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Field-Based Assessment of Vegetation Structure and Configuration (VSC) For Thermal Regulation in Tropical Residential Environments

Noorazlina Kamarulzaman[1], Mazran Ismail[2], Hazril Sherney bin Basher[3], Asmat Ismail[4]

Abstract

The increase of Urban Heat Islands (UHI) in tropical regions such as Malaysia has exacerbated thermal discomfort in residential areas due to diminished vegetation and inadequate landscape planning. Although vegetation is recognized for its passive cooling benefits, the precise influence of Vegetation Structure and Configuration (VSC) on microclimate regulation across different housing layouts is insufficiently investigated. This study examines the influence of VSC on thermal regulation in two low-rise residential typologies in Perak, Malaysia labelled as a Structured Landscape House (SLH) and a Semi-Structured Landscape House (SSLH). Field measurements were executed over five days in the wet season (October to November), documenting air temperature (oC), relative humidity (RH), and wind velocity (m/s) both indoors and outdoors using two units Thermal Microclimate Monitoring System (HD32.1) for outdoor measurements and Indoor Air Monitoring System (HD37AB1347) for indoors. The findings demonstrate that the SLH, distinguished by its dense, multi-layered vegetation and strategic configurations, consistently surpassed the SSLH in regulating indoor temperatures (30.55°C compared to 31.41°C), decreasing humidity levels (62.39% versus 72.03%), and stabilizing air velocity (0.01 m/s average for both, with enhanced consistency in SLH). These findings confirm that well-organized and strategically positioned vegetation substantially improves residential thermal comfort, underscoring the importance of VSC as a passive design approach in tropical urban planning.

Keywords: *Urban Heat Island, Vegetation Structure, Vegetation Configuration, Thermal Environment.*

Introduction

Tropical cities across Southeast Asia face intensifying challenges related to urban heat, particularly within dense, low-rise residential developments. The combination of impervious surfaces, reduced vegetation cover, and inefficient landscape design contributes to elevated ambient temperatures and reduced air movement, especially in single-storey housing (Gómez-Navarro et al., 2021; Ramakreshnan et al., 2018). At the same time, the world is confronting a serious climate emergency, where governments are urged to maintain global surface temperature rise below 1.5°C above pre-industrial levels. Malaysia is already experiencing an increase of about 1°C, highlighting the urgency of addressing climate resilience. Climate change, air pollution, and greenhouse gas emissions remain critical environmental issues, largely driven by unsustainable patterns of energy consumption (Mohd Shafie et al., 2024).

In response to these challenges, Malaysia has introduced a range of Energy Efficiency (EE) initiatives aimed at promoting sustainable development in the built environment. Among the most notable are the Green Building Index (GBI), launched on 21st May 2009 to accelerate the adoption of green technologies and establish rating systems for environmentally friendly buildings, as well as strategies outlined in the Ninth Malaysia Plan (2006–2010), which prioritized improvements in EE and encouraged the integration of Renewable Energy (RE) in buildings (Aris et al., 2015; Esfandiyari et al.,

[1] Architecture Programme, School of Housing, Building & Planning, Universiti Sains Malaysia. EMAIL: noorazlinakamarul@student.usm.my
Programme of Building Surveying, College of Built Environment, Universiti Teknologi MARA, Seri Iskandar Campus
[2] Architecture Programme, School of Housing, Building & Planning, Universiti Sains Malaysia
[3] Architecture Programme, School of Housing, Building & Planning, Universiti Sains Malaysia

[4] Programme of Building, College of Built Environment, Universiti Teknologi MARA, Seri Iskandar Campus

2024). These initiatives reflect the country's commitment to reducing energy consumption while supporting broader climate action goals.

Complementing these policy-driven efforts, vegetation is increasingly recognized as a passive yet highly effective environmental modifier capable of improving local microclimates. By providing shade, regulating humidity, and influencing wind patterns, vegetation contributes to natural cooling and enhances urban thermal comfort (Ding et al., 2023; Huang, G., Zhou, W., Qian, Y., & Yu, 2019; Ng E., 2012). Empirical evidence confirms that higher vegetation cover strengthens the cooling effect in urban areas (Fu et al., 2022), making it a valuable adaptation measure against the Urban Heat Island (UHI) effect. Beyond its environmental benefits, urban vegetation also delivers significant economic and social advantages, making vegetation planting a widely adopted practice in cities worldwide(Qiuyan Yu & Yu, 2018)

Meanwhile, urban greening initiatives, especially in residential settings, represent the most straightforward and cost-effective method to mitigate local air temperature. Effective landscape design can diminish the influx of sunlight into a building, thereby establishing suitable temperatures for both indoor and outdoor settings (Noorazlina et al., 2023). However, the thermal effectiveness of vegetation in residential contexts depends significantly on its physical structure and spatial configuration.

Although existing research demonstrates the general benefits of greenery, few studies systematically compare how vegetation performs across different low-rise housing typologies. Understanding how vegetation design varies in effectiveness depending on housing layout and lot configuration is crucial for optimizing microclimatic design in tropical urban planning.

This study addresses that gap by conducting a comparative field investigation into the influence of Vegetation Structure and Configuration (VSC) on thermal environments across two common residential typologies in Perak, Malaysia.

Literature Review

Vegetation is essential in regulating urban microclimate, especially in tropical areas where the Urban Heat Island (UHI) effect exacerbates thermal discomfort. It mitigates ambient temperatures and building heat absorption while enhancing thermal comfort via shade, evapotranspiration, and the manipulation of wind patterns (Antoniadis, 2018; Taleghani, 2018; Yu et al., 2018). The cooling effects are influenced by the structural composition and spatial arrangement of the vegetation.

The concept of Vegetation Structure and Configuration (VSC) encompasses two interrelated elements: Vegetation Structure (VS) and Vegetation Configuration (VC). Collectively, they delineate the role of vegetation in influencing the thermal environment.

Vegetation Structure (VS) refers to the physical and spatial characteristics of plant communities. It encompasses plant height, width, morphology, density, canopy coverage, leaf area index, coloration, and vertical stratification(Gaitán et al., 2014; Tricahyo et al., 2025). These characteristics are shaped by genetic factors, environmental circumstances such as solar radiation and soil moisture, and ecological processes include competition and herbivory. Tropical forests exhibit a particularly intricate vegetation structure, stratified into four layers: emergent, upper canopy, understory, and forest floor (Semaan et al., 2020) as depicted in Figure 1, which illustrates a fruit forest in West Sumatra, Indonesia.

Figure 1: A Sketch Profile of a Fruit Forest in West Sumatra, Indonesia, Illustrating the Vegetation's Complex, Forest-Like Structure.

