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Comparison of Microclimate Condition and Thermal Comfort Levels between Public and Private Green Open Space: A Case Study of Denggung Park and Gajah Mada University Wisdom Park

Perbandingan Kondisi Iklim Mikro dan Tingkat Kenyamanan Termal antara Ruang Terbuka Hijau Publik dan Privat: Studi Kasus Taman Denggung dan Taman Kearifan Universitas Gajah Mada

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ABSTRACT

Rapid urban population growth has driven extensive economic, residential, educational, and cultural development, leading to the conversion of green spaces into built-up areas. This conversion interferes with the regulations of air temperature and Thermal Humidity Index (THI). This research investigated the characteristics of green open spaces at Denggung Park and Gajah Mada University Wisdom Park, examining their effects on microclimate conditions and the relationship between green space conditions and THI levels. The methods included a literature review, field measurements of vegetation and microclimate variables, tree crown profile analysis using Sexl-FS, and Spearman Rank Correlation. Results showed that tree density has a direct relationship with THI. The private green space (Wisdom Park), with 126.33 trees/ha, achieved superior THI compared to the public space (Denggung Park), with 49.01 trees/ha. The Gajah Mada University Wisdom Park's more complex canopy structure and optimal canopy connectivity significantly enhanced THI. Spearman Rank Correlation analysis revealed strong relationships between the tree density and thermal comfort level for Denggung Park (-0.52) and for Gajah Mada University Wisdom Park (-0.69), with a p-value < 0.05. These findings confirm the critical importance of optimizing vegetation structure and density to support thermally comfortable urban environments.

INTISARI

Peningkatan populasi perkotaan yang pesat telah menjadi pendorong utama pembangunan ekonomi, perumahan, pendidikan, dan budaya yang signifikan, mengakibatkan konversi ruang hijau menjadi area terbangun. Penurunan vegetasi perkotaan ini terbukti berdampak negatif terhadap pengaturan suhu udara dan kenyamanan termal. Penelitian ini mengkaji karakteristik ruang terbuka hijau di Taman Denggung dan Taman Kearifan Universitas Gajah Mada, meneliti pengaruhnya terhadap kondisi iklim mikro dan hubungan antara kondisi ruang hijau dengan tingkat kenyamanan termal. Metodologi meliputi tinjauan literatur, pengukuran lapangan parameter vegetasi dan variabel iklim mikro, analisis profil tajuk pohon menggunakan Sexl-FS, dan pengujian Korelasi Rank Spearman. Hasil penelitian menunjukkan korelasi langsung antara kepadatan pohon dan kenyamanan termal. Ruang terbuka hijau privat (Taman Kearifan Universitas Gajah Mada) dengan kepadatan 126,33 pohon/ha menunjukkan kenyamanan termal superior dibandingkan ruang terbuka hijau publik (Taman Denggung) dengan 49,01 pohon/ha. Struktur kanopi yang lebih kompleks dan konektivitas kanopi optimal di Taman Kearifan Universitas Gajah Mada secara signifikan meningkatkan kenyamanan termal. Analisis korelasi Rank Spearman mengungkapkan hubungan kuat antara kerapatan pohon dan level kenyamanan termal untuk Taman Denggung (-0,52) dan Taman Kearifan Universitas Gajah Mada (-0,69) dengan nilai $p < 0,05$. Temuan ini menegaskan pentingnya mengoptimalkan struktur dan kepadatan vegetasi untuk mendukung lingkungan perkotaan yang nyaman secara termal.

Introduction

The decrease in green urban areas has resulted from the conversion of green spaces into built-up areas. Urban areas are home to more than half of the world's population, which is likely to grow rapidly (Zhao et al. 2024). People move to cities to improve their quality of life, driven by factors such as infrastructure, jobs, education, economic growth, and social development (Rochner et al. 2025). Urbanization exacerbates resource and environmental problems due to increased population and built-up areas while also intensifying the formation of urban heat islands (UHIs), which impact the surrounding area. Urbanization is likely to increase land surface temperatures in most parts of the world, particularly in developing countries (Kikon et al. 2023). Rapid urban development has transformed large areas of vegetation cover into impermeable surfaces, profoundly altering the atmospheric and climatic conditions within cities (Mu et al. 2023).

Population concentration in certain areas, combined with industrial and trading activities and dense urban transportation, has led to thermal pollution that contributes to the formation of heat islands. This heat island occurs due to heat emissions reflected from the Earth's surface into the atmosphere. The decrease in green space, intensified development, and competition for spatial resources further complicate this process (Yang et al. 2024). Green open space management is a systematic and integrated effort to maintain the function of these areas and prevent environmental damage. It includes planning, utilization, regulation, maintenance, monitoring, and law enforcement (Sucahyo & Fanida 2021). Effective green space management directly influences the quality and quantity of vegetation, strengthens urban institutional strategies, and affirms the difficulty of achieving tangible results in practice. Effective green space management can be achieved through educational campaigns, community outreach programs, and public awareness initiatives emphasizing the urgency and importance of climate change mitigation. Furthermore, policymakers should prioritize the perceived benefits of urban forests in addressing climate change (Maleknia & Salehi 2024).

According to Law No. 11/2020, as amended by Law No. 2/2022 on Job Creation, the green open space should constitute at least 30% of the city area, with 20% designated as public open space areas and 10% as private open space areas. The 10% allocation for the private space is divided into three categories: yard, park, and road. Public open spaces include city parks, green lanes, river borders, sports fields, urban forests, and cemetery parks. In contrast, private open spaces comprise gardens, homes, and building yards owned by the community or private sector and cultivated with vegetation. The required green open space is 20 m² per resident, as determined by the Minister of Public Works' Regulation No. 05/PRT/M/2008 on the Guidelines for the Provision and Utilization of Green Open Space in Urban Areas.

