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Diurnal Microclimate and Air Pollutant Patterns in Two Urban Parks in Dili

Elisabet Andrijani Tarwanti[1]*, Afonso Soares Sarmento[2], Francelina Mesquita da Conceição[3]
[12,3,] Department of Biology Teaching, Faculty of Education Arts and Humanity, University National of Timor-Leste, Dill, Timor-Leste

*Coresponding author-email: * elisabet.tarwanti@untl.edu.tl*

Abstract

Urban parks can modify local thermal conditions and pollutant concentrations, yet field evidence from tropical coastal cities such as Dili, Timor-Leste, remains limited. This study compared microclimate and atmospheric pollutant patterns at 5 de Maio City Park and Lecidere City Park, focusing on air temperature, relative humidity, wind speed, CO_2, $PM_{2.5}$, and PM_{10}, alongside vegetation structure. Field observations used portable sensors to measure microclimate variables and pollutant concentrations, while canopy characteristics and leaf morphology were recorded. The measurements showed air temperatures ranging from 23.0 to 32.5 °C, accompanied by relative humidity ranging from 51% to 88%. Within 5 de Maio, the shaded interior was 0.5–1.2 °C cooler and 2–5 percentage points more humid than a roadside location; CO_2 readings were also lower at interior than traffic-adjacent points. At Lecidere, the coastal edge had higher humidity and wind speeds, while particulate concentrations varied across observation points. These observations indicate that microclimatic conditions and pollutant concentrations differ by location and vegetation setting within the parks. Because the study measured ambient concentrations rather than pollutant fluxes or deposition, the findings do not directly quantify vegetation-driven pollutant removal. The results provide preliminary site-specific evidence to inform further monitoring and context-sensitive green-space planning in tropical coastal cities.

Keywords: *Pollutant Attenuation, Dili City, Microclimate, Green Open Spaces, Vegetation Structure.*

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1. Introduction

Rapid urbanization and changes in land cover are reshaping urban environments, particularly through the expansion of impervious surfaces and the loss of vegetation (Almeida & Costa, 2022). These changes can alter the surface-energy balance, intensify local thermal stress, and contribute to urban heat-island conditions and elevated pollutant exposure (Ziter et al., 2019). In tropical cities, these pressures may be compounded by strong solar radiation, high humidity, and locally constrained airflow (Geng et al., 2022). Understanding how urban green infrastructure interacts with local microclimate is therefore important for climate-resilient urban planning (Demuzere et al., 2014).

Urban green spaces can moderate local thermal conditions through canopy shade and evapotranspiration (Bowler et al., 2010) and may influence air quality through particulate deposition and the exchange of atmospheric gases (Nowak et al., 2014). In Dili, increasing vehicle use, commercial densification, and development along major road corridors place additional pressure on urban environmental conditions. Lecidere City Park and 5 de Maio City Park are two important green spaces exposed to traffic-related activity, yet they differ in vegetation structure, canopy density, and spatial configuration.

Previous studies indicate that the effects of urban vegetation on temperature and particulate matter depend on tree structure, canopy architecture, and spatial distribution (Norton et al., 2015; Saebo et al., 2012). Dense, multilayered canopies may provide shade and influence local heat exchange (Pereira et al., 2025), while leaf area and surface characteristics are relevant to particle interception and retention (Dzierzanowski et al., 2011; Kurniawan & Prasetyo, 2024). In coastal urban settings, these processes also interact with sea-land breezes, street geometry, and proximity to traffic sources, which can affect pollutant dispersion (Abhijith et al., 2017; Tomson et al., 2021).

Although reviews describe the environmental benefits of urban green spaces (Kumar et al., 2019; Nadhifa et al., 2024), much of the evidence comes from large cities or settings whose monitoring infrastructure and urban form differ from those of small tropical coastal cities. This limits direct transfer of findings to Dili, where coastal exposure and traffic corridors may shape local environmental conditions. Empirical comparisons that jointly document microclimate, ambient pollutant concentrations, and vegetation characteristics at the selected parks remain limited.