Vegetation Configuration (VC) delineates the spatial arrangement and orientation of plant components within a specific environment. Essential characteristics encompass spacing, orientation, layering, species composition, shading ability, and total coverage. Appropriate layout can diminish solar heat gain, augment airflow, and promote outdoor thermal comfort. Vegetation positioned on the eastern and western facades of buildings can mitigate direct solar exposure during peak hours (Kamarulzaman, 2024; Misni et al., 2013).

Vegetation reduces surface and air temperatures by shade and evapotranspiration. Shade from dense canopies can decrease surface temperatures by as much as 12°C (Ali-Toudert & Mayer, 2007), whereas evapotranspiration can reduce ambient air temperatures by up to 5°C (Heisler, in Antoniadis, 2018). Vegetation enhances airflow by directing or impeding wind, so affecting both external and internal ventilation. The selection and arrangement of species amplify these impacts. Deciduous trees give shade during warm seasons and permit sunshine in colder months, whereas evergreens provide consistent cooling (Akbari, H.,& Taha, 1992; VanDerZanden, A. M., & Rodie, 2008). Leaf texture, density, and color influence reflectance and moisture exchange (Kumar & Kaushik, 2005; Lin BS, 2010).

Furthermore, vegetation aids in regulating indoor humidity and acts as a natural windbreak, reducing surface heat accumulation (Wardoyo et al., 2012). In conclusion, vegetation is not solely decorative but functions as an essential design component for passive thermal control.

Research Methodology

Study Area

Malaysia, located in Southeast Asia, has a tropical climate and comprises two distinct regions: Peninsular Malaysia and East Malaysia (on the island of Borneo). The country features a diverse landscape, including mountainous regions, coastal plains, and tropical rainforests, with consistently high temperatures and humidity throughout the year. Peninsular Malaysia shares borders with Thailand to the north and Singapore to the south, while East Malaysia borders Brunei and Indonesia. The country's coastline stretches over 4,800 km (2,980 mi), encompassing the South China Sea and the Straits of Malacca, as illustrated in Figure 2.

This research was conducted in the northern region of Peninsular Malaysia, specifically in the Perak Tengah District of the state of Perak, situated at approximately 4°N latitude and 100°E longitude. The area was selected due to its warm tropical climate, ranking among the top three warmest states in Malaysia. Based on data from a nearby weather station in Ipoh, the district's average annual temperature is about 27°C. Monthly temperatures are relatively stable, ranging from 26°C in December and January to 28°C in April and May. The hottest months are typically March and April, with average daily temperatures peaking at around 31°C.

Perak Tengah experiences two distinct monsoon seasons. The northeast monsoon, from November to March, brings significant rainfall primarily to the district's eastern area, with average monthly precipitation ranging from 150 mm in January to 300 mm in December. The southwest monsoon, from May to September, affects the western region more, with monthly rainfall between 200 mm (in July) and 350 mm (in November). Between these monsoon periods, the inter-monsoon transition phase, occurring from April to October, is comparatively drier, with monthly rainfall ranging between 100 mm and 200 mm.

Figure 2. The Map Depicts the Location of the Research Area, Perak Tengah District, Perak Malaysia.

Case Study Selection and Microclimate Monitoring Procedures

This research utilized a field-based methodology to investigate the effects of residence landscaping on microclimate conditions. The study was conducted in a designated residential area in the Perak Tengah District, Perak, Malaysia, where two semi-detached houses were located via snowball sampling. The selected houses were based on differences in landscape design while being situated in a comparable residential setting. Each house was categorized according to the density and configuration of vegetation, with a residence exhibiting a formally ordered and dense landscape labeled as a Structured Landscape House (SLH), while one with moderately planned vegetation was referred to as a Semi-Structured Landscape House (SSLH).

Data collection was conducted over a period of seven days for each house during the wet season in October and November, a time when vegetation was typically lush due to regular rainfall. This period was purposefully selected to capture the maximum impact of vegetation on local microclimatic conditions. However, due to technical malfunctions affecting the instruments on-site, the final dataset analyzed covered only five days of measurement per house.

Measurements focused on three meteorological parameters such as air temperature (°C), relative humidity (%), and wind velocity (m/s). These were recorded both inside and outside each house. To document variations in surrounding vegetation, observations on the structure, density, and maturity of plants were collected during the same period. Each house's landscape differed in complexity and planting arrangements. The architectural style, building age, and construction methods of both houses were kept consistent to serve as control variables, ensuring that vegetation was the primary differentiating factor. Table 1 illustrates the criteria for selection for each house.

Two units of the Thermal Microclimate Monitoring System (HD32.1), a portable meteorological instrument, were used to monitor the outdoor environment. Simultaneously, the Indoor Air Monitoring System (HD37AB1347) was installed within each house to measure indoor conditions. The outdoor instruments were set up each morning at a height of one meter above ground and positioned approximately three meters from the exterior wall, operating daily from 7:30 a.m. until 6:00 p.m. The indoor sensors were fixed at the same height and ran continuously throughout the monitoring period.

Data was collected at 30-minute intervals to track temperature and humidity fluctuations throughout the day. To ensure consistency in data collection, the placement of instruments, indoors and outdoors was kept as similar as possible across the two case study sites. Their locations are shown in Figure 2. Regular site visits were conducted to inspect equipment functionality and ensure that all weather events and anomalies were accurately recorded throughout the monitoring period.

Table 1: Criteria Selection for the Case Study Houses

No	House Labelled	Criteria Selection								
		Building Construction	Building and Design	Built-Up	Landscape	Landscape orientation	Landscape	Landscape density	Climatic condition	Housing
1	Structured Landscape House (SLH)	*	*	*		*		ø	*	
2	Semi-Structured Landscape House (SSLH)	*	*	*		*		ø	*	