The development of built-up areas and a relatively high population density influenced the UHI in Yogyakarta (Handayani et al. 2024). As of 2023, the population of Sleman Regency was 1.2 million (Statistics Sleman Regency 2024). Despite Sleman Regency spanning 14,701 ha, the proportion of urban green space remained far below the environmental standard. Public green space accounted for only 9.70% of the target of 20% (Razak 2023). To address this shortfall, the Sleman Regency Government, through Regional Regulation No. 13/2021 concerning the Sleman Regency Spatial Plan for 2021–2041, promoted the development of urban green open spaces to meet the 30% minimum requirement. Based on observation, Denggung Park is one of the public green spaces in Sleman Regency. Managed by the Government, it functions as both a public green space and the official welcome park for the region. In contrast, certain institutions or individuals own private green open spaces and serve as limited-access facilities. These include gardens and courtyards planted with vegetation on residential or institutional properties. The Gadjah Mada University Wisdom Park becomes a prominent example of a private green open space in Sleman Regency. As an educational facility, Gadjah Mada University Wisdom Park falls under the Park category (Hermawan et al. 2018).

Microclimate elements such as temperature, humidity, solar radiation, and wind greatly affect environmental conditions. Topography, land surface three-dimensional objects, and thermal radiation

from particular objects influence these factors (Tjasyono 2004). Microclimate data, including temperature and humidity, can serve as a reference to determine the level of THI using the Thermal Humidity Index (THI). In this research, the differences in public and private green space management serve as the basis for identifying more effective approaches to green open space development. Therefore, this research aimed to compare tree density in Denggung Park and Gadjah Mada University Wisdom Park, their effect on microclimate conditions, and the relationship between tree density and thermal comfort level.

Methods

The research occurred in October at Denggung and Gadjah Mada University Wisdom Park. These locations represented public and private green spaces, respectively. Denggung Park (Figure 1) was a city park with high activity levels, as indicated by data from the Sleman Regency Environmental Service. Gadjah Mada University Wisdom Park (Figure 2) was a private green open space that remains accessible to the public

and offers free entry. It served as a physical facility supporting the needs and activities of Gadjah Mada University Residence residents, the academic community, and the general public. This research combined literature reviews to determine the typology of green open spaces and direct field surveys to assess tree species, air temperature, relative humidity, and wind speed in the selected areas.

Tree Community Structure

The tree community structure was measured by inventorying individual trees at each location with a Diameter at Breast Height (DBH) greater than 20 cm. The assessment included individual density (Equation 1-2), species dominance (Equation 3), Index of Important Value (Equation 4), and species diversity (Equation 5). Species dominance was calculated from the Index of Important Value (INP) from Indriyanto (2006) by summing the relative density, dominance, and frequency. As this research employed a census method, the relative frequency value could not be obtained and was therefore excluded from the INP calculation. A high INP value signified the most dominant species within the green space.

