

Evaluation of the Role of Vegetation in Microclimate Amelioration and Thermal Comfort in the Pagutan Green Open Space, Mataram City, Lombok, Indonesia

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ABSTRACT

Green open spaces play an important role in improving urban environmental quality through microclimate amelioration and thermal comfort creation. This study evaluates the role of vegetation in microclimate improvement (through its shade and wind reduction) and analyzes thermal comfort levels based on measurements and visitor perceptions in the Pagutan Green Open Space, Mataram City. Data collected included vegetation characteristics, air temperature, humidity, and visitor perceptions. The analysis used the Key Performance Index (KPI) to assess shade and wind reduction, and the Temperature Humidity Index (THI) to evaluate thermal comfort. Results showed the average KPI was good, with shade effectiveness of 79% and wind reduction of 80%. THI values ranged from 26–29°C, with dense vegetation showing the lowest THI (27°C). Based on visitor perceptions, 76.7% felt comfortable, highlighting vegetation's role in enhancing microclimate comfort.

INTRODUCTION

Green Open Spaces are an important component of urban spatial planning that serve as a counterbalance to the urban ecosystem. Their existence provides ecological, social, and aesthetic benefits, including microclimate control, improved air quality, carbon sequestration, and the provision of social interaction spaces for the community. Ecologically, vegetation in plays a role in reducing air temperature through evapotranspiration, absorbing pollutants, reducing noise, and improving air circulation (Erdianto *et al.*, 2019). From a social perspective, green spaces serve as recreational facilities, environmental education spaces, and areas for physical activity and community interaction (Santoso *et al.*, 2012).

Various studies have shown the strategic role of green spaces in ameliorating microclimate and improving thermal comfort. Research by Azahra *et al.* (2023) in the green space of Pontianak City confirms that tree species such as trembesi (*Samanea saman*), tanjung (*Mimusops elengi*), and mahogany (*Swietenia mahagoni*) have high *Key Performance Index* values in terms of microclimate amelioration. These findings confirm that the effectiveness of green spaces in stabilizing the local climate is greatly influenced by the characteristics of the vegetation that composes them, such as canopy shape, leaf density, and planting patterns. A study by Nugroho *et al.* (2016) found that vegetation with high canopy density can reduce surface temperatures by 2–3°C compared to open areas without vegetation. Thermal comfort is an important factor in determining the quality of the environment and community activities in open spaces (Damayanti *et al.*, 2023). Balanced thermal conditions, namely air temperature and humidity at optimal levels, can create a sense of comfort that encourages people to be more active and productive outdoors.

Research by Nuraini *et al.*, (2024) shows that vegetation has a significant effect on regulating air temperature and humidity. Areas with high vegetation density have lower average temperatures and higher humidity compared to areas with low vegetation cover. The temperature difference between these areas ranges from 2°C to 4°C, depending on the type of vegetation and the density of its canopy. The denser the vegetation, the greater the environment's ability to lower temperatures through shading and evapotranspiration.

One of the areas that functions as the main green space in Mataram City is the Pagutan Green Space, covering an area of 8.2 hectares (Nufus *et al.*, 2025), and covered with various types of vegetation. The presence of this vegetation contributes significantly to lowering temperatures, increasing humidity, and creating comfort for visitors. However, the variety and density of vegetation in this area have not been thoroughly evaluated to determine the role of vegetation in microclimate amelioration. Therefore, an evaluation of the vegetation is needed to identify the types of trees that are most effective in lowering temperatures, increasing humidity, and creating thermal comfort. In addition, an analysis of thermal comfort levels is important to determine the extent to which vegetation density contributes to creating comfortable conditions for visitors. This study also needs to involve visitor perceptions as a basis for understanding human subjective experiences of environmental comfort, so that the research

results can provide recommendations for more ecological green space management that is oriented towards public comfort.

The purpose of this study is to assess rule of vegetation for microclimate amelioration (in terms of temperature shading and wind reduction) using Key Performance Index (KPI), to assess thermal comfort levels based on the Temperature Humidity Index (THI), and to understand visitors' perceptions of thermal comfort in the Pagutan Green Space. The results of this study are expected to provide a scientific basis for the management and planning of urban green spaces that are more adaptive to climate change and the comfort needs of urban communities.