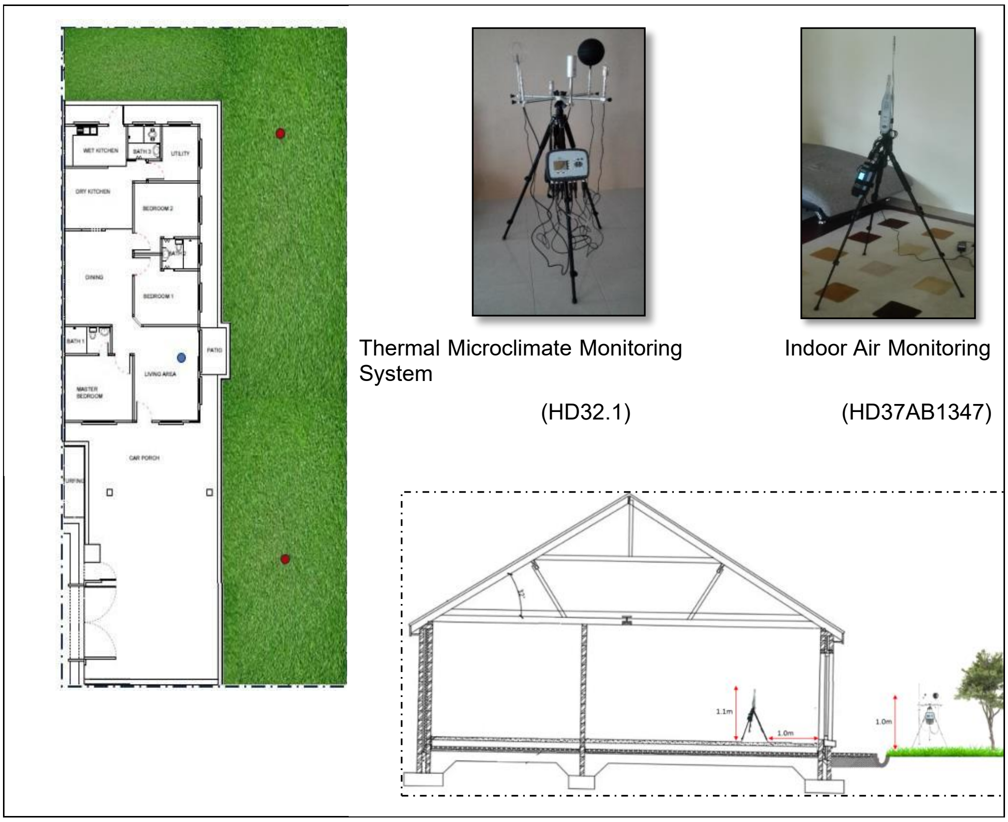

Figure 2. Outdoor and Indoor Instrument Configuration per ASHRAE 2010 and ISO7726

Case Study 1: Structured Landscape House (SLH)

The Structured Landscape House (SLH) features a systematically planned and maintained landscape designed to enhance environmental quality and aesthetic appeal. The specific layout and spatial distribution are illustrated in Figures 3-6, demonstrating adherence to core landscape design principles such as environmental suitability, visual balance, spatial organization, and plant grouping.

The landscape incorporates both softscape and hardscape elements, including ceramic pots and water features, enhancing visual texture and functional design. A total of 54 vegetation species is identified across six categories: garden trees (12 species), edible trees (6), garden shrubs (26), edible shrubs (2), groundcovers, vines (2), and turf. Notable edible plants include sweet potato, banana, mango, coconut, and guava, adding utilitarian value alongside aesthetic function. Vegetation is arranged in both clusters and individual placements, contributing to high species diversity. The lawn area is fully covered with Philippine grass, offering cohesive ground cover. The healthy condition and consistent maintenance of the landscape elements reflect the homeowner's commitment to sustaining this structured design.

Figure 3. Front and Side Elevation of Structured Landscape House (SLH)

Figure 4. Front Elevation of the SLH, Where Densely Arranged Vegetation with Mixed Heights Including Tall Shrubs and Small Trees Up To 3m.

Figure 5. Side Elevation of the SLH, Featuring Layered Vegetation With Varied Heights That Enhances Lateral Shading and Improves the Microclimate Along the Building Perimeter.

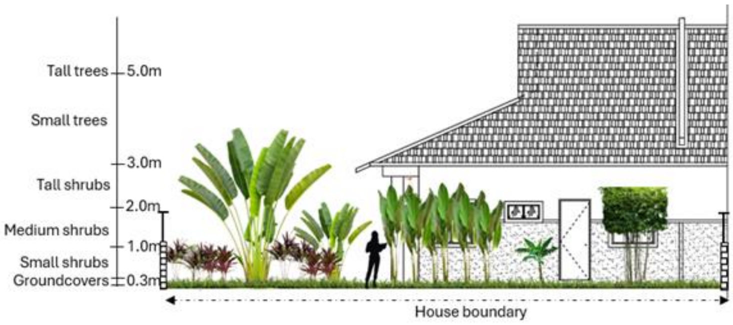

Figure 6. Rear Elevation of the SLH, Where Compact Vegetation Including Medium Shrubs and Groundcovers, Offers Minimal Shading to the Building but Contributes to Ground-Level Cooling

Case Study 2: Semi-Structured Landscape House (SSLH)

The Semi-Structured Landscape House (SSLH) features a minimalist and orderly landscape arrangement, characterized by a limited variety of vegetation with a focus on visual balance. A pair of Yucca aloifolia shrubs, placed in pots on the front porch, serve as key focal points, enhancing the visual interest at the entrance.

Complementing this are three Foxtail Palm trees (Wodyetia bifurcata), arranged in a linear formation approximately 6 meters from the front wall façade. This parallel configuration reinforces a clean and harmonious landscape composition. No vegetation is present in the southern or rear sections of the house, reflecting a simplified planting strategy.

The entire landscaped area is uniformly covered with well-maintained Philippine grass, which provides a neat, continuous ground layer that contributes to the SSLH's overall aesthetic and coherence. The limited yet deliberate plant selection reflects a semi-structured design approach that balances simplicity with functional and visual intent. The precise layout of vegetation on the site is recorded and included in the vegetation arrangement plan, as shown in Figures 7 to 10.

Figure 7. Front and Side Elevation of Semi-Structured Landscape House (SSLH)

Figure 8. Front Elevation of SSLH showing two *Yucca aloifolia* in pots (2–3 m), providing minimal shading to ground-level cooling

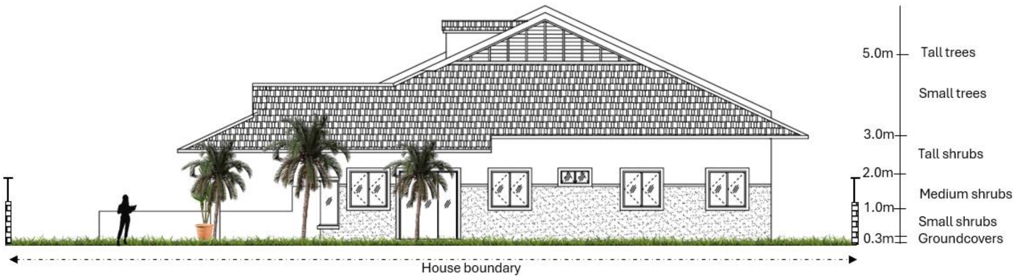

Figure 9. Side Elevation of SSLH with three *Wodyetia bifurcata* (2–5m), offering limited lateral shading due to sparse canopy and farther from wall

Data Collection and Analysis

Five-day Outdoor and Indoor Air Temperature (°C) Analysis

The following graphs summarize the data collected over a five-day period that examined the effects of different vegetation structures and configuration on various meteorological parameters. As shown in

Figure 11, the five-day trends of the outdoor and indoor air temperatures documented at the Structured Landscape House (SLH).

