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The role of vegetation in enhancing thermal comfort in open spaces: a study on the impact of temperature and humidity

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ABSTRACT

Introduction: Thermal comfort in outdoor urban spaces is largely shaped by microclimatic elements like air temperature, humidity, and wind speed, all of which are strongly influenced by vegetation. This study investigates how vegetation, especially tree canopies and vegetative cover, affect microclimate regulation and contributes to thermal comfort in urban settings. **Methods**: The research was carried out at the IPB Arboretum on August 28, 2024, using observational techniques over a three-hour timeframe. Tools such as a digital thermohydrometer and a mini weather station were employed to measure temperature, humidity, and wind speed, while vegetation mapping was used to classify canopy density. **Findings**: The analysis found that trees like *Ficus benjamina* can significantly lower air temperature and raise humidity beneath their canopies through processes such as evapotranspiration and interception of solar radiation. Areas with dense, overlapping canopies were observed to have noticeably cooler and more humid conditions, while areas with minimal vegetation showed characteristics typical of the Urban Heat Island (UHI) phenomenon. However, statistical regression did not reveal a significant correlation between canopy cover percentage and temperature or humidity, implying that other variable—like human presence or surface materials—may also play important roles. **Conclusion**: These results underline the ecological value of vegetation in moderating urban microclimates. Although canopy density alone may not directly correlate with climate indicators, strategically placing vegetation in city planning remains crucial for reducing heat stress and improving environmental quality in urban open spaces. **Novelty/Originality:** The novelty of this research lies in its focused examination of how specific tree species and canopy densities influence thermal comfort in an urban arboretum setting, using real-time, on-site environmental measurements.

KEYWORDS: urban microclimate, vegetation cover, tree canopy, air temperature, green infrastructure.

1. Introduction

Climatological comfort in open spaces is greatly influenced by climatic elements, including air temperature, relative humidity, and wind speed. Vegetation plays a crucial role in creating environmental comfort, especially in densely populated urban areas. The presence of vegetation can affect various environmental aspects, such as air temperature, humidity, and air quality. Vegetation, particularly trees and green plants, provides a cooling

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effect through the process of evapotranspiration, where water evaporating from leaf surfaces helps lower the surrounding air temperature. Vegetation also offers shade, reducing direct exposure to solar radiation.

Additionally, vegetation has the ability to absorb air pollutants and produce oxygen, contributing to improved air quality. This leads to a reduction in surface and air temperatures, thereby enhancing thermal comfort in open spaces. Thermal comfort is defined as the human response to the sensation of heat or cold perceived by skin in relation to the surrounding air temperature, which in turn affects human activities (Karyono, 2001).

The determination of the comfort index is calculated based on the Temperature Humidity Index (THI), which combines air temperature and relative humidity, as developed by Nieuwolt in the form of an equation (Kakon et al., 2010). Relative humidity is also influenced by vegetation, as plants release water vapor into the atmosphere through the process of transpiration. This can increase air humidity, which is essential for maintaining thermal balance, especially in hot and dry climates.

Furthermore, vegetation can impact wind speed by acting as a natural barrier that reduces wind velocity in certain areas. This can mitigate the discomfort of cold winds during winter and help maintain more stable temperatures in summer. Air temperature is a key parameter affecting human comfort (Kurnia, 2016). As air temperature increases or decreases significantly, human comfort levels tend to decline due to excessive heat or cold (Hidayat, 2010).

2. Methods

This practicum on the effect of vegetation was conducted on Tuesday, August 28, 2024, at Arboretum IPB. Observations of air temperature and relative humidity were made for 3 hours at 14:30 - 17:30 WIB. The tools used in this practicum are digital thermohygrometer, mini weather station, meter, stationery, stakes and smartphone. The implementation stages for observing temperature and relative humidity in the IPB Arboretum are as follows:

Observing the effect of a single tree canopy on air temperature reduction. Temperature and relative humidity observations are conducted by selecting a tree whose canopy provides shade. Measurements using a thermohygrometer are taken under the tree canopy. A weather station is placed in an open area without shade to measure temperature and relative humidity as a comparison. Observations are conducted every 30 minutes for a total of 3 hours, from 14:30 to 17:30 WIB. Observing the effect of vegetation cover on the distribution of air temperature and relative humadity (RH). Observations are conducted by selecting a site measuring 40 m x 50 m. A grid is then created with a 10 m distance between each grid point. At the end of each grid post (Ajir), temperature and relative humidity are measured. The measurements are completed within 30 minutes.