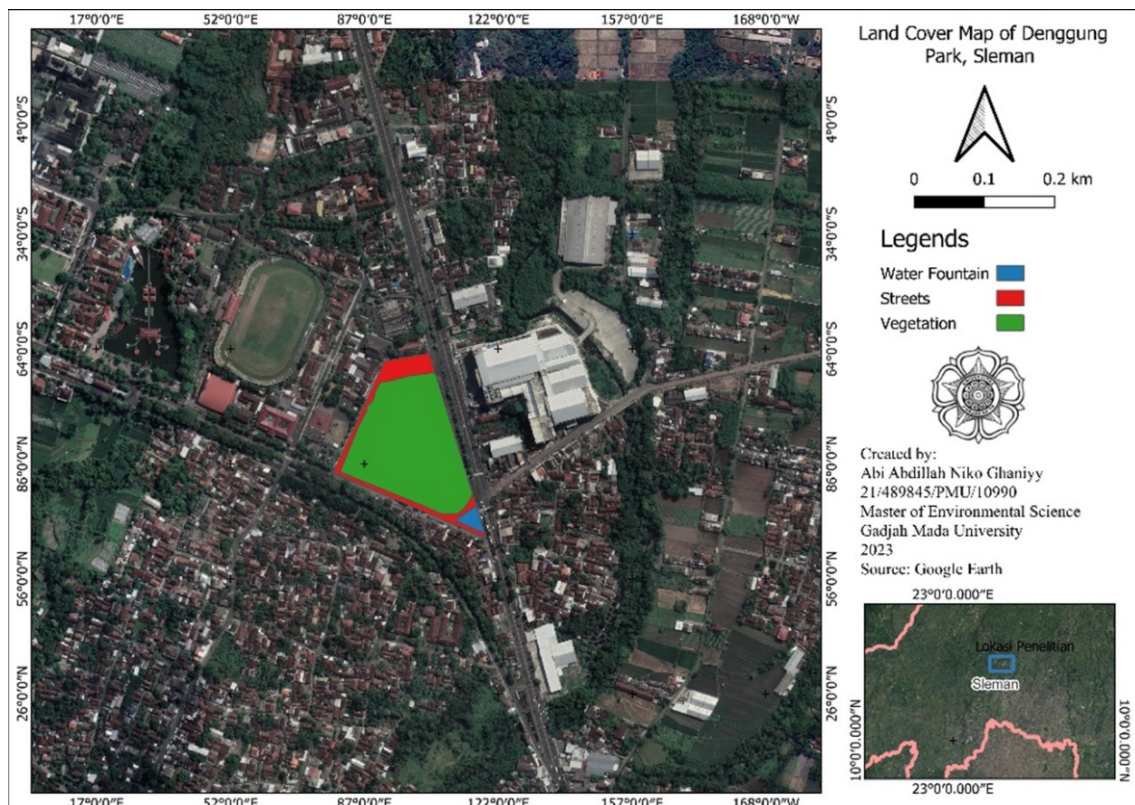


Figure 1. Research location of Denggung Park

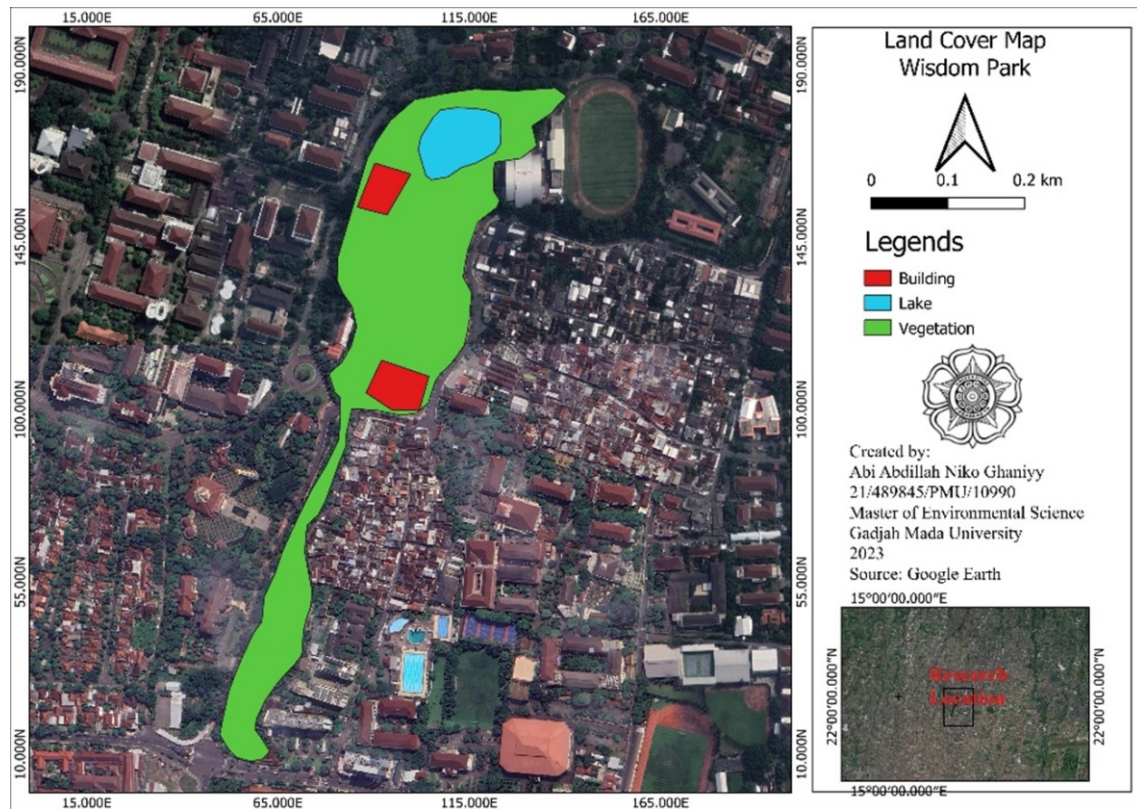


Figure 2. Research location of Gadjah Mada University Wisdom Park

The calculation of each parameter used the following equations.

1. Density (trees/ha)

$$\text{Species Density (K)} = \frac{\text{Number of individuals of a species}}{\text{Observation area}} \dots\dots \text{Equation (1)}$$

$$\text{Relative Density (KR)} = \frac{\text{Density of species}}{\text{Total density of all species}} \times 100\% \dots\dots \text{Equation (2)}$$

2. Domination (m^2/ha)

$$\text{Species Dominance (D)} = \frac{\text{Basal area of a species}}{\text{Observation area}} \dots\dots\dots \text{Equation (3)}$$

$$\text{Relative Dominance (KR)} = \frac{\text{Dominance of species}}{\text{Total dominance of all species}} \times 100\% \dots\dots \text{Equation (4)}$$

3. Importance Index

Index of Importance Value (INP) = Relative density + Relative dominance

4. Diversity Index

To determine the diversity of species, the Shannon index was used with the following formula (Ludwig & Reynolds 1988).

$$\hat{H} = -\sum_{i=1}^s \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right] \dots\dots\dots \text{Equation (5)}$$

Profile Diagram

Data was collected using three plots for each research location. The plot size was 20 m x 20 m or 400 m^2 , allowing a structured approach to studying a set number of trees. Within the plots, DBH, tree height, and crown shape were measured using a diameter tape, a haga altimeter, and a compass. A camera was used to document the physical characteristics of trees and the study area visually. The Tree Identifier Application helped in identifying tree species based on various characteristics. Relevant stationery was used for note-taking during the data collection process. The development of the profile diagram used the SexI-FS software version 2.1.0.