Outdoor temperatures exhibited significant variety, fluctuating between 24.40°C and 37.25°C, characterized by a consistent daily pattern of milder mornings, increasing midday temperatures, and a pronounced decrease post-sunset. Conversely, interior temperatures exhibited relative stability, characterized by little variation.

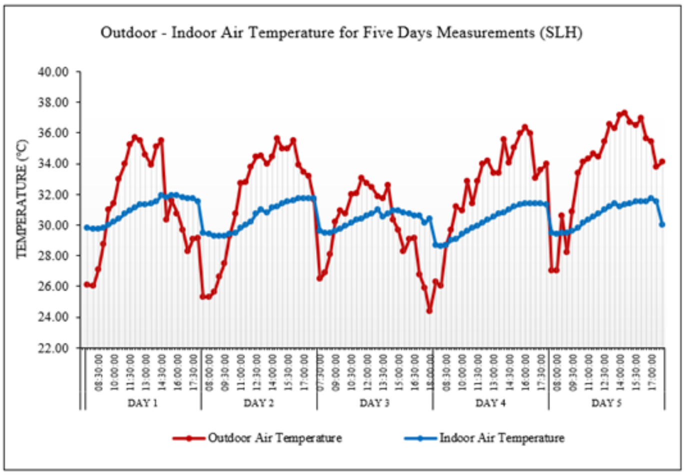

Figure 11. Outdoor and Indoor Air Temperature Readings for SLH

On the fifth day, the outdoor temperature reached a maximum of 37.25°C at 14:30, and the minimum outdoor temperature of 24.40°C was recorded on the third day. The highest temperature differential between outside and inside environments was recorded at 08:30 on the fifth day, attaining 3.55°C. Indoor temperatures varied from a low of 28.60°C on day four (08:00) to a high of 31.90°C on day one (14:30–16:00). Indoor temperatures are notably above 30°C between 11:00 and 11:30 on multiple occasions.

The maximum indoor-outdoor temperature differential recorded was 0.50°C on the second day, while the minimum was 0.10°C. The data demonstrates the buffering impact of the SLH landscape design in regulating indoor heat conditions compared to the outdoor environment. Outdoor maximum temperatures varied from 33.05°C to 37.25°C, while low values ranged from 24.40°C to 27.00°C. The average outdoor temperatures ranged from 29.79°C to 33.92°C. Significant inter-day temperature variations were recorded, with maximum differences between 1.95°C and 3.55°C and lowest differences ranging from 1.60°C to 5.15°C, reflecting considerable daily swings.

Conversely, indoor temperatures exhibited relative stability. Maximum temperatures ranged from 31.00°C to 31.90°C, whereas minimum temperatures were between 28.60°C and 29.70°C. The average indoor temperatures exhibited minimal fluctuation, ranging from 30.25°C to 31.00°C. The greatest daily variations were negligible, ranging from 0.30°C to 0.50°C, whilst the minimum variations spanned from 0.10°C to 1.50°C. The statistics reveal that outside temperatures exhibited greater variability than the more consistent inside the thermal environment.

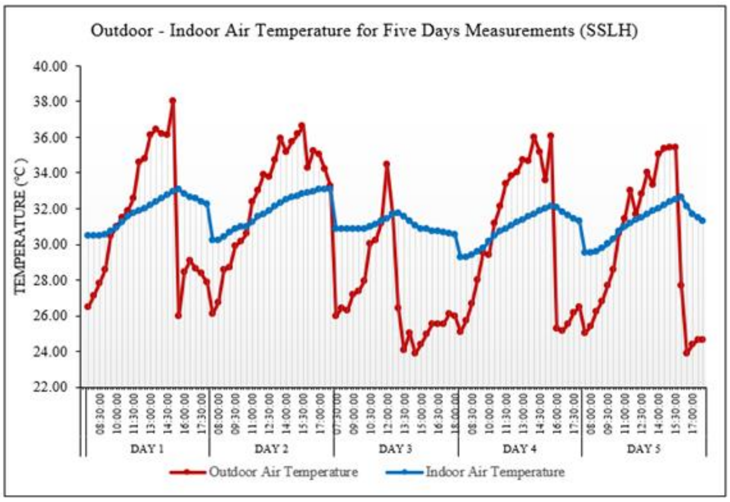

Figure 12. Outdoor and Indoor Air Temperature Readings for SSLH

Figure 12 depicted the five-day trends in outdoor and indoor air temperatures for the Semi-Structured Landscape House (SSLH). Outdoor temperatures exhibited significant variety, fluctuating between 24°C and 38.05°C, with the peak recorded on the first day at 15:00. The peak outdoor temperature variation (3.25°C) was recorded on the third day between 11:30 and 12:00.

Conversely, indoor air temperatures exhibited greater stability, fluctuating between 29°C and 33.10°C, with an average of approximately 31°C. Heat accumulation within the building transpired incrementally, predominantly via the concrete roof and brick walls, with peak indoor temperatures observed on the first and second days at 15:30 and 17:30, respectively.

The largest temperature differential between outdoor and indoor environments was 12.10°C, and the minimum recorded was 0.10°C. Outdoor temperatures exhibited greater variability than indoor temperatures whereas outdoor maximum temperatures varied between 34.45°C and 38.05°C, minimums between 23.90°C and 26.10°C, and daily averages between 27.10°C and 32.73°C. The maximum variances between consecutive days ranged from 2.35°C to 12.10°C, and the minimum differences varied from 0.00°C to 0.10°C.

Indoor maximum temperatures varied between 31.75°C and 33.10°C, minimums between 29.25°C and 30.55°C, and daily averages between 30.94°C and 31.86°C. The daily indoor temperature variations were negligible, ranging from 0.25°C to 0.50°C, with certain intervals exhibiting no fluctuation. The SSLH demonstrated more pronounced variations in outdoor air temperatures relative to the consistent indoor environment.