THEORETICAL REVIEW

The interaction of vegetation and the urban climate has been the focus of various studies, highlighting the important role of plants in reducing the urban heat island effect (Santoso et al., 2012). Vegetation helps lower air temperature through shade and evapotranspiration, which cools the surrounding environment, providing relief from the heat (Azahra et al., 2023). Tree canopy shape and leaf density are important factors that influence the extent to which microclimate improvement can occur. Dense and wide canopies tend to provide better shade, reducing direct solar radiation and lowering air temperature (Saroh & Krisdianto, 2020).

Several studies have explored the effectiveness of various tree species in reducing surface temperature and increasing humidity. For example, research by Nugroho et al. (2016) shows that trees with high canopy density, such as Trembesi (*Samanea saman*) and Mahogany (*Swietenia mahagoni*), are very effective in reducing surface temperature by 2-3°C compared to areas without vegetation. Similarly, the Temperature Humidity Index (THI), a common indicator used to measure thermal comfort, is highly correlated with vegetation type and density. Studies by Effendy et al. (2018) and Lukić (2019) found that areas with dense vegetation recorded lower THI values, indicating more comfortable thermal conditions for visitors.

The impact of vegetation on thermal comfort is not only related to temperature regulation but also to increased humidity levels. Areas with dense canopies, such as those dominated by broad-leaved mahogany or Trembesi trees, not only lower temperatures but also help maintain higher humidity levels, which significantly contribute to human comfort (Nuraini et al., 2024). Perceptions of thermal comfort, as expressed by Wayan et al. (2018), are also influenced by individual factors such as adaptation to the local climate, clothing, and physical activity, in addition to environmental factors such as temperature and humidity.

METHODOLOGY

This study was conducted from April to August 2025 in the Pagutan Green Open Space, Mataram City, West Nusa Tenggara. Figure 1 shows a map of the research location.

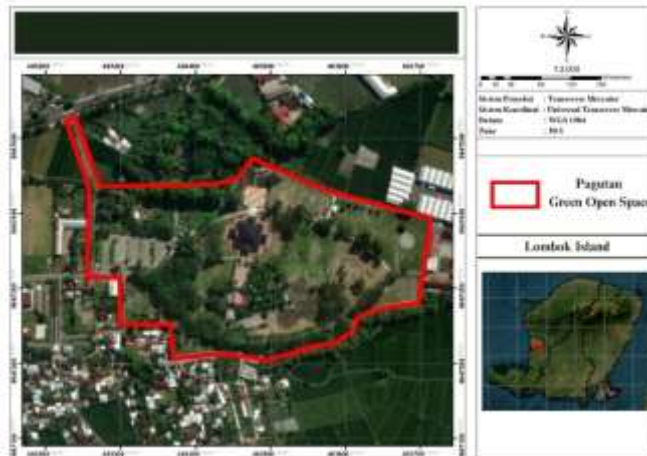


Figure. 1 Research Location

Data Collection

The data collected includes: 1. Vegetation data, 2. Thermal data, and 3. Visitor perception data. 1. Vegetation data includes tree species, determined using a determination key, the number of trees determined by census method, morphology and phenotype (crown width, measured using a roll meter, leaf shape observed visually, and tree height measured using a Hagameter) as well as assessing planting patterns and distances. 2. Thermal data includes air temperature and humidity, measured using a thermohygrometer for 3 consecutive days in the morning, afternoon, and evening for 3 different types of canopy cover of vegetation, namely dense vegetation (all tree crowns touching each other), sparse vegetation (only some tree crowns touching each other), and no vegetation (open area or no canopy cover). 3. Visitor perception data collected from interviews with 30 respondents in the morning, afternoon, and evening.

Data Analysis

1. Vegetation Evaluation Based on *Key Performance Index* Values

Vegetation assessment was conducted using Key Performance Index (KPI). KPI is a quantitative method for assessing the level of success, effectiveness, or performance based on several predetermined criteria or indicators. KPI values are expressed as percentages (%), which indicate the level of achievement against the maximum criteria.