Microclimate

Microclimate parameters, including air temperature, relative humidity, and wind speed, were collected at purposively selected sample points to represent both shaded and unshaded areas, thereby minimizing bias from buildings. Air temperature (Equation 6) and relative humidity (Equation 7) were measured using a calibrated sling psychrometer, while an anemometer determined wind speed (Equation 8). Temperature,

defined as a physical measure of heat content, signifies the thermal state of an object, where higher values correspond to hotter conditions. Measurements were taken over 10 minutes at each point, three times daily, to represent average values for three consecutive days. Data were processed using the formulas by Tjasyono (2004).

$$T = \frac{T_1 + T_2 + T_3}{3} \dots\dots\dots \text{Equation (6)}$$

Remarks: T = daily average air temperature (°C); T₁ = air temperature in the morning (time range 07.00–08.00); T₂ = air temperature during the day (time range 12:00–13:00); T₃ = air temperature in the afternoon (time range 16.00–17.00).

$$RH = \frac{RH_1 + RH_2 + RH_3}{3} \dots\dots\dots \text{Equation (7)}$$

Remarks: RH = daily average relative humidity (%); RH₁ = relative humidity in the morning (time range 07.00–08.00); RH₂ = relative humidity during the day (time range 12:00–13:00); RH₃ = relative humidity in the afternoon (time range 16.00–17.00).

$$W = \frac{W_1 + W_2 + W_3}{3} \dots\dots\dots \text{Equation (8)}$$

Remarks: W = daily average wind speed (m/s); W₁ = wind speed in the morning (time range 07.00–08.00); W₂ = Wind speed during the day (time range 12:00–13:00); W₃ = wind speed in the afternoon (time range 16.00–17.00).

Thermal Humidity Index (THI)

The THI calculation examined the THI characteristics of green open spaces concerning vegetation cover (Equation 9). According to the Directorate General of Spatial Planning, vegetation refers to the entire plant life in an area, whether natural or introduced from outside. Trees and vegetation in these areas enhanced comfort by reducing air temperature and increasing surrounding air humidity. Comfort levels were determined quantitatively using the comfort index, which incorporated air temperature and relative humidity as parameters (Nieuwolt 1975).

$$THI = 0.8T + (RH \times T) \div 500 \dots\dots\dots \text{Equation (9)}$$

Remarks: T = air temperature (°C); RH = relative humidity (%).

The calculation formula produced a comfort level classification according to Nieuwolt (1975) for tropical low-latitude areas. Hermawan et al. (2018) modified this classification and applied it to tropical areas (Table 1).

Statistical Analysis

The influence of green spaces on the microclimate was analyzed using descriptive statistics, Independent Samples T-tests, and Spearman Rank Correlation (Chang et al. 2023). Data analysis was performed using the IBM SPSS version 23.0 software. Levene's test became a prerequisite before conducting an independent T-test to evaluate the homogeneity of variance among samples for each variable, such as temperature, wind speed, and humidity. Levene's test examines the hypothesis of whether the variances of the data are homogeneous (H₀) or heterogeneous (H₁), with a significance level of $\alpha > 0.05$ indicating homogeneous variance and $\alpha \leq 0.05$ indicating heterogeneous variance. The T-test for independent samples compared the microclimate variables, including air temperature, relative humidity, and wind speed, between the two research locations. This test evaluated whether there was no significant difference in microclimate between the two locations (H₀) or there was a significant difference (H₁). The data analysis was conducted using a significance level of $\alpha > 0.05$, indicating no significant difference, and $\alpha \leq 0.05$, suggesting a significant difference. The Spearman Rank Correlation Analysis assessed the strength and direction of the relationship—whether positive (+) or negative (–)—between tree density and comfort level derived from THI (1 = cozy, 2 = quite comfortable, 3 = uncomfortable). The hypotheses considered were H₀ (there is no relationship between tree density and comfort level) and H₁ (there is a relationship between tree density and comfort level). If $\alpha > 0.05$, the null hypothesis (H₀) was accepted, while an $\alpha \leq 0.05$ or lower led to its rejection. This analysis used a 95% confidence level, with the correlation coefficient interpretation provided in Table 2.

Table 1. Comfort Level Classification Based on THI

THI	Comfort Level Classification
< 27	Cozy
27-29	Quite comfortable
> 29	Uncomfortable

Table 2. Interpretation of Spearman Rank Correlation

Coefficient	Relationship Strength
0.00	No relationship
0.01 - 0.09	Meaningless relationship
0.10 - 0.29	Weak relationship
0.30 - 0.49	Moderate relationship
0.50 - 0.69	Strong relationship
0.70 - 0.89	Very strong relationship
>0.90	Near perfect relationship

Source: Correlation Coefficient Interpretation according to De Vaus (2002)

Result and Discussion

Type and Typology

The Denggung Park and Gadjah Mada University Wisdom Park fall into the "park" category of green open spaces (Table 3). Each location featured intentionally planted vegetation that creates a structured layout for specific purposes, representing a non-natural green open space. The open spaces at both sites served ecological, socio-cultural, and aesthetic functions.

Denggung Park was a publicly owned urban green space managed by the Sleman Regency government through its Forestry and Environment Service Agency. The park's physical typology includes non-natural green spaces resulting from human intervention. Functionally, the park serves as a vital ecological feature, acting as the lungs of the Sleman Regency, and supports socio-cultural interaction through community engagement. It also contributes to the visual character of the region as the welcome park of Sleman Regency. The structure of this green open space followed a planological pattern. Previous research has identified Denggung Park as a space for social interaction (Sadewa 2022), and an effective public facility (Wursita 2023).