Five-Day Outdoor and Indoor Relative Humidity (RH) Analysis

Figure 13 depicts the five-day trends of outdoor and interior relative humidity (RH) for SLH. Outdoor relative humidity had greater variability than interior relative humidity, fluctuating between 37.15% and 96.25%, with the peak value seen at 18:00 on the third day. The most significant outdoor relative humidity variation (14.05%) transpired between 16:00 and 16:30 on the same day. The outdoor relative humidity was often elevated in the early morning, averaging 80%, and experienced a significant fall in the afternoon as temperatures increased.

Indoor relative humidity remained steady, fluctuating between 49.10% and 70.90%, adhering to the design criteria established by MS 1525. Indoor relative humidity exhibited a trend analogous to that of the outdoors, peaking in the early morning, declining in the afternoon, and subsequently increasing in the evening. The highest indoor relative humidity difference observed was 5.70%, while the lowest was 1.90%, both reported on the fourth day.

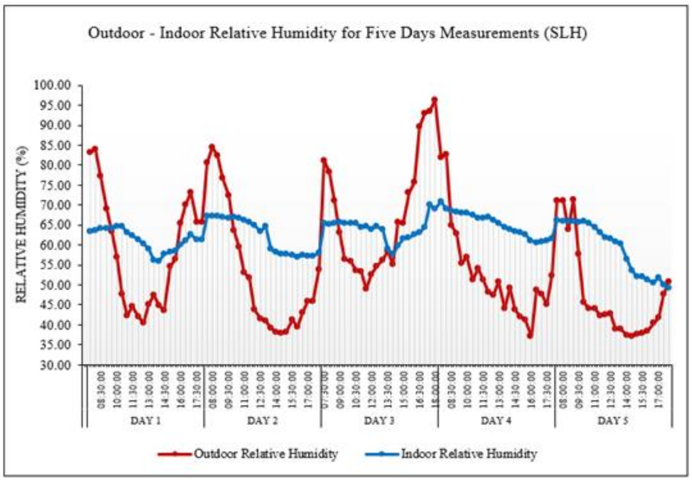

Figure 13. Outdoor and Indoor Relative Humidity Recorded for SLH

Additionally, Figure 14 illustrates the five-day trends of outdoor and indoor relative humidity (RH) for SSLH. Outdoor relative humidity exhibited considerable variability, ranging from 33.35% to 99.65%, with maximum being observed in the mornings and late afternoons. The peak outdoor relative humidity (99.65%) was documented at 17:00 on the fifth day, whilst the nadir (33.35%) was noted at 15:00 on the first day. The highest outside relative humidity difference (63.90%) was observed on the first day

between 15:30 and 16:00. Conversely, indoor relative humidity remained generally constant, varying between 66.80% and 78.50%, with little variation during the period. The RH data analysis indicates that the maximum indoor relative humidity (78.50%) occurred on day four at 7:30 and 8:00, whereas the minimum (66.80%) was observed on day one at 15:00 and 15:30. Daily indoor relative humidity variations were negligible, fluctuating between 0.80% and 2.50%.

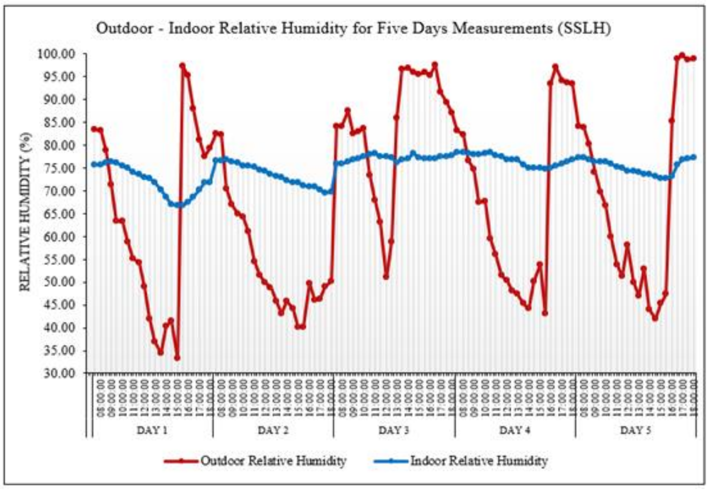

Figure 14. Outdoor and Indoor Relative Humidity Recorded for SSLH

Five-Day Outdoor and Indoor Air Velocity (m/s) Analysis

Figure 15 displays the five-day data of outdoor and indoor air velocity for SLH. The outdoor air velocity exhibited considerable variations, oscillating between 0.16 m/s and a maximum of 3.05 m/s on the fourth day at 14:30. The minimum figure (0.16 m/s) was recorded on the first day at 09:30, but the maximum average daily outside velocity was 0.96 m/s on the fourth day.

Conversely, interior air velocity constantly remained low and stable, ranging from 0.00 m/s to 0.14 m/s, which is below the ASHRAE minimum requirement of 0.25 m/s and the comfort range of 0.15–0.50 m/s as per MS 1525. The diminished values are ascribed to the regulated conditions: the residences were uninhabited, and all apertures were sealed during operational hours, in accordance with residents' safety preferences.

This regulated methodology guaranteed consistent indoor conditions across all case studies, facilitating the evaluation of vegetation's passive impact on indoor air quality without disruption from occupant activities. The air velocity data, revealing interior measurements often approximating 0.00 m/s, with average values fluctuating between 0.01 and 0.02 m/s within the observed timeframe.

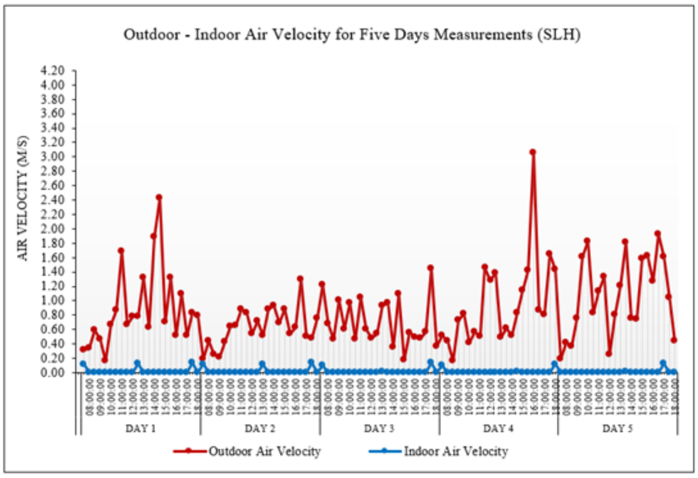

Figure 15. Outdoor and Indoor Air Velocity Patterns for SLH

Figure 16 depicts the air velocity patterns, both outdoor and interior, for SSLH throughout a five-day duration. The outside air velocity exhibited significant variations, with a minimum of 0.06 m/s (day three, 09:30) and a maximum of 2.68 m/s (day five, 16:00), while the highest average was 1.01 m/s on day four. Conversely, indoor air velocity constantly measured 0.00 m/s during the observation. The unoccupied conditions and closed apertures during measurement led to readings far below the ASHRAE (≥0.25 m/s) and MS 1525 (0.15–0.50 m/s) recommended indoor air velocity standards.