Fig. 1. Temperature and relative humidity observation locations

3. Result and Discussion

3.1 The influence of a single tree canopy on air temperature reduction

The graph above illustrates temperature and humidity observations inside and outside the canopy at different times. Based on Figure 2, it can be seen that the air temperature outside the canopy (represented by the yellow line) tends to be higher than the air temperature inside the canopy (orange line) for most of the observation period. This indicates that the tree canopy is effective in lowering air temperature in shaded areas. A significant temperature difference is observed around 15:00, when the temperature outside the canopy peaks above 34°C, while the temperature inside the canopy only reaches around 33°C. This temperature reduction occurs because the tree canopy reduces the intensity of solar radiation reaching the ground surface. The tree chosen as a reference for measuring temperature and relative humidity under the canopy is the banyan tree (*Ficus benjamina*).

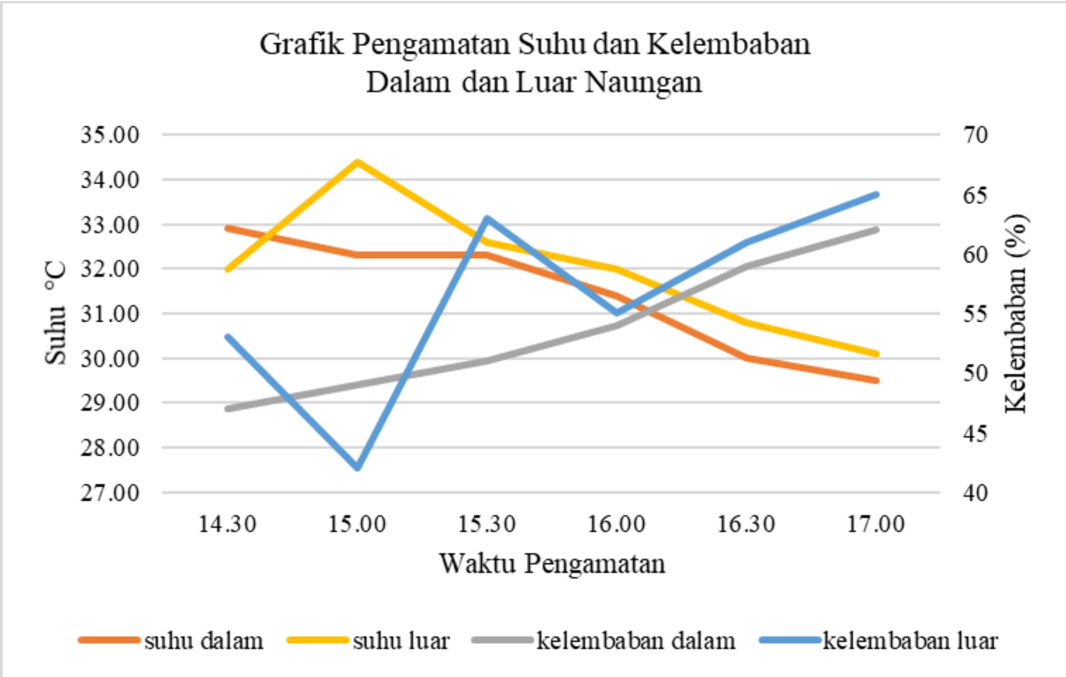

Fig. 2. Graph of temperature and humidity observations inside and outside the canopy

The air humidity inside the canopy (gray line) is generally higher than the humidity outside the canopy (blue line). This is due to transpiration from the tree canopy, which helps maintain higher humidity under the shade. At 15:30, there is an increase in humidity outside the canopy that surpasses the humidity inside the canopy. However, after this time, the humidity inside the canopy becomes higher and remains stable until the end of the observation period.