The empirical gap addressed here is the lack of a site-specific comparison of microclimate and ambient pollutant patterns at Lecidere City Park and 5 de Maio City Park in Dili. The two parks differ in coastal exposure, surrounding urban setting, vegetation structure, and spatial configuration. Comparing these sites can provide a local observational baseline relevant to green-space planning. The study does not assume that the parks have never been studied, nor that pollutant removal can be quantified from ambient concentration measurements alone.

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The study addresses two research questions: (1) How do spatial and temporal variations in microclimate parameters (air temperature, relative humidity, and wind speed) and ambient concentrations of CO_2, $PM_{2.5}$, and PM_{10} differ between Lecidere City Park and 5 de Maio City Park? (2) How do observed differences in vegetation structure, leaf morphology, and spatial configuration correspond to the measured microclimate and pollutant patterns at the two parks? Accordingly, the objective is to compare these environmental measurements and examine how their spatial variation relates to the contrasting vegetation and site settings. The study is intended to provide baseline evidence for context-sensitive green-space planning in Dili, while recognizing that concentration measurements alone do not quantify pollutant fluxes, deposition, or vegetation-driven removal.

2. Literature Review

2.1 Urban Green Infrastructure and Microclimate Regulation

Urban green spaces (UGS), encompassing public parks, botanical gardens, and linear vegetation corridors, serve as fundamental structural components of sustainable urban ecosystems (Demuzere et al., 2014; Gunawardena et al., 2017) . Within the framework of modern urban climatology, vegetation acts as a primary moderator of the surface-energy balance, directly counteracting the adverse thermal modifications induced by high fractions of impervious, heat-absorbing built surfaces (Almeida & Costa, 2022) . The cooling capacity of an urban park is predominantly driven by two biophysical mechanisms: solar radiation interception through canopy shading and enhanced latent heat flux via plant evapotranspiration (Bowler et al., 2010; Yan et al., 2018).

Recent empirical investigations underscore that the spatial configuration, dimensional scale, and internal structural complexity of urban parks dictate their thermal regulation efficiency (Geng et al., 2022; Ziter et al., 2019) . As demonstrated by Pereira *et al.* (2025) , heterogeneous canopy structures and well-distributed green patches generate localized cooling islands that diffuse outward, significantly lowering ambient air temperatures and improving outdoor thermal comfort for urban populations.

2.2 Urban Heat Island (UHI) Dynamics and Atmospheric Stress

The Urban Heat Island (UHI) phenomenon remains a critical environmental challenge in rapidly developing metropolitan areas, characterized by persistently elevated surface and atmospheric temperatures in urban cores compared to adjacent rural peripheries (Norton et al., 2015) . This thermal anomaly is exacerbated by anthropogenic heat emissions, high thermal admittance of construction materials, and the spatial deficit of natural vegetation.

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Microclimatic stability within the urban canopy layer is heavily dependent on the presence of green infrastructure to disrupt harsh solar radiation fluxes and wind flow patterns (Janhall, 2015) . Santoso *et al.* (2025) note that strategic integration of urban green spaces acts as a vital mechanism for microclimate regulation, effectively mitigating peak diurnal temperatures and dampening thermal stress gradients across densely built environments.

2.3 Bioremediation of Atmospheric Pollutants (CO2 and Particulate Matter)

Beyond thermal regulation, urban vegetation functions as a natural biological filter capable of modifying local air quality through gas exchange and particulate interception (Abhijith & Kumar, 2020; Hewitt et al., 2020) . Urban parks play an active role in the global carbon cycle by sequestering atmospheric carbon dioxide (CO2) via photosynthetic assimilation, storing carbon within woody and foliar biomass (Nowak & Crane, 2002) . The efficiency of carbon sequestration is tightly coupled with species selection, physiological growth rates, and canopy density (Escobedo et al., 2011) .

Concurrently, urban tree canopies intercept airborne particulate matter (PM2.5 and PM10) originating from vehicular exhaust and industrial combustion through dry deposition (Pugh et al., 2012; Selmi et al., 2016) . The morphological characteristics of leaf surfaces, such as cuticular waxes, trichomes (hairs), and surface roughness, greatly enhance particulate adhesion and retention (Corada et al., 2021; Saebo et al., 2012) . According to Kurniawan & Prasetyo (2024) , multi-layered vegetation structures combining high-density canopy trees, understory shrubs, and ground cover exhibit vastly superior particulate trapping and pollutant mitigation capacities compared to mono-layered or sparse green spaces (Barwise & Kumar, 2020; Vashist et al., 2024) .

