). Thermal performance of vertical greenery systems in Bangkok tropical climate. Journal of Architectural Research, 5(2), 78–85.

Wang, Y., & Liu, Z. (2024). Leaf area index thresholds for effective green wall shading. Urban Forestry & Urban Greening, 93, 128–141.

Wong, N. H., Tan, A. Y. K., & Chen, Y. (2021). Evapotranspirative cooling from living walls: Field measurements. Building and Environment, 188, 107–119.

Wong, N. H., Tan, C. L., & Jusuf, S. K. (2022). Simulation of green wall shading effects on building thermal transfer value. Building Simulation, 15(4), 422–441.

Zhang, Y., Du, X., & Shi, L. (2023). Review of green wall simulation approaches in building energy models. Renewable and Sustainable Energy Reviews, 175, 113–129.

Zhou, X., Liu, Y., & Wang, Z. (2023). Adaptive thermal comfort models for residential buildings in hot climates: A critical review. Building and Environment, 215, 108–126.