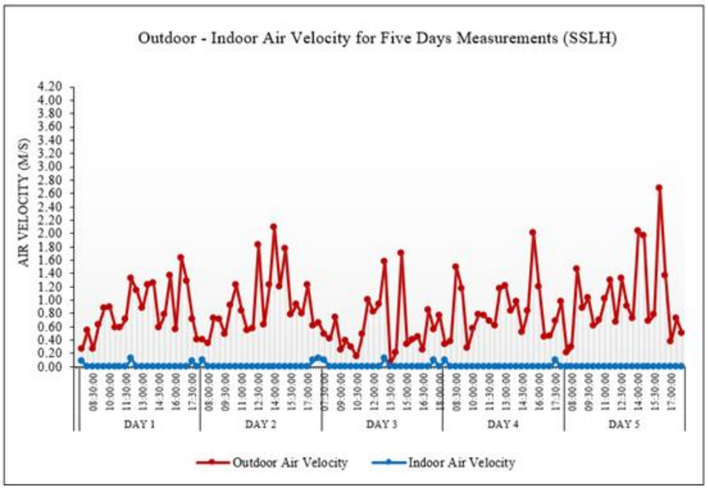

Figure 16. Outdoor and Indoor Air Velocity Patterns for SSLH

Comparison of Data Analysis

A comprehensive analysis of all climatic parameters recorded over the five-day period for each case study house is encapsulated in Table 2. This includes the minimum, maximum, average values, and the discrepancies between external and inside temperatures. The analysis seeks to determine the optimal Vegetation Structure and Configuration (VSC) for single-storey semi-detached houses by assessing the five-day average values of all assessed parameters. The performance is evaluated at various times of day, categorized into three quartiles: Quartile 1 (07:30–11:00), Quartile 2 (11:00–14:30), and Quartile 3 (14:30–18:00). This method offers an in-depth assessment of each VSC's efficacy during the day, building upon the results of the previous five-day analysis

Table 2: Summary of the Average Five-Day Analysis of Climatic Parameters Gathered for SLH And SSLH.

Criteria	Outdoor Temp (℃)		Outdoor RH (%)		Outdoor Air Vel. (m/s)	
	SLH	SSLH	SLH	SSLH	SLH	SSLH
Max Avg.	34.96	34.20	80.15	83.34	1.19	1.31
Min Avg.	26.24	25.93	44.97	49.39	0.37	0.34
Avg.	31.93	30.37	55.92	67.32	0.85	0.84
Criteria	Indoor Temp (℃)		Indoor RH (%)		Indoor Air Vel. (m/s)	
	SLH	SSLH	SLH	SSLH	SLH	SSLH
Max Avg.	31.42	32.24	66.64	76.30	0.09	0.07
Min Avg.	29.32	30.20	58.42	66.80	0.00	0.00
Avg.	30.55	31.41	62.39	72.03	0.01	0.01
Quartile	Outdoor-Indoor Temp diff.		Outdoor-Indoor RH diff.		Outdoor-Indoor Air Vel. diff.	
Q1	1.97℃	2.02℃	10.06%	7.40%	0.65m/s	0.63m/s
Q2	3.40℃	1.35℃	15.64%	16.97%	0.91m/s	1.04m/s
Q3	1.19℃	2.73℃	4.58%	8.88%	0.98m/s	0.88m/s

*Temp: Temperature *RH: Relative Humidity *Air Vel.: Air Velocity *diff: different

According to the analysis presented in Figure 17, SLH and SSLH exhibit distinct disparities in thermal performance across all quartiles. During Quartile 1 (07:30–11:00), SLH documented the peak outdoor air temperature of 32.88°C at 11:00, succeeded by SSLH. Nonetheless, despite elevated outdoor temperatures, SLH sustained the lowest inside air temperature (30.18°C), illustrating robust thermal buffering attributed to its denser vegetation, notably garden shrubs and edible trees. SSLH had commendable performance, achieving the second-lowest indoor temperature, which signifies moderate cooling, attributed to its semi-structured plant arrangement.

In Quartile 2 (11:00–14:30), SLH demonstrated the greatest outdoor temperature (34.17°C) while consistently maintaining the lowest indoor air temperature, so affirming its exceptional capacity to alleviate heat during peak hours. SSLH, despite having lower outdoor temperatures than SLH, had a higher inside temperature, indicating diminished cooling efficacy attributed to its reduced vegetation density and canopy height.

During Quartile 3 (14:30–18:00), as temperatures commenced their decline, SSLH documented the minimum outside temperature by 18:00. Nonetheless, its interior temperature exceeded that of SLH, signifying that SLH maintained superior indoor thermal control despite fluctuations in external conditions.

In summary, SLH surpasses SSLH in all quartiles by sustaining consistently lower indoor air temperatures, due to its denser vegetation structure, more strategic orientation, and diverse plant species, while SSLH provides moderate thermal regulation with less reliable indoor cooling advantages

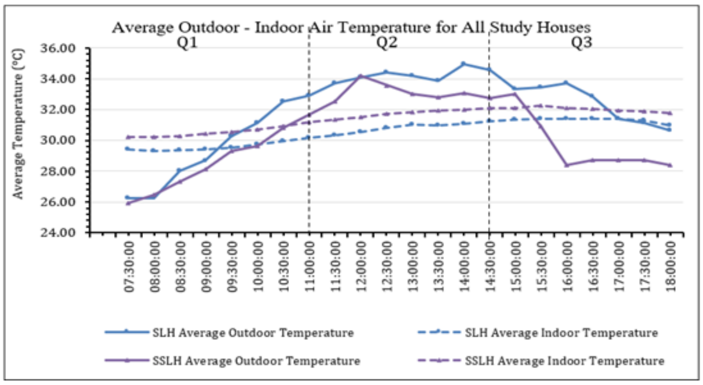

Figure 17. Average Outdoor and Indoor Air Temperature for All Study Houses

Figure 18 illustrates significant disparities in relative humidity between the SLH and the SSLH. During Quartile 1 (07:30–11:00), SLH documented the minimum outdoor relative humidity at 49.39%, but SSLH had elevated readings. Under indoor conditions, SLH consistently exhibited a lower relative humidity with a five-day average of 62.39%, in contrast to SSLH at 72.03%, signifying superior indoor humidity regulation in SLH.