In this study, KPI values were determined based on shade and wind reduction functions. Table 1 shows the assessment criteria for the shade function, and Table 2 shows the assessment criteria for the wind reduction function. The assessment criteria are as follows:

Table 1. Vegetation assessment criteria based on shade function

No	Criteria	Score	Criteria Description
1	Tree crown and leaf mass	1	Cone/column/irregular crown, sparse foliage
		2	Cone/column/irregular crown, sparse foliage
		3	Spreading crown with sparse foliage, dense foliage on column/cone crown
		4	Spreading crown, dense foliage
2	Tree height	1	Height < 3 meters
		2	Height 3-6 meters
		3	Height 7-12 meters
		4	Height > 12 meters
3	Tree crown interference	1	Crowns do not touch, are not continuous, distance between crowns > 3 meters
		2	Crowns do not touch, are not continuous, distance between crowns < 3 meters
		3	Crowns do not touch, are continuous
		4	Crowns touch, are continuous
4	Leaf characteristics	1	Leaves fall off
		2	Not dense, not thick
		3	Dense, not thick
		4	Dense and thick
5	Planting pattern	1	Planted separately, irregularly
		2	Planted sparsely > 6 meters, discontinuous
		3	Planted not too densely (3-6 m), continuous
		4	Planted densely < 3m, continuous

Table 2. Vegetation assessment criteria based on wind reduction function

NO	Criteria	Score	Criteria Description
1	Tree crown and leaf mass	1	Cone/column/irregular crown, sparse foliage
		2	Cone/column/irregular crown, sparse foliage
		3	Spreading crown with sparse foliage, dense foliage on column/cone crown
		4	Spreading crown, dense foliage
2	Tree height	1	Height < 3 meters

NO	Criteria	Score	Criteria Description
		2	Height 3–6 meters
		3	Height 7–12 meters
		4	Height > 12 meters
3	The sensitivity of tree crowns	1	Crowns do not intersect, not continuous, distance between crowns > 3 meters
		2	Crowns do not intersect, not continuous, distance between crowns < 3 meters
		3	Crowns do not intersect, continuous
		4	Crowns intersect, continuous
4	Leaf characteristics	1	Leaves fall off
		2	Not dense, not thick
		3	Dense, not thick
		4	Dense and thick
5	Planting pattern	1	Planted separately, irregularly
		2	Planted sparsely > 6 meters, discontinuous
		3	Planted not too densely (3-6 m), continuous
		4	Planted densely < 3m, continuous

After conducting an assessment based on the above criteria, the *Key Performance Index* (KPI) value is determined using the following formula:

$$\text{KPI} = \frac{\text{Total Score}}{\text{Maksimum Score}} \times 100\%$$

Description :

- KPI : *Key Performance Index* Score
 Total Score : The scores obtained from each criterion are then added together
 Maximum Score : The maximum total score from all criteria

After obtaining the percentage value of each type of vegetation based on its shade and wind reduction functions, these values will be entered into several categories. The KPI assessment categories are listed in Table 3 below :

Table 3. KPI Assessment Categories

Value	category
0-40	Poor
41-60	Not Good
61-80	Good
81-100	Very Good

2. Thermal comfort analysis based on *Temperature Humidity Index* (THI)

The level of thermal comfort is obtained from the temperature humidity index (THI) value. The Temperature Humidity Index (THI) is a quantitative indicator used to assess the level of human thermal comfort based on a combination of air temperature (Temperature, °C) and relative air humidity (Relative Humidity, %) (Effendy *et al.*, 2018). This value is obtained from the following formula :

$$THI = 0.8 Ta + \frac{RH \times Ta}{500}$$

Keterangan:

THI : Temperature Humidity Index

Ta : Air temperature (°C)

RH : Relative humidity (%)

Once the THI score has been obtained, it will be assigned to several categories or assessment classes. The THI assessment classes are listed in Table 4 below:

Table 4. Temperature Humidity Index (THI) class ranges

THI Value Range (°C)	Description
<20	Uncomfortable (too cool)
21-24	Comfortable
24-26	Fairly comfortable
>26	Uncomfortable (too hot)

Source : (Andani *et al.*, 2018)

3. Thermal comfort analysis based on visitor perception

Thermal comfort data based on visitor perceptions was processed using simple descriptive analysis. Simple descriptive analysis is a data analysis method that aims to describe or explain a phenomenon as it is, based on data obtained from observations, measurements, or interviews without performing complex statistical tests. This study presents visitor perception data in the form of graphs and percentages of visitor perceptions of several thermal aspects.