Gadjah Mada University Wisdom Park was a green space owned and managed by Gadjah Mada University, specifically under the University Residence. It was classified as a park and remains accessible to the general public. Physically, the space was non-natural due to human intervention, and its functions include providing ecological benefits, such as one of Sleman Regency's green lungs, facilitating socio-cultural interactions, and enhancing the university's image through aesthetic value.

Vegetation Structure

The vegetation condition at the research site was assessed through a census to determine tree species composition, individual counts, and tree density, as summarized in Table 4. Furthermore, profile diagram was created for the tree's life levels at each green open space to obtain crown closure levels. Analysis of vegetation structure and biodiversity between the two locations revealed significant ecological differences. Wisdom Park demonstrated superior biodiversity metrics, with a Shannon diversity index of 3.55, encompassing 66 species and a density of 126.33 trees/ha. In contrast, Denggung Park exhibited a Shannon diversity index of 2.43, with only 30 species and 49.01 trees/ha.

A single species, Glodokan Tiang (*Polyalthia longifolia*), dominated the vegetation structure in Denggung Park. This species exhibited the highest density (19.22 trees/ha), dominance (5.79 m²/ha), and Importance Value Index (68.02). Conversely, Wisdom Park demonstrated a more balanced distribution pattern, with Broadleaf Mahogany (*Swietenia macrophylla*) recording the highest density (11.5 trees/ha) and highest Importance Value Index (18.14). At the same time, White Teak (*Gmelina arborea*) showed the highest dominance (1.52 m²/ha). This pattern reflected fundamentally different ecosystem dynamics between the two green spaces. Wisdom Park supported more complex plant communities,

Table 3. Types and typologies of green open spaces in the research location

No.	Name	Type	Typology			
			Physical	Function	Structure	Ownership
1	Denggung Park	City park	Non-natural green space	Ecological, Socio-cultural, Aesthetic	Planological Pattern	Public
2	Wisdom Park	Garden	Non-natural green space	Ecological, Socio-cultural, Aesthetic	Planological Pattern	Private

Table 4. Vegetation structure of Denggung Park and Gajah Mada University Wisdom Park

Vegetation Structure	Location	
	Denggung Park	Wisdom Park
Number of tree species	30	66
Tree density (trees/ha)	49.01	126.33
Diversity index	2.43	3.55
Tree species with the lowest density	Belimbing Wuluh (<i>Averrhoa bilimbi</i>), Biola Cantik (<i>Ficus lyrata</i>), Burahol (<i>Stelechocarpus burahol</i>), Cempaka (<i>Magnolia macrophylla</i>), Jambu air (<i>Syzygium aqueum</i>), Rubber (<i>Ficus elastica</i>), Butterfly (<i>Bauhinia purpurea</i> L.), Luwingan (<i>Ficus hispida</i>), Small leaf Mahogany (<i>Swietenia mahagoni</i>), Mundu (<i>Garcinia dulcis</i>), Nagasari (<i>Mesua ferrea</i>), Sawo Bludru (<i>Chrysophyllum cainito</i>), Soursop (<i>Annona muricata</i>).	<i>Pterocarpus indicus</i> , <i>Averrhoa bilimbi</i> , <i>Camptotheca acuminata</i> , <i>Tectona grandis</i> , <i>Senna siamea</i> , <i>Cananga odorata</i> , <i>Dipterocarpus littoralis</i> , <i>Eucalyptus deglupta</i> , <i>Pterygota alata</i> , <i>Azadirachta indica</i> , <i>Morus alba</i> , <i>Calophyllum inophyllum</i> , <i>Pinus merkusii</i> , <i>Azalia xylocarpa</i> , <i>Bombax ceiba</i> , <i>Kleinhovia hospita</i> , <i>Entelea arborescens</i>
Tree species with the highest density	Glodokan Tiang (<i>Polyalthia longifolia</i>)	Broadleaf mahogany (<i>Swietenia macrophylla</i>)
Tree species with the lowest dominance	Burahol (<i>Stelechocarpus burahol</i>)	Angsana (<i>Pterocarpus indicus</i>), Belimbing wuluh (<i>Averrhoa bilimbi</i>)
Tree species with the highest dominance	Glodokan tiang (<i>Polyalthia longifolia</i>)	White teak (<i>Gmelina arborea</i>)
Tree species with the lowest INP	Burahol (<i>Stelechocarpus burahol</i>)	Angsana (<i>Pterocarpus indicus</i>), Belimbing wuluh (<i>Averrhoa bilimbi</i>)
Tree species with the highest INP	Glodokan tiang (<i>Polyalthia longifolia</i>)	Broadleaf mahogany (<i>Swietenia macrophylla</i>)

Source: Primary Data 2023

potentially providing a more comprehensive range of ecosystem services, including biodiversity conservation, carbon sequestration, and enhanced microclimate regulation, compared to Denggung Park.

Profile Diagram

The spatial distribution of trees in Denggung Park exhibited vertical stratification and clear groupings in certain parts of the green open space while exhibiting sparse arrangements elsewhere, as evidenced by the analysis of crown profile diagrams (Figure 3). This uneven arboreal configuration manifested in discontinuous canopy profiles across the landscape, with some areas showing a multilayered and overlapping canopy structure of varying heights and diameters, while other areas showed individuals occurring in isolation with considerable gaps between canopies. Quantitative assessments of canopy profile diagrams revealed suboptimal horizontal connectivity and insufficient vertical stratification diversity throughout the park, disrupting essential ecosystem functions, including microclimate regulation, habitat provision, and aesthetic

coherence. The disjunctive nature of crown projection areas creates substantial differences in light transmission, resulting in heterogeneous understory conditions that affect plant community development and visitor THI. The implications extend to reduced ecological resilience, as analysis of crown profiles reveals insufficient structural complexity to support diverse trophic interactions.