The tree canopy acts as a physical barrier that reduces the intensity of direct sunlight reaching the ground surface. This causes the shaded area to have a lower temperature compared to areas exposed to direct sunlight. A comfortable condition for humans is when their body temperature is around 37°C. Each region has different air temperatures, influenced by several factors such as the angle of sunlight, altitude, wind direction, ocean currents, cloud cover, and duration of sunlight exposure (Nasution, 2019). The decrease in air temperature under the tree canopy can contribute to thermal comfort and reduce the risk of heat stress for living organisms beneath it (Fadhlurrahman, 2018). The tree canopy also helps maintain surrounding air humidity, which can increase relative humidity under the shade. This higher humidity helps maintain air coolness and reduces the rate of water evaporation from the soil and nearby plants (Nasution, 2019).

3.2 The effect of vegetation cover on the distribution of air temperature and relative humidity (RH)

The vegetation map in Figure 3 illustrates the distribution and canopy size of plants within a specific area. Larger circles represent plants with wide canopies, often indicating tall trees or plants with extensive foliage. Large canopies play a crucial role in the ecosystem by providing shelter for fauna, reducing wind speed, and influencing the flow of rainwater to the ground. Areas with many overlapping circles indicate regions with high vegetation density. This typically occurs in zones that are more fertile or have environmental conditions that support lush plant growth. High-density vegetation can create a cooler and more humid microclimate, as well as enhance biodiversity (Smith et al., 2022).

The different colors of the circles represent various plant species or different growth conditions. Plant diversity is essential for supporting a balanced ecosystem since each plant species has a unique role, such as carbon absorption, soil quality improvement, or providing habitats for other species. The overlapping of circles indicates canopy interactions, such as competition for sunlight or synergy in creating broader shade. Greater overlap suggests areas almost entirely covered by canopy, which is commonly found in rainforests or highly dense vegetative areas (Sadono, 2018).