RESULT AND DISCUSSION

Assessment of Vegetation Function on Microclimate Amelioration

The vegetation in Pagutan Green Space has different capabilities in terms of shade and wind reduction functions based on an assessment using the *Key Performance Index* (KPI) method. Most tree species show good values in terms of their ecological function. The results of the calculations are shown in Table 5. The tree assessment categories for shade function based on the *Key Performance Index* (KPI) and Table 6. The tree assessment categories for wind reduction function based on the *Key Performance Index* (KPI) are as follows:

Table 5. Tree assessment categories as shade function based on *Key Performance Index (KPI)*

No	Tree Species	Shade function					Value	Category
		K1	K2	K3	K4	K5		
1	Trembesi (<i>Samanea saman</i>)	4	4	4	4	3	95	Very Good
2	Mango (<i>Mangifera indica</i>)	3	3	3	4	3	80	Good
3	mahogany (<i>Swietenia mahagoni</i>)	4	4	4	4	4	100	Very Good
4	Jackfruit (<i>Artocarpus heterophyllus</i>)	3	3	4	4	3	85	Very Good
5	cedar (<i>Casuarina equisetifolia</i>)	1	4	3	2	3	65	Good
6	Ketapang (<i>Terminalia catapa</i>)	4	3	3	3	3	80	Good
7	Golden Ketapang (<i>Terminalia mantali</i>)	3	3	3	4	3	80	Good
8	Beringin (<i>Ficus benjamina</i>)	4	4	4	3	3	90	Very Good
9	White teak (<i>Gmelina arborea</i>)	4	4	4	4	3	95	Very Good
10	Dao (<i>Dracontomelon Dao</i>)	3	4	4	4	3	90	Very Good
11	Bintaro (<i>Cerbera manghas</i>)	3	4	4	3	4	90	Very Good
12	Glodokan (<i>Polyalthia longifolia</i>)	3	4	3	3	2	75	Good
13	Tabebuia (<i>Tabebuia</i>)	2	3	2	2	3	60	Not Good
14	Flamboyan (<i>Delonix regia</i>)	3	4	4	3	3	85	Very Good
15	Broad leaf mahogany (<i>Swietenia Macrophylla</i>)	4	4	4	4	4	100	Very Good
16	Matoa (<i>Pometia pinnata</i>)	3	3	3	3	3	75	Good
17	kersen (<i>Muntingia calabura</i>)	3	3	1	1	1	45	Not Good
18	banten (<i>Lannea coromandelica</i>)	3	3	2	3	2	65	Good
19	candlenut (<i>Aleurites moluccana</i>)	3	4	4	4	4	95	Very Good
20	Breadfruit (<i>Artocarpus altilis</i>)	2	3	3	2	1	55	Not Good
21	Guava (<i>Psidium guajava</i>)	1	2	3	2	3	55	Not Good
Average							79	Good

The shade function shows the important role of vegetation in regulating thermal conditions in the Pagutan green space. Based on the results of the *Key Performance Index (KPI)* analysis in Table 5, the overall average value of 79 is in the good category. The tree species with the highest values in reducing temperature and increasing humidity are Mahogany (*Swietenia mahagoni*) and Broadleaf Mahogany (*Swietenia Macrophylla*) with a KPI value of 100 (excellent), indicating maximum ability to modify the microclimate through shading and high evapotranspiration mechanisms.

The Trembesi (*Samanea saman*) and White Teak (*Gmelina arborea*) tree species ranked next with a score of 95 (very good), followed by Jackfruit (*Artocarpus heterophyllus*), Beringin (*Ficus benjamina*), Dao (*Dracontomelon dao*), Bintaro (*Cerbera manghas*), Flamboyan (*Delonix regia*), and Candlenut (*Aleurites moluccana*) with KPI scores between 85–95 (very good). These trees generally have broad crowns, dense foliage, and high canopy density, which are effective in blocking direct sunlight and maintaining humidity underneath. Mango

(*Mangifera indica*), Ketapang (*Terminalia catappa*), Golden Ketapang (*Terminalia mantali*), Glodokan (*Polyalthia longifolia*), and Banten (*Lannea coromandelica*) are classified as good with KPI values of 65–80. Although their ability is lower than the excellent group, these species still contribute significantly to temperature and humidity regulation, especially in open areas with extensive air circulation. Meanwhile, Tabebuaya (*Tabebuia*), Kersen (*Muntingia calabura*), Breadfruit (*Artocarpus altilis*), and Guava (*Psidium guajava*) are classified as poor with a KPI value between 45–60, due to their narrow crown shape, low leaf density, and relatively short tree height, resulting in limited shading and water evaporation from the leaves.