2.4 Synthesis of Prior Research and Research Gap

Previous scholarly works have extensively documented the macro-level ecological benefits of urban green spaces (Almeida & Costa, 2022; Nadhifa et al., 2024; Nowak et al., 2014) . However, localized, high-resolution empirical assessments examining the micro-meteorological behavior and pollutant attenuation dynamics (CO2 and particulate matter) of specific tropical coastal urban parks, such as those operating under the distinct environmental pressures of Dili, Timor-Leste, remain exceptionally sparse. This study addresses this critical gap by systematically quantifying and comparing the microclimatic performance and pollutant concentrations between Taman Kota Lecidere and Taman Kota 5 de Maio, providing rigorous baseline evidence for tropical urban climate resilience.

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3. Research Method

The research is conducted in two primary urban green spaces situated within the core metropolitan area of Dili, Timor-Leste: Taman Kota Lecidere and Taman Kota 5 de Maio, both experiencing high anthropogenic pressure from surrounding arterial roadways. A comparative observational network is established across distinct micro-zones within each park, comparing core interiors under dense canopy versus peripheral boundaries adjacent to traffic corridors. To meet rigorous environmental monitoring standards, high-precision portable digital sensors and data loggers are utilized across standardized diurnal intervals encompassing morning (07:00–09:00), midday (12:00–14:00), and afternoon (16:00–18:00) phases over a systematic sampling campaign. Microclimate parameters, including air temperature and relative humidity, are measured using calibrated digital thermo-hygrometers, while wind velocity is recorded via portable digital anemometers. Atmospheric pollutants, specifically carbon dioxide (CO2), are recorded in parts per million using non-dispersive infrared monitors, and mass concentrations of fine particulate matter (PM2.5 and PM10) are measured via laser-scattering particulate monitors. Furthermore, vegetation metrics involving canopy closure estimation and classification of leaf surface morphology, such as waxy or hairy textures favoring particulate interception, are evaluated following standardized urban forestry methodologies (Abhijith & Kumar, 2020; Vigevani et al., 2024) .

In accordance with quantitative environmental data processing standards, raw observational data undergo rigorous quality control filtering prior to statistical evaluation. Descriptive metrics such as means and standard deviations, alongside comparative evaluations utilizing Mann-Whitney U tests or independent sample t-tests, are executed to examine significant variations in pollutant attenuation and microclimatic cooling efficiency between Lecidere and 5 de Maio parks across different diurnal phases.

The successful execution of this methodology will yield comprehensive high-resolution datasets detailing spatial-temporal gradients of temperature, humidity, CO2, and particulate matter within core tropical urban parks. Additionally, this study will provide empirical quantification of vegetative buffer efficiency in mitigating vehicular emissions and local thermal stress under Dili's coastal-urban climate conditions, while delivering actionable insights for municipal planners to optimize green infrastructure layouts for urban climate adaptation and air quality enhancement.

4. Result

4.1 Dynamics of Spatial-Temporal Variations in the Urban Microclimate

Measurements of microclimate parameters at two major green open spaces (RTH) in Dili, 5 de Maio City Park (inner-city area) and Lecidere City Park (coastal area), revealed

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diurnal dynamics that closely align with solar radiation patterns and the influence of microgeographic location. Based on observational data from September 2026, both parks recorded their lowest air temperatures in the morning (7:00–9:00 a.m.) within a range of 23.0–27.5 °C, with high relative humidity ranging from 73–88%. As solar radiation intensity increased, air temperatures peaked at midday (12:00–13:00), reaching 30.0–32.5 °C, which simultaneously lowered relative humidity to its lowest levels of 51–65%. A key aspect of this dynamic is the presence of a microclimatic cooling effect, as evidenced by variations among observation points within each park.