The profile diagram of Wisdom Park indicated a balanced spatial distribution of trees, exhibiting optimal horizontal continuity and vertical stratification patterns (Figure 4), with even coverage of crown projections and suitable inter-crown spacing that facilitated crown connectivity and adequate light penetration to understory vegetation. The vertical profile revealed a multi-layered canopy structure comprising crown, canopy, sub-canopy, and understory components, creating a complex three-dimensional arrangement that optimized ecological function and microclimate regulation. Species composition analysis, derived from crown profile diagrams, documented significant taxonomic diversity, with a range of crown architectures, leaf phenologies, and growth forms contributing to

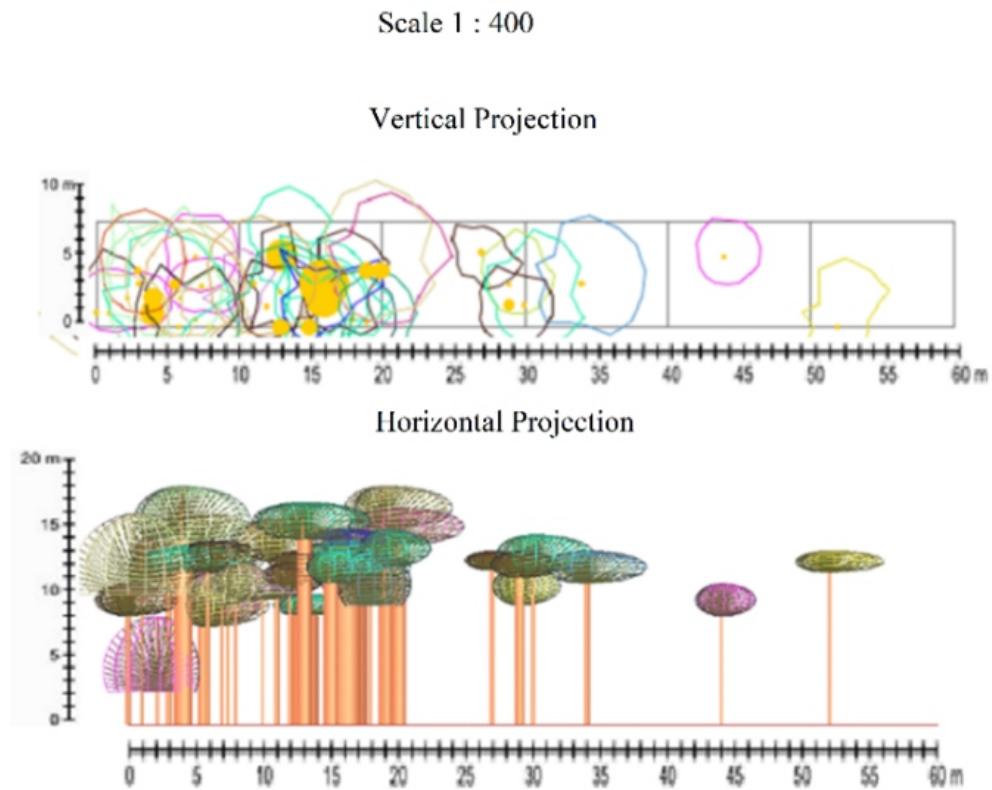


Figure 3. Profile diagram of Denggung Park

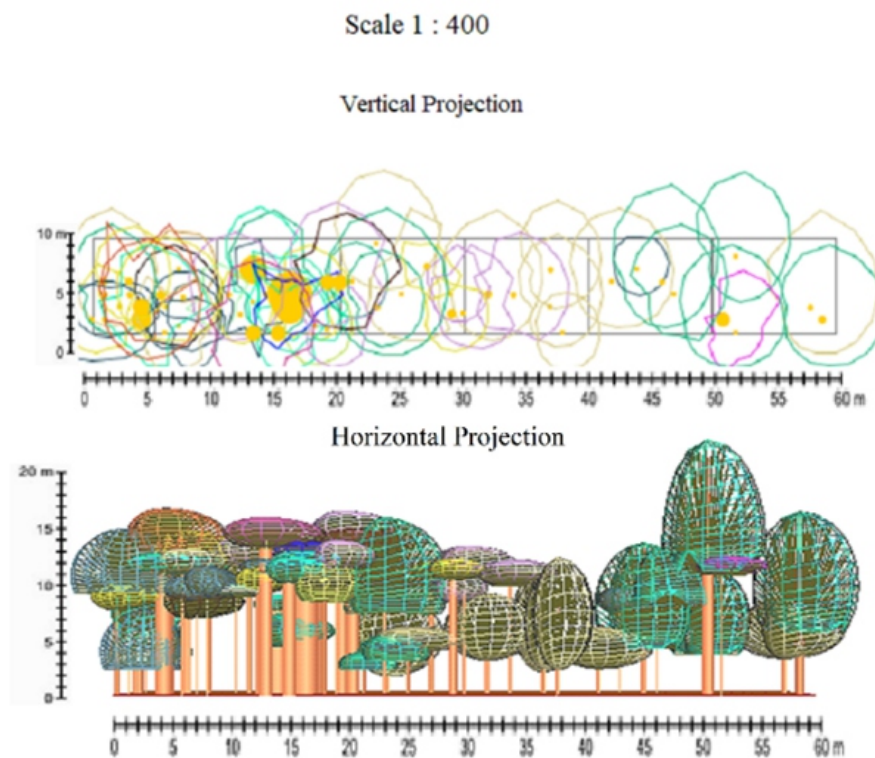


Figure 4. Profile diagram of Gadjah Mada University Wisdom Park

structural heterogeneity and enhanced ecosystem resilience. This balanced arboreal configuration, as evidenced in the crown profile visualizations, promoted uniform shade distribution across the park landscape, creating a thermally comfortable microclimate for visitors while supporting biodiversity through habitat diversification, optimal rainwater sequestration, and effective carbon sequestration.