The differences in *Key Performance Index* (KPI) values for each type of vegetation in Table 5 are due to several morphological factors that directly affect the ability of trees to provide shade, particularly the shape and density of the canopy. According to Saroh & Krisdianto, (2020) canopy shape is one of the main components that determines the amount of shade and the quality of the microclimate in green open spaces. Trees with spreading crowns such as Mahogany (*Swietenia mahagoni*), Rain Tree (*Samanea saman*), and Banyan (*Ficus benjamina*) tend to have high KPI values because they are able to cover a large area from direct exposure to solar radiation (Azahra et al., 2023). This is in line with the results of research by Saroh & Krisdianto, (2020), which states that umbrella- or pagoda-shaped crowns produce maximum shade and are able to significantly reduce temperature and increase humidity under the canopy.

Research by Alfian & Nuraini, (2019) shows that planting distance, tree height, and vegetation age affect the ability of vegetation to provide shade, in line with the results in Table 5. Trees with close planting distances and overlapping crowns are able to reduce temperature and increase humidity better than trees that are planted further apart. Tall trees such as Trembesi (*Samanea saman*), Mahogany (*Swietenia mahagoni*), and Beringin (*Ficus benjamina*) provide wider shade compared to medium-sized species such as Kersen or Tabebuaya. In addition, mature vegetation with dense canopies provides optimal shade, while young trees such as guava (*Psidium guajava*) do not yet function optimally.

Table 6. Tree assessment categories as wind reduction functions based on *Key Performance Index* (KPI).

No	Species	Wind reduction					Value	Kategori
		K1	K2	K3	K4	K5		
1	Trembesi (<i>Samanea saman</i>)	4	4	3	4	3	90	Very Good
2	Mango (<i>Mangifera indica</i>)	3	3	3	3	4	80	Good
3	Mahogany (<i>Swietenia mahagoni</i>)	4	3	3	4	4	90	Very Good
4	Nangka (<i>Artocarpus heterophyllus</i>)	3	3	3	3	3	75	Good
5	Cemara (<i>Casuarina equisetifolia</i>)	4	4	4	1	3	80	Good
6	Ketapang (<i>Terminalia catapa</i>)	3	2	2	4	4	75	Good
7	Golden Ketapang (<i>Terminalia mantali</i>)	3	4	2	4	4	85	Very Good
8	Beringin (<i>Ficus benjamina</i>)	4	3	4	4	4	95	Very Good
9	Jati putih (<i>Gmelina arborea</i>)	4	3	3	4	4	90	Very Good

10	Dao (<i>Dracontomelon Dao</i>)	4	3	3	4	4	90	Very Good	
11	Bintaro (<i>Cerbera manghas</i>)	4	3	3	4	4	90	Very Good	
12	Glodokan (<i>Polyalthia longifolia</i>)	4	3	2	3	4	80	Good	
13	Tabebuaya (<i>Tabebuia</i>)	3	3	2	2	4	70	Good	
14	Flamboyan (<i>Delonix regia</i>)	4	4	2	3	4	85	Very Good	
15	Broad leaf mahogany (<i>Swietenia Macrophylla</i>)	4	3	4		4	4	95	Very Good
16	Matoa (<i>Pometia pinnata</i>)	3	3	3	3	4	80	Good	
17	kersen (<i>Muntingia calabura</i>)	3	1	1	1	4	50	Not Good	
18	banten (<i>Lannea coromandelica</i>)	3	3	1	3	4	70	Good	
19	candlenut (<i>Aleurites moluccana</i>)	3	3	3	3	4	80	Good	
20	breadfruit (<i>Artocarpus altilis</i>)	3	2	1	2	4	60	Not Good	
21	Guava (<i>Psidium guajava</i>)	2	3	2	2	3	60	Not Good	
Average							80	Good	

In terms of wind reduction, the assessment of tree phenotypes in the Pagutan green space showed variations in effectiveness between tree species groups. Based on the results of the *Key Performance Index* (KPI) analysis in Table 3, the overall average score of 80 is classified as good. The tree species that showed the highest wind reduction capacity were the banyan (*Ficus benjamina*) and the broad-leaved mahogany (*Swietenia Macrophylla*) with a KPI score of 95 (very good). They are followed by Trembesi (*Samanea saman*), Mahogany (*Swietenia mahagoni*), White Teak (*Gmelina arborea*), Dao (*Dracontomelon dao*), and Bintaro (*Cerbera manghas*), which scored 90 (very good). These trees generally have broad crowns with dense foliage, are over 12 m tall, and have strong trunk and root structures, making them effective as natural barriers to wind flow and maintaining microclimate stability.