At 5 de Maio City Park, Point 3 (-8.55504, 125. 57065), located in the park's interior under a dense canopy of trees, consistently recorded air temperatures 0.5–1.2 °C lower and humidity levels 2–5% higher than Point 2 (-8.55195, 125.57870), which borders a paved highway. Meanwhile, at Lecidere City Park, Point 2 (-8.54933, 125.58425), which is closest to the shoreline, recorded the highest relative humidity (reaching 88% in the morning and 65% in the afternoon) as well as the highest wind speed (17–22 km/h or 4.8 m/s in the afternoon). The sea breeze in Lecidere proved effective in moderating the thermal load of the coastal environment, although solar radiation penetration in open, sandy areas kept daytime temperatures in the range of 30.0–31.5 °C.

Table 1. Average Microclimate Parameters and Comparative Air Quality Among Parks

Locations & Points	Morning/Afternoon Temperature (°C)	Daytime Humidity (%)	Wind Speed (m/s)	Peak CO2 (ppm)	PM2.5 Peak (µg/m³)
May 5 - Q1 (Indoor)	26.5 / 31.3	58%	2.9	432	19.2
May 5 - T2 (Roadside)	26.8 / 31.5	56%	3.4	440	21.0
May 5 - T3 (Rindang)	26.2 / 30.8	60%	2.5	424	16.8
Lecidere - T1 (Central Park)	26.8 / 31.6	56%	3.8	435	19.8
Lecidere - T2 (Beach)	27.1 / 31.6	62%	4.5	438	18.7
Lecidere - T3 (Eastern Corridor)	26.5 / 31.0	58%	3.1	427	17.2

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4.2 Analysis of Vegetation Structure Characteristics and Canopy Typology

The thermal regulation capacity and phytoremediation of air pollutants in both green spaces are significantly influenced by their species composition and canopy architecture. Based on the field vegetation inventory sheet, 5 de Maio City Park is dominated by large tree species with a dense canopy, such as the Trembesi tree (*Samanea saman*), which reaches a height of 10–14 m and has a diameter at breast height (DBH) ~220 cm, as well as massive Beringin trees (*Ficus benjamina*) with heights of 15–20 m and a DBH of ~1370 cm. The vegetation structure at 5 de Maio forms a multi-layered canopy stratification that effectively blocks direct solar radiation and provides a very large leaf area index (LAI) to capture fine particulate matter.

In contrast, Lecidere City Park features a more open coastal vegetation type dominated by Katapang trees (*Terminalia catappa*) with sparse canopies (height 10–15 m, DBH 90 cm), the Waru tree (*Hibiscus tiliaceus*) with a dense canopy and hairy leaf surfaces (height 5–10 m, DBH 150 cm), Mahogany (*Swietenia macrophylla*), and Sonokembang (*Pterocarpus indicus*). The presence of hairy leaves on *Hibiscus tiliaceus* in Lecidere constitutes a morphological advantage for particulate trapping, although the overall canopy density of this park is lower than that of 5 de Maio due to its linear layout along the coastline.

Table 2. Inventory of Dominant Species and Morphological Characteristics of Leaves in the Dili Green Open Space

Species Name / Park	Latin Name	High Estimate	DBH (cm)	Canopy Density	Leaf Morphology
Trembesi (May 5)	*It's the same*	10–14 years	220 cm	Close	Simple / Compound
Beringin (May 5)	*Ficus benjamina*	15–20 m	1370 cm	Very Close	Smooth / Characteristics of Candles
Squirrel-Tailed Palm (May 5)	*Wodyetia bifurcata*	3–6 m	40 cm	Rarely	Smooth
Manila (May 5)	*Adonidia merrillii*	3–5 m	100 cm	Rarely	Smooth
Katapang (Lecidere)	*Terminalia catappa*	10–15 m	90 cm	Rarely	Fine / Wide
Waru (To Harm)	*Hibiscus tiliaceus*	5–10 m	150 cm	Close	Berbulu (Pubescent)
Mahoni (Lecidere)	*Swietenia macrophylla*	15–20 m	160 cm	Currently	Smooth

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Sonokembang (Lecidere)	*Pterocarpus indicus*	5–10 m	40 cm	Currently	Smooth

4.3 Dynamics of Atmospheric Pollutant Attenuation (CO2, PM2.5, and PM10)

Concentrations of atmospheric pollutants in both parks showed a very strong correlation with the patterns of anthropogenic activity and vehicle traffic volume in the surrounding corridor. Unlike temperature, which peaks during the day, concentrations of carbon dioxide (CO2) and fine particulate matter (PM2.5 and PM10) actually reached their highest levels in the morning (7:00–9:00 a.m.) and in the afternoon (4:00–6:00 p.m.). This bimodal peak phenomenon directly coincides with the rush hours of motorized vehicle traffic (motorcycles, cars, and minibuses) experiencing traffic congestion or idling near the observation points.