Microclimate Condition

Vegetation and microclimate conditions of green open spaces influenced their THI. Higher tree density corresponded to more comfortable thermal conditions, as evidenced by lower THI values. Table 5 indicated that Wisdom Park could provide a THI value of 24.62 (cozy) with the highest tree density of 126.33 trees/ha. The public-managed green open space, Denggung Park, was insufficient to create THI during the daytime. Meanwhile, several observation points at the privately managed Wisdom Park could create moderately comfortable thermal conditions during the daytime. Both green open spaces at Denggung Park and Wisdom Park successfully created cozy thermal conditions in the morning, but uncomfortable thermal conditions in the afternoon.

Comparison of Microclimate Conditions

Levene's Test for Variance Homogeneity

The homogeneity of variance test carried out using Levene's test on temperature, humidity, and wind speed showed $\alpha > 0.05$ (Table 6). This result led to the rejection of the null hypothesis, and that the variance between groups is homogeneous. Levene's test results showed that the homogeneity of variance ($p > 0.05$) had positive implications for the validity and reliability of the independent samples T-test, which was applied to all variables. This test employed a pooled variance estimate, which yields a more precise standard error and enhances the statistical power to detect differences between groups. This condition enabled the use of optimal degrees of freedom, which utilize all information from both samples, resulting in more accurate confidence intervals and more reliable p-values, leading to strong statistical validity for research conclusions.

T-test for Mean Comparisons

The number of trees affected the temperature and humidity levels of the air around the park, thereby creating a microclimate that provides comfort in activities (Mariana & Warso 2016). The air temperature, relative humidity, and wind speed influenced the THI value in each green open space. Factors that affected microclimate conditions also

Table 5. Microclimate conditions of Denggung Park and Gadjah Mada University Wisdom Park

Microclimate Condition	Location	
	Denggung Park	Wisdom Park
Ownership of green space	Public green space	Private green space
Area (ha)	3.122	6.00
Lowest air temperature (°C)	24.75	25.75
Highest air temperature (°C)	34.25	35.25
Lowest air relative humidity (%)	46.00	47.00
Highest air relative humidity (%)	86.00	86
Lowest wind speed (m/s)	0.07	0.0
Highest wind speed (m/s)	2.83	4.6
Lowest THI	22.70	24.62
Highest THI	30.62	31.51

Source: Primary Data 2023

Table 6. Results of Levene's test for variance homogeneity

Variable	Denggung Park		Wisdom Park		df	F-value	Sig p-value
	n	Value ($\bar{Y} \pm s$)	n	Value ($\bar{Y} \pm s$)			
Temperature (°C)	18	29.60 $\pm$ 3.16	75	29.91 $\pm$ 2.94	2,91	.021	.884
Relative Humidity (%)	18	59.89 $\pm$ 12.46	75	64.39 $\pm$ 13.44	2,91	1.727	.192
Wind Speed (m/s)	18	1.03 $\pm$ 0.83	75	1.15 $\pm$ 1.25	2,91	3.738	.056

Remarks: n = number of observations; df = degree of freedom; * significant at $\alpha = 0.05$

indirectly influenced the THI value. Microclimate conditions differed between the two green open space locations. The T-test result also showed $\alpha > 0.05$. This rejection of the null hypothesis indicates a significant difference in temperature, humidity, and wind speed between the two research locations (Table 7). Gadjah Mada University Wisdom Park recorded lower temperatures, humidity, and wind speed than Denggung Park. Despite covering a larger area, Wisdom Park offered more favorable THI due to higher vegetation density. Denser tree cover limited solar radiation at ground level, reducing air temperature and increasing humidity through enhanced evapotranspiration (Aluyah & Rusdianto 2019). Variations in tree species also influenced microclimate regulation, as differences in shape, structure, color, and size affected performance (Rogi & Rombang 2016). Trees reduce wind speed by breaking up airflow, with effectiveness depending on factors such as height, shape, leaf density, and foliage arrangement.

Correlation between Tree Density and Comfort Level

The Spearman Rank correlation analysis examined the relationship between tree density and the comfort level in two urban green spaces. The analysis revealed significant negative correlations ($r = -0.51$ for Denggung Park and $r = -0.69$ for Gadjah Mada University Wisdom Park, with $p < 0.05$), as summarizes in Table 8. This negative correlation indicates that as tree density increases, the comfort level decreases, resulting in improved thermal

comfort as lower temperatures correspond to better thermal comfort. The relationship demonstrates that tree density serves as a crucial factor of comfort level in green open space, with Wisdom Park showing a stronger correlation compared to Denggung Park. These results suggested that tree density has a more pronounced effect on comfort level improvement in private green spaces, likely due to better vegetation management and more optimal spatial distribution. Both correlations are statistically significant and robust, with Wisdom Park showing a stronger association, indicating that higher tree density effectively contributes to enhanced comfort level. The strong relationships confirmed that tree density became a significant factor in creating favorable thermal conditions, though other environmental factors may also contribute to the overall comfort level.