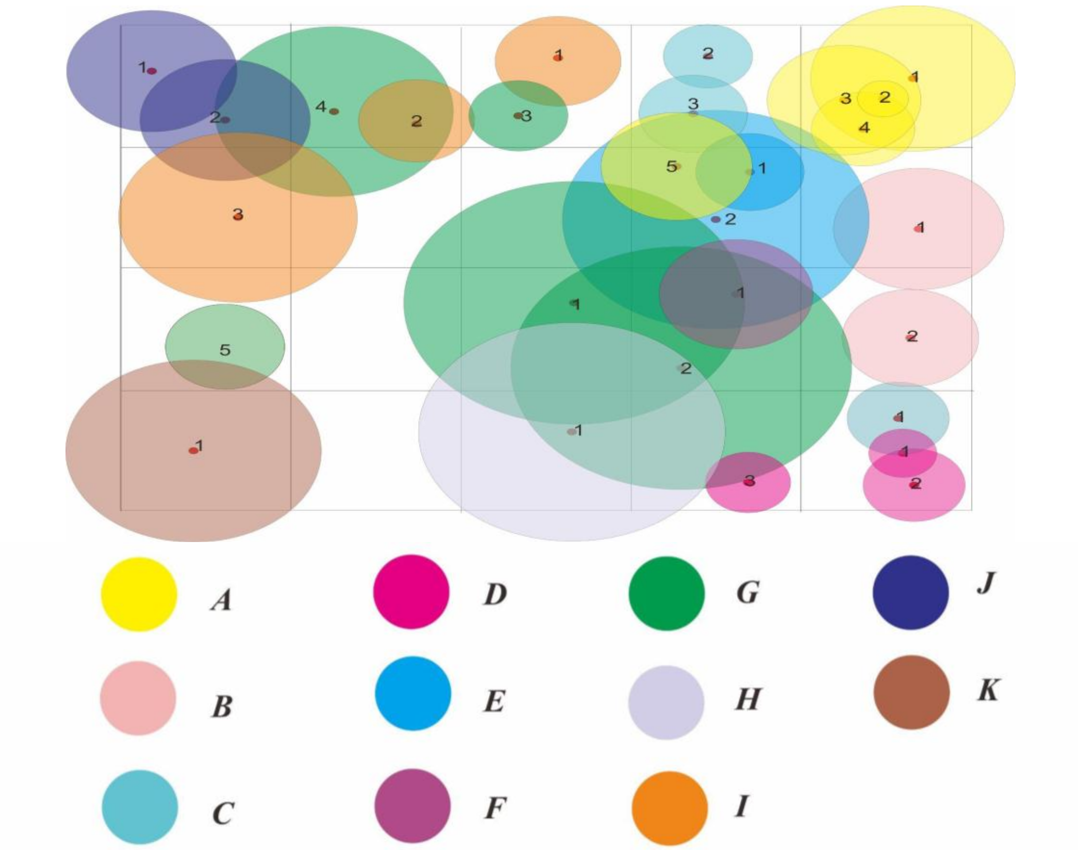

Fig. 3. Tree stand map in grid

The competitive strength of trees in acquiring environmental resources is assumed to be proportional to their size. Larger (dominant) trees with wider canopies and more extensive root systems are likely better at competing for environmental factors such as light, nutrients, and water (Sharma et al., 2016). The placement of circles within the grid represents the spatial distribution of plants. An evenly distributed pattern indicates a balanced vegetation system, whereas clustering in certain areas may reflect variations in soil conditions or resource availability, such as water.

Table 1. Tree type and crown area

No	Code	Tree types	Crown radius (m²)	Crown area (m²)
1	A 1	*Pterocarpus indicus*	6	113.04
2	A 2	*Pterocarpus indicus*	1.5	7.06
3	A 3	*Pterocarpus indicus*	4.5	63.58
4	A 4	*Pterocarpus indicus*	3	28.26
5	A 5	*Pterocarpus indicus*	4.2	55.39
6	B 1	*Pangium edule Reinw*	5	78.50
7	B 2	*Pangium edule Reinw*	4	50.24
8	C 1	*Cassia grandis*	3	28.26
9	C 2	*Cassia grandis*	2.6	21.23
10	C 3	*Cassia grandis*	3.2	32.15
11	D 1	*Adenanthera microsperma*	2	12.56
12	D 2	*Adenanthera microsperma*	3	28.26
13	D 3	*Adenanthera microsperma*	2.5	19.62
14	E 1	*Ficus benjamina*	3.2	32.15
15	E 2	*Ficus benjamina*	9	254.34
16	F 1	*Heritiera littoralis*	4.5	63.58
17	G 1	*Dalbergia latifolia*	10	314.00
18	G 2	*Dalbergia latifolia*	10	314.00
19	G 3	*Dalbergia latifolia*	2.8	24.62
20	G 4	*Dalbergia latifolia*	7	153.86
21	G 5	*Dalbergia latifolia*	3.5	38.46
22	H 1	*Sundacarpus amarus*	9	254.34
23	I 1	*Delonix regia*	3.7	42.99
24	I 2	*Delonix regia*	3.2	32.15
25	I 3	*Delonix regia*	7	153.86
26	J 1	*Spathodea campanulata*	5	78.50
27	J 2	*Spathodea campanulata*	5	78.50
28	K 1	*Cynometra browneoides*	7.5	176.62

The temperature distribution pattern on the map indicates that areas with lower temperatures tend to be in the wider sections (yellow). The yellow-colored areas represent lower temperatures (around 31.7°C to 31.9°C), which correspond to regions with more vegetation or areas benefiting from plant shading. A "heat island" observed in the central area, with a temperature of approximately 33.0°C, reflects a region with sparse vegetation, resulting in higher temperatures compared to its surroundings.