In Quartile 2 (11:00–14:30), SLH maintained the lowest outside humidity at 46.43%, while SSLH recorded the highest levels among all houses. Likewise, SSLH exhibited the highest indoor humidity during this peak period, whereas SLH recorded the lowest, indicating superior thermal and moisture buffering in SLH attributable to denser vegetation and canopy covering.

During Quartile 3 (14:30–18:00), SSLH recorded the highest indoor relative humidity, reaching a peak of 77.55% at 18:00, whilst SLH reported a lower level of 63.82%. The prevailing trend demonstrates that SSLH faced challenges in efficiently regulating indoor humidity, especially during the late afternoon, despite decreased exterior measurements.

The SLH exhibits enhanced humidity regulation during all time intervals owing to its organized vegetation approach, whereas the SSLH, characterized by less canopy and fewer plant strata, displays elevated indoor humidity and diminished overall efficacy.

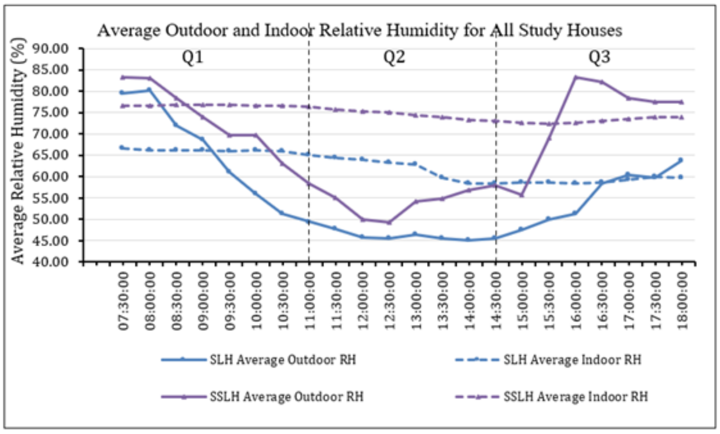

Figure 18. Average Outdoor and Indoor Relative Humidity All Study Houses

Figure 19 depicts the air velocity trends for the SLH and the SSLH, highlighting significant disparities in wind buffering efficacy. SLH had considerable variations in outside air velocity, commencing at 0.49 m/s at 07:30 and attaining a maximum of 1.19 m/s at 16:00. Indoor air velocity was consistently minimal over the day, with a slight maximum of 0.09 m/s at 07:30 and 0.08 m/s at 17:30. These figures indicate significant wind attenuation facilitated by the structured and dense vegetation encircling the SLH.

Conversely, SSLH had marginally higher fluctuating outside air velocities, commencing at 0.34 m/s at 07:30 and reaching a maximum of 1.31 m/s at 14:00. The indoor air velocity in SSLH remained low, exhibiting slightly more variability than in SLH, varying between 0.00 m/s and 0.07 m/s during the day. This indicates moderate wind buffering, aligned with its semi-structured vegetation configuration, characterized by fewer canopy layers and more sparse plant groupings compared to SLH.

During Quartile 1 (07:30–11:00), SLH had a superior average outdoor air velocity (reaching 1.05 m/s at 11:00) relative to SSLH, although indoor air velocity was comparatively lower, underscoring SLH's efficient wind filtration. SSLH, despite experiencing slightly reduced outdoor velocities, had comparable inside values, indicating that its vegetation provided moderate albeit less effective wind attenuation.

During Quartile 2 (11:00–14:30), SSLH registered a maximum outdoor air velocity of 1.31 m/s, but SLH exhibited a slightly lower value. Both study houses exhibited low internal air velocity values (about 0.01 m/s to 0.02 m/s), indicating a certain level of buffering, with SLH demonstrating superior indoor stability.

During Quartile 3 (14:30–18:00), SLH attained its maximum outdoor velocity of 1.19 m/s at 16:00, while SSLH had a marginally superior velocity of 1.23 m/s at 17:00. Once more, indoor air velocity was notably low in both residences, demonstrating good management in both environments, although SLH exhibited marginally superior overall consistency.

In summary, the SLH's organized and dense vegetation configuration yields more stable and buffered indoor air conditions, whereas the SSLH, characterized by its semi-structured vegetation, demonstrates increased variability and diminished wind regulation efficacy. These observations highlight the significance of thick vegetation and planned landscape design in alleviating outdoor wind effects and ensuring inside comfort.

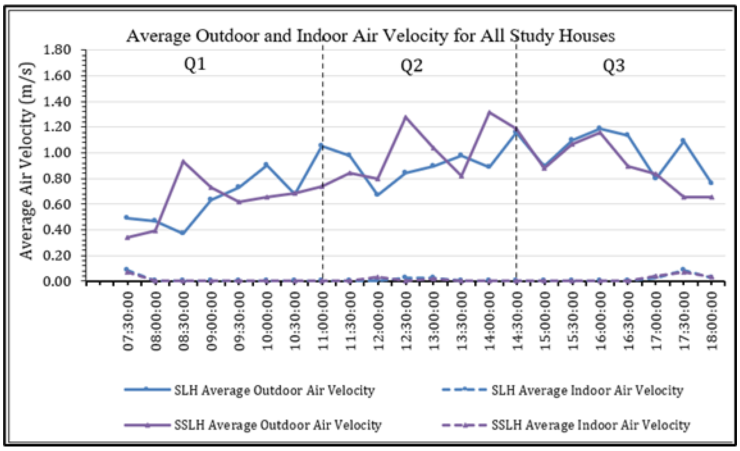

Figure 19. Average Outdoor and Indoor Air Velocity for All Study Houses

Conclusion

The comparative analysis of the Structured Landscape House and Semi-Structured Landscape House underscores the efficacy of vegetation structure and configuration (VSC) in regulating thermal conditions in low-rise residential contexts. SLH routinely exhibits exceptional temperature control across all metrics. It documented the lowest average inside air temperature (30.55°C), the lowest indoor relative humidity (62.39%), and the most constant indoor air velocity (average 0.01 m/s), notwithstanding elevated outdoor values. This performance is due to its dense, multi-layered vegetation with strategic placement and canopy covering, which effectively mitigates solar radiation, decreases ambient heat gain, and restricts wind penetration.

In contrast, SSLH exhibits inferior thermal moderation, characterized by a higher average indoor air temperature of 31.41°C and the greatest indoor humidity at 72.03% among all examined residences. While SSLH had a little elevated peak outdoor air velocity (1.31 m/s) compared to SLH, its indoor air velocity was minimal, suggesting some wind buffering but diminished consistency. The moderate density and arrangement of vegetation in SSLH offered some shading and cooling but did not possess the structural layering of vegetation found in SLH, which is essential for optimal microclimatic regulation.