At 5 de Maio City Park, CO2 concentrations in the afternoon reached 430–460 ppm at Point 2 (an area along the main road with moderate-to-heavy traffic), while at Point 3 (a shaded interior area), CO2 concentrations were lower, ranging from 412 to 425 ppm. This demonstrates CO2 uptake by vegetation through photosynthetic assimilation as well as the creation of a buffer zone from emission sources. Similarly, PM2.5 and PM10 concentrations peaked in the afternoon (PM2.5: 18–24 μg/m^3; PM10: 10–14 μg/m^3) at Point 2 (5 de Maio) and Point 3 (Lecidere). During the day, PM2.5 concentrations dropped to 8–13 μg/m^3 in both parks. This daytime decrease was caused by an increase in planetary boundary layer height and thermal convection, which accelerated the dispersion of pollutants into higher atmospheric layers.

5. Discussion

The comparison of 5 de Maio City Park and Lecidere City Park indicates that local microclimate and measured pollutant concentrations varied across observation points with different vegetation and exposure settings. The findings are best interpreted as site-specific spatial associations rather than direct tests of vegetation-driven cooling or pollutant removal. This distinction is important because shading, evapotranspiration, deposition, and ventilation are plausible mechanisms, but the measurements reported here do not isolate their individual contributions.

5.1. Microclimate patterns and park setting

At 5 de Maio, the reported interior point beneath a dense canopy was approximately 0.5–1.2 °C cooler and 2–5 percentage points more humid than the roadside point. The site-level contrast is consistent with the potential role of canopy shade in modifying near-

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ground thermal conditions. A systematic review by Norouzi et al. (2024) similarly identifies tree cover, vegetation composition, park configuration, surrounding urban form, and wind conditions as important factors shaping park cooling performance. In Lecidere, the coastal point recorded comparatively higher humidity and wind speed, suggesting that the park's exposure to coastal airflow may be relevant to its local microclimate.

These patterns should not, however, be attributed to canopy structure or sea-breeze circulation alone. The study does not report direct measurements of solar radiation, surface temperature, evapotranspiration, or a matched non-vegetated reference site, and the manuscript does not present a statistical model that separates vegetation effects from differences in site exposure. The observed contrasts therefore support the interpretation that park microclimates vary with local configuration, but they do not establish the magnitude of cooling attributable to any single mechanism. The reported ranges in the Results should also be reconciled with the averages in Table 1 before the strength of the contrast is discussed quantitatively.

5.2. Pollutant concentrations: source proximity, dispersion, and deposition

At 5 de Maio, the roadside point recorded a higher peak CO_2 concentration than the shaded interior point in the values reported in Table 1 (440 versus 424 ppm). The same table reports a higher $PM_{2.5}$ peak at the roadside point than at the shaded point (21.0 versus 16.8 $\mu g/m^3$). These differences are consistent with the possibility that source proximity, local airflow, and vegetation configuration jointly shape measured concentrations. They do not, by themselves, demonstrate that trees removed CO_2 or particulate matter: traffic volume was not quantified in the reported results, no background monitoring location is presented, and the statistical significance of the point-to-point differences is not reported.

The distinction between concentration and removal is especially important for interpreting CO_2. Lower ambient CO_2 at an interior point cannot be treated as direct evidence of photosynthetic uptake or carbon sequestration because concentration also varies with emission sources, atmospheric mixing, and wind. Establishing a carbon-sink function would require additional evidence, such as measurements or estimates of carbon stocks, biomass change, or CO_2 exchange fluxes. The current results support a comparison of ambient CO_2 readings across locations, not a quantitative claim about the parks' carbon sequestration capacity.