Other species such as Golden Ketapang (*Terminalia mantali*) and Flamboyant (*Delonix regia*) are also classified as very good (score of 85), while Mango (*Mangifera indica*), Casuarina (*Casuarina equisetifolia*), Ketapang (*Terminalia catappa*), Glodokan (*Polyalthia longifolia*), Candlenut (*Aleurites moluccana*) and several other species are categorized as good (score of 70–80). Conversely, Kersen (*Muntingia calabura*), Breadfruit (*Artocarpus altilis*), and Guava (*Psidium guajava*) are classified as poor with a KPI score of 50–60 because their canopy is not dense and the trees are relatively short, resulting in weaker wind resistance.

The KPI value of vegetation as a wind reducer is influenced by canopy density, leaf porosity, tree height, canopy structure, and planting pattern. Based on the results of Table 6 and research by Pratama *et al.*, (2021), vegetation with dense canopy and low porosity, such as broad-leaved mahogany (*Swietenia Macrophylla*), rain tree (*Samanea saman*), and golden ketapang (*Terminalia mantaly*), has a high ability to withstand wind gusts and maintain temperature stability under the canopy. The dense canopy structure creates a physical barrier to air flow, while the combination of tall trees such as Trembesi and Beringin (*Ficus benjamina*) with medium-sized trees such as Golden Ketapang forms an

effective natural wind reduction layer. In addition, dense and continuous planting patterns with distances between trees of less than three meters reinforce the protective effect, reducing air gaps that allow wind to penetrate green areas. Thus, dense, multi-layered canopy vegetation such as Mahogany, Trembesi, and Golden Ketapang show the highest KPI values due to their ability to create natural wind barriers while improving thermal comfort in parks and green open spaces.

Thermal comfort based on the Temperature Humidity Index

The measurement results and THI value calculations are shown in Table 7. As follows:

Table 7. Temperature and humidity measurement results and THI value calculations

Location	Time	THI factor		THI	Criteria
		Temperature (°C)	Humadity (%)		
Dense Vegetation	Morning	27,08	68,14	25	Fairly comfortable
	Afternoon	31,57	50,52	28	Uncomfortable
	Evening	29,44	58,1	26	Fairly comfortable
	average	29,36	58,92	27	Uncomfortable
Sarse Vegetation	Morning	27,01	70,12	25	Fairly comfortable
	Afternoon	33,94	51,93	31	Uncomfortable
	Evening	29,43	61,65	27	Uncomfortable
	average	30,13	61,23	28	Uncomfortable
No vegetation	Morning	25,45	79,67	24	Comfortable
	Afternoon	37,59	55,29	34	Uncomfortable
	Evening	30,41	70,43	29	Uncomfortable
	average	31,15	68,46	29	Uncomfortable

The results of thermal comfort measurements based on the Temperature Humidity Index (THI) in three types of vegetation cover in the Pagutan Green Space show significant variations in thermal conditions between areas with dense vegetation (all tree crowns touching each other), sparse vegetation (only some tree crowns touching each other), and no vegetation (open areas or no canopy cover) . In general, the highest average THI value was found in open vegetation areas with a value of 29, followed by sparse vegetation areas with a value of 28, while dense vegetation had the lowest THI value of 27. Based on comfort classification, all three types of cover were generally in the uncomfortable category, although at certain times, especially in the morning and afternoon, the thermal conditions were still fairly comfortable to comfortable.

In dense vegetation areas, the THI value of 25 in the morning and 26 in the afternoon indicates fairly comfortable conditions, while at noon it increases to 28 (uncomfortable) due to high solar radiation intensity. This condition confirms that the presence of trees with wide canopies and high density plays a role in lowering air temperature and increasing humidity, thereby improving thermal comfort, especially during hours with low solar radiation. Meanwhile, in areas with sparse vegetation, the THI value ranged from 25 to 31, where conditions were only fairly comfortable in the morning, while the afternoon and evening were classified as uncomfortable. Low vegetation density resulted in greater direct heat exposure and a decrease in the vegetation's ability to block solar radiation and regulate air humidity.