These findings highlight the significance of systematically organized and strategically positioned plants in improving interior thermal conditions. SLH demonstrates how an effectively built VSC can yield quantifiable enhancements in thermal comfort by alleviating heat, controlling humidity, and regulating airflow in tropical residential settings.

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REFERENCES

[1] Akbari, H.,& Taha, H. (1992). The Impact of Trees and White Surfaces on Residential Heating and Cooling Energy Use in Four Canadian Cities,. Energy. The International Journal, 17 (2), 141–149.

[2] Ali-Toudert, F., & Mayer, H. (2007). Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons. Solar Energy, 81(6), 742–754. https://doi.org/10.1016/j.solener.2006.10.007

[3] Antoniadis, D. G. . (2018). Investigation of the effect of vegetation and green infrastructures on outdoor bioclimatology: the case study of the environment of urban school buildings. University Of Thessaly School.

[4] Aris, S. M., Dahlan, N. Y., Nawi, M. N. M., Nizam, T. A., & Tahir, M. Z. (2015). Quantifying energy savings for retrofit centralized hvac systems at Selangor state secretary complex. Jurnal Teknologi, 77(5), 93–100. https://doi.org/10.11113/jt.v77.6125

[5] Ding, N., Zhang, Y., Wang, Y., Chen, L., Qin, K., & Yang, X. (2023). Effect of landscape pattern of urban surface evapotranspiration on land surface temperature. Urban Climate, 49(April). https://doi.org/10.1016/j.uclim.2023.101540

[6] Fu, J., Dupre, K., Tavares, S., King, D., & Banhalmi-Zakar, Z. (2022). Optimized greenery configuration to mitigate urban heat: A decade systematic review. Frontiers of Architectural Research, 11(3), 466–491. https://doi.org/10.1016/j.foar.2021.12.005

[7] Gaitán, J. J., Oliva, G. E., Bran, D. E., Maestre, F. T., Aguiar, M. R., Jobbágy, E. G., Buono, G. G., Ferrante, D., Nakamatsu, V. B., Ciari, G., Salomone, J. M., & Massara, V. (2014). Vegetation structure is as important as climate for explaining ecosystem function across patagonian rangelands. Journal of Ecology, 102(6), 1419–1428. https://doi.org/10.1111/1365-2745.12273

[8] Gómez-Navarro, C., Pataki, D. E., Pardyjak, E. R., & Bowling, D. R. (2021). Effects of vegetation on the spatial and temporal variation of microclimate in the urbanized Salt Lake Valley. Agricultural and Forest Meteorology, 296(February 2020), 108211. https://doi.org/10.1016/j.agrformet.2020.108211

[9] Huang, G., Zhou, W., Qian, Y., & Yu, W. (2019). Urban trees mitigate heat island effects in desert cities. Science of the Total Environment, 653, 113–121.

[10] Kumar, R., & Kaushik, S. C. (2005). Performance evaluation of green roof and shading for thermal protection of buildings. Building and Environment, 40(11), 1505–1511. https://doi.org/10.1016/j.buildenv.2004.11.015

[11] Lin BS, L. Y. (2010). Cooling Effect of Shade Trees with Different Characteristics in a Subtropical Urban Park. Hort Scie 45(1):83–86. https://doi.org/10.21660/2016.24.1262 Lin

[12] Mohd Shafie, S., Khua, S. Y., & Nu'man, A. H. (2024). Student Perspective Toward Energy Conservation in Universiti Utara Malaysia. Journal of Technology and Operations Management, 19(1), 69–88. https://doi.org/10.32890/jtom2024.19.1.6

[13] Ng E., et al. (2012). A Study on Urban Heat Island and Mitigation Strategies in the Context of Malaysia. Building Research & Information.

[14] Noorazlina, K., I.Mazran, Sherney, B. H., & I.Asmat. (2023). Influences of Vegetation Structure (Vs) on Meteorological Parameters in Built Environment; a Fieldwork Study. International Journal of Innovation and Industrial Revolution, 5(13), 225–239. https://doi.org/10.35631/ijirev.513018

[15] Qiuyan Yu, & Yu, Q. (2018). Assessing the Cooling Effects of Urban Vegetation on Urban Heat Mitigation in Selected U . S . Cities. November, 114.

[16] Ramakreshnan, L., Aghamohammadi, N., Fong, C. S., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Wong, L. P., Hassan, N., & Sulaiman, N. M. (2018). A critical review of Urban Heat Island phenomenon in the context of Greater Kuala Lumpur, Malaysia. Sustainable Cities and Society, 39(January), 99–113. https://doi.org/10.1016/j.scs.2018.02.005

[17] Semaan, M., Day, S. D., Garvin, M., Ramakrishnan, N., & Pearce, A. (2020). Optimal sizing of rainwater harvesting systems for domestic water usages: A systematic literature review. Resources, Conservation and Recycling: X, 6(November 2019), 100033. https://doi.org/10.1016/j.rcrx.2020.100033

[18] Taleghani, M. (2018). Outdoor thermal comfort by different heat mitigation strategies- a review. Renew. Sust. Energ., 81, 2011–2018.

[19] VanDerZanden, A. M., & Rodie, S. N. (2008). Landscape Design Theory and Application (Vol. 424). Canada Thomson Delmar Learning.

[20] Wardoyo, J., Suprapti, A., & Wediningsih, H. (2012). Vegetation configuration as microclimate control strategy in hot humid tropic urban park. Journal of Applied Sciences Research, 8(11), 5306–5310.

[21] Yu, Q., Acheampong, M., Pu, R., Landry, S. M., Ji, W., & Dahigamuwa, T. (2018). Assessing effects of urban vegetation height on land surface temperature in the City of Tampa, Florida, USA. International Journal of Applied Earth Observation and Geoinformation, 73(April), 712–720. https://doi.org/10.1016/j.jag.2018.08.016

[22] Tricahyo, A., & Nursalam, Y. F. (2025). Metaphors and Idioms of Wayang Tradition. Ascarya: Journal of Islamic Science, Culture, and Social Studies, 5(1), 60–75. https://doi.org/10.53754/iscs.v5i1.731
[23] Esfandiyari, V., Zarifian, S., Isanezhad, A., & Raheli, H. (2024). Effect of Optimizing Cultivation Pattern of Agricultural Crops on Water Consumption Management Under Virtual Water and Water Footprint Approach. Environment and Water Engineering, 10(2), 243-261.