The vegetation inventory notes differences in canopy structure and leaf morphology, including the pubescent leaves of Hibiscus tiliaceus in Lecidere. These traits provide a plausible basis for future investigation, since particulate deposition and retention can vary with leaf roughness, hairiness, wax content, canopy structure, and the likelihood of resuspension or wash-off (Lindén et al., 2023). However, the study does not report

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particulate loading on leaves, deposition fluxes, or a direct comparison of leaf-level retention. Reviews also emphasize that vegetation can affect particulate concentrations through both deposition and changes in dispersion, with outcomes depending on local airflow, source strength, and urban geometry (Diener & Mudu, 2021; Wang et al., 2024). Consequently, the present observations do not establish that Hibiscus tiliaceus is more effective at capturing $PM_{2.5}$ or PM_{10}, nor that the denser canopy at 5 de Maio functions as a proven particulate filter. Direct measurements are required to substantiate those mechanisms (Vigevani et al., 2024).

5.3. Implications for green-space planning and study limitations

For planning, the findings support a site-sensitive approach rather than a universal prescription for particular tree species. Dense shade may be valuable for thermal comfort in exposed urban areas, while maintaining adequate airflow near traffic corridors may also be important where pollutant accumulation is a concern. The literature cautions that vegetation effects on air quality are context-dependent: canopy placement can support deposition in some settings but can also restrict pollutant dispersion in others (Diener & Mudu, 2021; Wang et al., 2024). Accordingly, the proposed combination of dense canopy, varied leaf morphology, and coastal ventilation should be treated as a design hypothesis for further testing, not as an intervention already demonstrated to reduce pollution in Dili.

Several limitations constrain the interpretation. The results as presented do not provide sufficient information on the number of repeated measurements, uncertainty around site averages, or inferential test outputs to determine whether observed differences are statistically robust. Table 1 reports $PM_{2.5}$ but not PM_{10}, while the Results text provides PM_{10} values that are lower than the reported $PM_{2.5}$ range; these values require verification against the raw measurements before submission. In addition, the manuscript does not report direct traffic counts, background pollutant concentrations, wind direction, or leaf-deposition measurements. Future monitoring should use synchronized and replicated measurements across park interiors, road edges, and reference locations; document traffic and meteorological conditions; report variability and statistical results; and measure particulate accumulation on leaves if pollutant removal is a central claim. Such a design would allow future research to distinguish the relative contributions of source proximity, dispersion, and vegetation characteristics more reliably.

6. Conclusion

A comparison between Lecidere City Park and 5 de Maio City Park in Dili, Timor-Leste, examined spatial variations in microclimate and ambient pollutant concentrations

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in relation to their contrasting site settings and vegetation characteristics. The observations showed that air temperature, relative humidity, and wind speed varied across measurement points. At 5 de Maio, the shaded interior was reported to be 0.5–1.2 °C cooler and 2–5 percentage points more humid than the roadside location. At Lecidere, the coastal edge recorded comparatively higher humidity and wind speed. These patterns indicate that environmental conditions differ within and between the two parks, although the observational design does not isolate the contribution of any single mechanism.

Ambient CO_2 and particulate concentrations also varied by measurement location. At 5 de Maio, the reported CO_2 readings were higher at the traffic-adjacent point than at the shaded interior point, while particulate concentrations varied across observation points in both parks. These differences are consistent with possible associations among source proximity, local airflow, and vegetation configuration, but they do not demonstrate that vegetation directly removed CO_2 or particulate matter. Likewise, the recorded canopy structures and leaf characteristics, including the pubescent leaves of Hibiscus tiliaceus at Lecidere, provide a basis for further investigation rather than proof of superior pollutant interception or retention.

The study therefore provides a preliminary, site-specific observational baseline for understanding microclimate and ambient pollutant patterns in two urban parks within a tropical coastal city. For green-space planning, the findings support attention to local exposure, shade, vegetation structure, and airflow rather than a universal prescription for particular species or canopy arrangements. Further research should use replicated and synchronized measurements, report statistical results and uncertainty, document traffic and wind conditions, and include reference locations. If pollutant removal is a central research claim, direct measurements of leaf-level particle loading or deposition and suitable measurements of CO_2 exchange or carbon storage will also be needed. These steps would allow subsequent studies to test the mechanisms suggested by the present observations more rigorously.

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