In open vegetation areas, the difference in THI values between time sessions is very striking. The morning THI value of 24 indicates comfortable conditions, but it increases dramatically to 34 (uncomfortable) at noon and 29 (uncomfortable) in the afternoon. This shows that the absence of trees and shade directly increases surface temperature and decreases air humidity, especially at the peak of solar radiation at noon. The higher average THI values in open areas compared to densely vegetated areas confirm that vegetation plays an important role in microclimate amelioration through the mechanisms of solar radiation reduction, humidity increase, and air temperature decrease in the surrounding area.

The THI values in Table 7 show variations influenced by microclimate environmental factors such as air temperature, humidity, wind speed, and solar radiation intensity, which are directly related to the presence and quality of vegetation in an area. Based on research by Mala *et al.*, (2019), differences in thermal comfort values in three green open spaces in Manado City are caused by differences in canopy cover area, vegetation type, and the level of paving and buildings around the area. Locations with high tree canopy cover and dense vegetation, such as the UNSRAT Field, showed the highest thermal comfort values (low THI) because the dense canopy was able to reduce direct solar radiation and increase air humidity. Conversely, areas with sparse canopies and a predominance of asphalt or open surfaces, such as the KONI Field, had high THI due to high air temperature and low relative humidity.

The study also confirmed that layered vegetation structures and the presence of water elements contribute to lowering THI values through natural cooling effects (evaporation and evapotranspiration), which enhance thermal comfort in green open spaces. This aligns with the results in Table 7, where areas with dense vegetation and extensive canopies produce cooler thermal conditions compared to areas with sparse vegetation.

Solar radiation is also one of the factors contributing to the increase in surface and air temperatures. Direct exposure to sunlight increases the ambient temperature and THI values, especially in areas that are not protected by vegetation or shade structures. During the day (around 1:00–2:00 p.m.), when radiation intensity peaks, the THI tends to be at its maximum value. Lukić, (2019), noted that the Humidex14h sub-index always showed the categories “great

discomfort” to “dangerous” in July and August, when solar radiation was at its highest.

Visitors' Perceptions of Thermal Comfort in Pagutan Green Space

Visitor perceptions are shown using the graph in Figure 2, which is as follows:

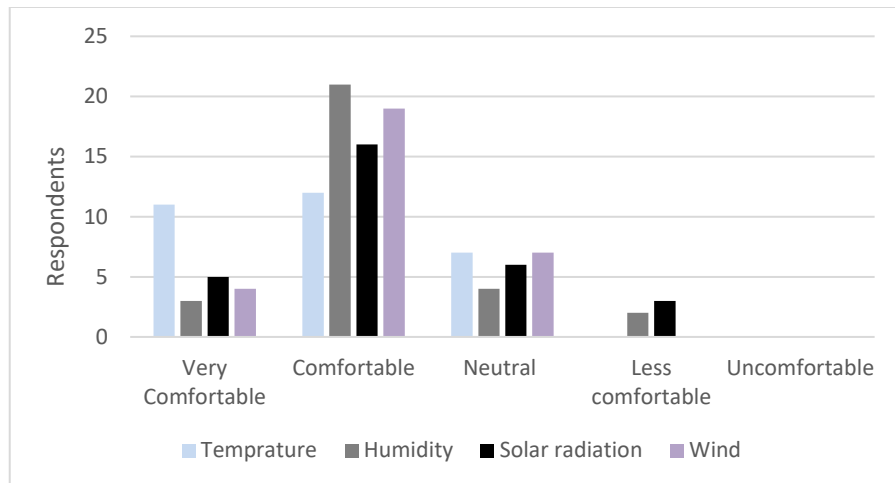


Figure 2. visitors' perceptions of thermal comfort in Pagutan Green Space

The results of visitor perception analysis (Figure 2) show that the thermal comfort conditions in Pagutan Green Space are generally in the comfortable category in all four aspects measured, namely temperature, humidity, sunlight, and wind. Most respondents rated the Pagutan Green Space environment as comfortable for activities, indicating that vegetation plays an important role in regulating and improving the microclimate of the area. Approximately 40% of visitors felt that the air temperature was comfortable, 37% felt it was very comfortable, and only 23% stated that it was neutral to uncomfortable, indicating that the temperature in the area is relatively cool and conducive to outdoor activities. The aspect of air humidity received the highest level of comfort, with around 70% of respondents stating that it was comfortable and 10% very comfortable, indicating that the air humidity in Pagutan Green Space is within the optimal range for thermal comfort in tropical regions.