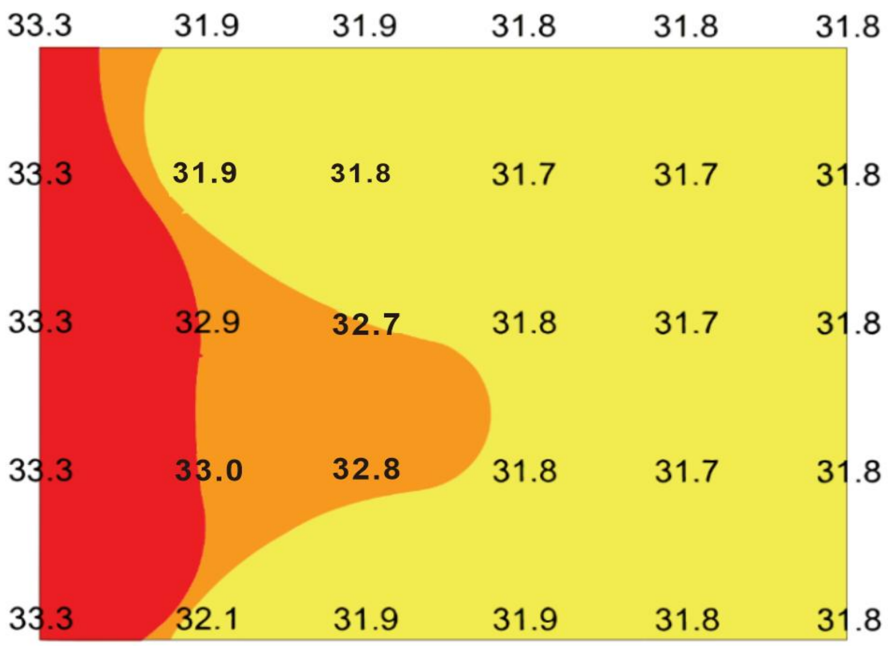

Fig. 3. Isothermal map

Vegetation, such as trees and other plants, can lower air temperatures through the process of evapotranspiration, where water absorbed by plant roots is released as vapor through the leaves. This process helps cool the surrounding environment. Vegetation also provides shading effects, reducing heat absorption by surfaces such as soil or buildings, which in turn helps lower air temperatures in the surrounding area.

The increase in temperature in urban areas is known as the Urban Heat Island (UHI) phenomenon, where air temperatures in urban areas are higher compared to suburban and rural areas. The term UHI is used because, on an isothermal map, urban areas with the highest temperatures appear like islands (Voogt, 2002). The reduction of green open spaces (RTH), increased population density, urban expansion, and the rising number of vehicles can contribute to the occurrence of UHI (Quattrochi et al., 2000). The rate of temperature increase due to green space reduction is greater than the rate of decrease resulting from the addition of RTH because, when RTH is increased, the urban revegetation process does not immediately compensate for the loss of existing green spaces. Newly planted vegetation requires time to mature and provide adequate shading (Effendy, 2006).