The lower correlation value in Denggung Park is attributed to the irregular tree spatial distribution, as shown in Figure 3, which creates inconsistent shading patterns and thermal comfort zones throughout the public green space. This irregular spatial distribution reduces the predictive power of tree density on the comfort level, as areas with similar tree densities may experience different comfort levels depending on their specific location and tree spatial distribution patterns.

Meanwhile, in the Wisdom Park, the trees were more evenly distributed, resulting in more consistent shading patterns and uniform thermal comfort zones across the green space. This regular spatial distribution enhances the correlation between tree density and comfort level, as areas with similar tree

Table 7. Results of the T-test for all microclimate variables

Variable	Denggung Park		Wisdom Park		df	F-value	Sig p-value
	n	Value ($\bar{Y} \pm s$)	n	Value ($\bar{Y} \pm s$)			
Temperature (°C)	18	29.60 $\pm$ 3.16	75	29.91 $\pm$ 2.94	91	.399	.691
Relative Humidity (%)	18	59.89 $\pm$ 12.46	75	64.39 $\pm$ 13.44	91	1.303	.196
Wind Speed (m/s)	18	1.03 $\pm$ 0.83	75	1.15 $\pm$ 1.25	91	.391	.697

Remarks: n = number of observations; df = degree of freedom; * significant at $\alpha = 0.05$

Table 8. Results of Spearman Rank correlation test

Variable	Tree density (trees/ha)		Comfort Level		df	Spearman Rho Correlation	Sig p-value
	n	Value ($\bar{Y} \pm s$)	n	Value ($\bar{Y} \pm s$)			
Denggung Park	18	49.01 $\pm$ 3.41	18	1 = cozy, 2 = quite comfortable	16	-0.51	0.03
Wisdom Park	75	126.33 $\pm$ 2.46	75	3 = uncomfortable	73	-0.69	0.00

Remarks: n = number of observations; df = degree of freedom; * significant at $\alpha = 0.05$

densities tend to provide more predictable and comparable comfort levels. The strong correlations in both locations demonstrate that increasing tree density could become a reliable strategy for improving the thermal comfort of green spaces. The use of the categorical variables revealed that increases in tree density directly correspond to better comfort levels, effectively shifting conditions from the "uncomfortable" category to the "quite comfortable" or "cozy" categories.

Research consistently demonstrates the critical role of vegetation in urban green spaces through multiple interconnected mechanisms. Lestari (2023) establishes a statistically significant negative correlation between NDVI and thermal comfort ($p < 0.05$), where higher vegetation density substantially increases comfort levels while sparse vegetation results in thermal stress. The use of a categorical comfort level variable directly relates to user comfort perception, making the results more applicable for urban planning decisions. Urban development and vegetation reduction directly contribute to microclimate disruption and reduced thermal comfort (Rahardjo & Afrianto 2024), making city parks and green spaces vital as both microclimate regulators and urban "lungs" that maintain ecosystem balance through temperature and humidity control (Cahyaningprastiwi et al. 2021).

The effectiveness of vegetation in thermal regulation varies significantly based on species selection and spatial planning strategies (Rastkhadiv & Rahimi 2025), urban form and density configurations (Hami et al. 2019), leaf morphology characteristics (Zhang et al. 2018), and planting pattern arrangements. Notably, Sodoudi et al. (2018) found that green spaces positioned parallel to and against prevailing wind directions generate superior cooling effects, emphasizing that optimal comfort level enhancement requires integrated approaches considering vegetation density, species characteristics, spatial arrangement, and environmental factors such as wind patterns in urban planning and climate adaptation strategies. Relative humidity, wind speed, and air temperature significantly affected outdoor comfort levels (Sachindra & Nowosad 2022). However, wind speed significantly affected outdoor comfort levels by influencing how individuals perceive

temperature and overall comfort in outdoor environments (Hami et al. 2019). Wind speed became a crucial factor in determining outdoor THI, with its effects varying by climate and context. Although wind speed played a cooling role, its influence was often overshadowed by other environmental factors, particularly solar radiation.

Conclusion

In conclusion, Wisdom Park's private green open space had a superior comfort level compared to the public green open space of Denggung Park. The primary factor contributing to the enhanced comfort level was the tree density (126.33 trees/ha for Wisdom Park and 49.01 trees/ha for Denggung Park) and biodiversity (Shannon Index of 3.55 for Wisdom Park and 2.43 for Denggung Park). The THI values varied from a minimum of 22.7 (comfortable) to a maximum of 31.51 (uncomfortable), with comfortable conditions observed during morning hours at both locations. Denggung Park was insufficient to create a comfortable thermal condition during the daytime, while several observation points at Wisdom Park could create moderately comfortable thermal conditions during the daytime. The tree crown profile analyzed critical differences in vegetation distribution. Wisdom Park had a more connected, vertically stratified, multilayered canopy structure, while Denggung Park had a more heterogeneous and discontinuous spatial configuration. Spearman Rank correlation coefficients between tree density and comfort levels were -0.51 for Denggung Park and -0.69 for Wisdom Park ($\alpha < 0.05$). This negative correlation demonstrates that increased tree density led to improved thermal comfort levels, as evidenced by lower THI values in areas with higher tree density. This relationship suggests that urban planning strategies should prioritize increasing tree density and selecting effective tree species, such as Broadleaf Mahogany and White Teak, with broader canopies in public green spaces, rather than merely expanding the total area. Future research could consider investigating optimal tree species compositions and spatial arrangements to maximize comfort level in urban green spaces of varying sizes and contexts.

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