The aspect of sunlight also showed a comfortable trend, with 55% of respondents feeling comfortable and 25% feeling very comfortable, indicating that the tree canopy was effective in reducing the intensity of direct solar radiation. In addition, the wind aspect also contributes to thermal comfort, with 65% of respondents feeling comfortable and 15% feeling very comfortable, which means that air circulation in the area is quite good and helps maintain a cool environment.

Overall, more than 75% of visitors rated the thermal conditions in the Pagutan green space as comfortable to very comfortable, confirming that the vegetation structure, especially broad-canopied trees such as Trembesi (*Samanea saman*) and Mahogany (*Swietenia mahagoni*), plays a significant role in ameliorating the microclimate. Both types are effective in providing shade and

slowing down wind movement, thereby lowering air temperature and increasing humidity. These results are in line with previous studies that mention canopy density and vegetation layout as major factors in creating thermal comfort in urban green open spaces, especially in tropical climates.

User perceptions of outdoor thermal comfort, as shown in Figure 2, indicate that individual perceptions are influenced not only by physical environmental conditions such as temperature, humidity, and wind speed, but also by personal and adaptive factors that play a role in assessing comfort levels. Based on the findings of Wayan *et al.*, (2018), differences in comfort perceptions in each zone of the city park are closely related to the level of user activity, type of clothing, and ability to adapt to the tropical climate. For example, in zones with high vegetation shade, such as the western and northern areas of the park, the majority of respondents felt “comfortable” even though objective measurements showed that the temperature was rather warm. This indicates that users have psychologically and physiologically adjusted to the local climate, where people who are accustomed to high temperatures tend to consider thermal conditions above the ideal limit to be comfortable.

In addition to adaptation factors, vegetation and the physical layout of the park also shape visitors' perceptions of thermal comfort. The presence of tall vegetation such as Trembesi and Beringin trees, which form shaded zones, increases the perception of comfort compared to open areas without shade. Mustika and Sastrawan also emphasize that the balanced distribution of softscape and hardscape elements affects thermal sensations, as areas dominated by pavement absorb heat more quickly and increase the perception of “warmth” during the day. Meanwhile, shaded areas with dense vegetation create a perception of “coolness” even though the thermal values are not much different.

Thus, these findings reinforce the interpretation in Figure 2, that the perception of thermal comfort is subjective and contextual, influenced by a combination of environmental factors, user activities, clothing types, and adaptation to the climate. These factors cause differences between perceived comfort and measured comfort, with tropical populations showing higher tolerance to warm thermal conditions than subtropical climate standards.

CONCLUSIONS AND RECOMMENDATIONS

1. The vegetation in Pagutan Green Space has good value in microclimate amelioration, with an average KPI value of 79% for shade function and 80% for wind reduction (good category). Mahogany and broadleaf mahogany have a KPI of 100%, followed by Trembesi and white teak (95%).
2. The THI value shows that the dense vegetation area is 27°C, sparse vegetation is 28°C, and open vegetation is 29°C (uncomfortable), but in the morning (THI 25°C) and afternoon (THI 26°C) in the dense vegetation area it is quite comfortable, while at noon in the open vegetation area the THI reaches 34°C (very uncomfortable). Vegetation can lower the temperature by 3–5°C and maintain humidity above 60%.

3. Of the 30 respondents, 76.7% felt comfortable, 20% felt fairly comfortable, and 3.3% felt neutral, indicating the important role of vegetation in improving thermal comfort and visitor experience.

Recommendations for Future Research

For future research, some recommendations that can be given are as follows: It is recommended that the management of Pagutan Green Open Space focus on routine maintenance of layered vegetation, especially tree species such as *Swietenia mahagoni*, *Samanea saman*, and *Ficus benjamina* to maintain shade and microclimate functions. In further research, THI measurement points should be determined based on vegetation conditions using NDVI, and canopy density should be analyzed with a *Gap Light Analyzer* (GLA) for more accurate results.

FURTHER STUDY

In this study, temperature and humidity measurements were only taken over a period of three days at a single point in time, so they do not fully describe seasonal variations. In addition, the number of respondents was only 30, which is insufficient to describe the overall perceptions of a large number of visitors.

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