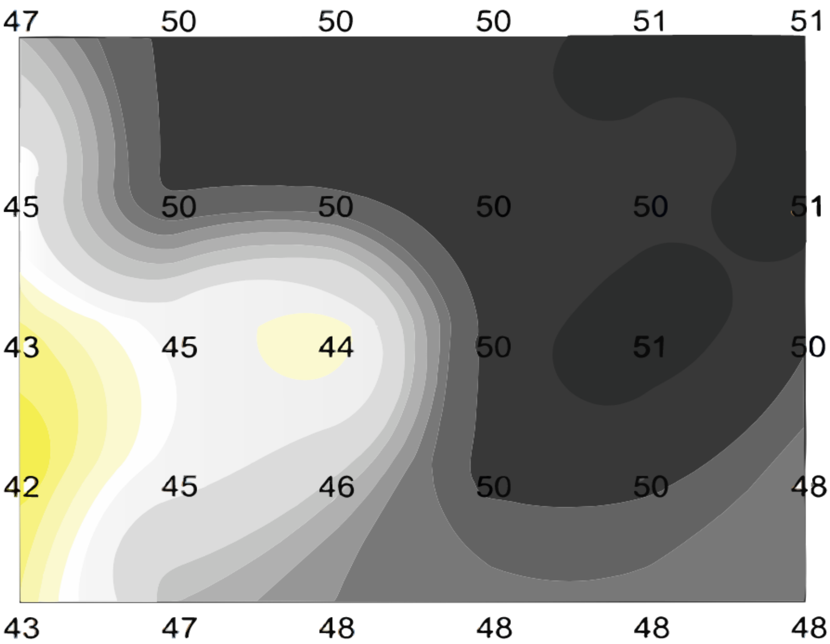

Fig. 4. Isohygro Map

The lowest humidity values are observed in the lower-left part of the map, with humidity levels around 42-43. This area has more open canopy or less vegetation, resulting in lower air humidity. The humidity gradually increases towards the upper-right part of the map, reaching a value of 51. This area has denser vegetation and less human activity, which contributes to the increase in humidity. Vegetation plays a crucial role in regulating the microclimate through the process of evapotranspiration, which significantly influences air humidity in a given area (Oke, 2002).

From this distribution of air humidity, it can be observed that areas with higher humidity are likely to have more vegetation. Vegetation is essential in increasing air humidity through evapotranspiration, where plants release water vapor into the atmosphere. Areas with higher humidity tend to feel more comfortable and cooler, while areas with lower humidity may feel drier and warmer. Proper spatial planning should take this humidity distribution into account to create a comfortable environment, especially in urban areas. Gill et al. (2007) state that the implementation of green infrastructure, such as urban parks and tree planting, can significantly increase air humidity and reduce the extreme temperature effects caused by climate change.

3.3 Regression analysis of percentage shade on temperature and humidity

Regression analysis shows no statistically significant relationship between temperature, average humidity, and the percentage of canopy cover. The Urban Heat Island phenomenon can be influenced by various variables other than canopy cover, such as the intensity of human activity and heat-absorbing surface materials (Lauer et al., 2023). The very low R Square value and high p-value indicate that canopy cover is not significant in explaining the variability of temperature and average humidity. While canopy cover is important, it is not the only influencing factor. Other factors related to vegetation itself, such as species composition, canopy structure, lighting, and other elements, may also play a role. Therefore, there are likely other factors affecting temperature that are not captured in this model. These influencing factors include the sampling location being near a high-mobility roadway or the canopy cover of trees in the grid not being dense (Weng et al., 2004).

Table 2. Anova

	df	SS	MS	F	Significance F
Regression	2	366.5549621	183.277	0.34917	0.710213656
Residual	17	8923.193038	524.894		
Total	19	9289.748			

Table 3. Linear regression statistical analysis results

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	39.03692	390.8	0.09	0.921	-785.6	863.75	-785.67	863.75
X Variable 1	4.91	14.38	0.34	0.736	-25.43	35.25	-25.4	35.25
X Variable 2	-2.47	3.04	-0.81	0.427	-8.89	3.94	-8.89	3.94

4. Conclusion

The Influence of Tree Canopy on Temperature and Humidity. Based on observations, tree canopies, such as those of the banyan tree (*Ficus benjamina*), are effective in reducing air temperature in areas beneath their shade. The temperature under the tree canopy tends to be lower compared to open areas that are not protected by shade. Additionally, the humidity under the canopy is also higher than in open areas, indicating that tree canopies contribute to maintaining air humidity in their surroundings.

The Effect of Vegetation Cover on Temperature and Humidity Distribution. Denser vegetation cover, especially from trees with wide canopies, significantly influences the creation of areas with lower temperatures and higher humidity. Dense vegetation can lower temperatures through the process of evapotranspiration and provide shade that reduces heat absorption by the ground surface. Conversely, areas with sparse vegetation tend to have higher temperatures and lower humidity, creating less comfortable conditions.

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Author Contribution

Conceptualization, B.A. and D.T.W.; Methodology, D.T.W. and E.A.H.; Investigation, B.A., E.A.H., and M.A.K.; Data curation, M.A.K. and T.M.I.; Writing – original draft preparation, B.A. and D.T.W.; Writing – review and editing, E.A.H., M.A.K., and T.M.I.

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