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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

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## Abstract

The increasing number of motorized vehicles in Jakarta is causing environmental damage and can harm human health. In recent years, the Jakarta local government has the vision to focus on improving the human mobility network, including the pedestrian networks. As a heavily trafficked road, Jalan Kyai Tapa, West Jakarta, is used by many people. However, it may feel uncomfortable to walk there due to heat and sun exposure, which is compounded by extensive pavement coverage. The thermal condition of the pedestrian corridor is essential to create a comfortable walking experience. The objective of this study was to analyze the thermal comfort of the pedestrian corridors at Jalan Kyai Tapa concerning the landscape composition, including vegetation structure and pavement. This study was conducted quantitatively. This study identified the vegetation structure, including the tree species, canopy diameter, and height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate thermal comfort using the Temperature Humidity Index (THI). The results showed that the air temperature ranges from 31.01°C to 31.54°C, and the relative humidity ranges from 56.19% to 57.74%. The average THI value is 28.52 °C, which falls into the comfortable category. Despite having relatively wide canopies and providing shade, the trees in this pedestrian corridor do not seem to improve the thermal environment enough to achieve comfortable conditions for pedestrians. Interestingly, the result shows that, at certain observation times, points without trees had lower air temperatures compared to other spots with trees. Trees may not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with more expansive canopies can be less comfortable than spots near trees with smaller canopies. Tree species and the planting spacing determine the efficiency of trees to improve thermal comfort.

**Keywords**: Koridor; Pedestrian way; Thermal comfort; Vegetation.

## 1. Introduction

The urban population has kept increasing in the past few decades. The population growth in Jakarta from 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase follows the increase in motor vehicles. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, infamous for its severe traffic congestion due to overloaded motor vehicles, would suffer more. Increasing the number of motor vehicles means more emissions of air pollutants and greenhouse gases that could eventually harm human health and the environment. If the environment is damaged, pedestrians are the most

impacted group of road users, as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

A roadside greenbelt is a linear green open space formed by landscape elements, such as trees and shrubs, providing users comfort, safety, and beauty (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban areas play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (Nowak et al., 2006; Biao et al., 2010; Simangunsong et al., 2021; Simangunsong & Fitri, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spagenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin & Waryono, 2010), such as ameliorating microclimate, reducing pollutants, including particle and gas, controlling glare, producing oxygen (Simangunsong et al., 2021; Simangunsong & Fitri, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. The vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions to optimize the role of roadside vegetation. Additionally, selecting the local species would make the adaptation more accessible for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only on a micro scale but also at a city scale.

Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. The direct benefits of roadside greenbelts to humans are providing shade, user safety, and improving users' comfort, especially pedestrians and cyclists. The position of the greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if it is too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building–environment interaction, which includes various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and street width (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity directly influence THI, an index used to measure human body comfort. By paying attention to the thermal comfort of roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetics. Vegetation in roadside landscape serves as a view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, and the planting design and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etcetera). The interaction between softscape and hardscape determines thermal comfort.

Jakarta's local government initiated the concept of a Smart City in 2014 by improving the city based on six elements: Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to reduce traffic congestion, air pollution, citizen mobility, etcetera. Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infra-structure) revitalizes public facilities such as pedestrian corridors to support public

transportation. Dinas Bina Marga cooperates with the Institute for Transportation Development Policy (ITDP) Indonesia to plan a human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facilities for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road with two pedestrian corridors and green belts on the side. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Quite a lot of people use pedestrian corridors at Jalan Kyai Tapa. However, in the afternoon, it may feel uncomfortable to walk there due to heat and sunlight exposure, and significant coverages of pavements worsen that. The thermal condition of a pedestrian corridor is essential to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas but is still relatively limited in Indonesia. Existing studies have analyzed pedestrian corridors' comfort in Indonesia cities concerning its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). Only a few studies specifically focus on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). Even fewer studies exist on the thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta primarily relate to transit-oriented development concepts (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. This study analyzes the thermal comfort of pedestrian corridors at Jalan Kyai Tapa concerning its landscape composition, including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can briefly illustrate other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can help improve the pedestrian corridors in Jakarta.

## 2. Methods

### 2.1 Study area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a significant road passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot (Figure 1). There are two sides of pedestrian corridors at Jalan Kyai Tapa: (1) the terminal side (north side) and (2) the university side (south side).

The terminal side has a bus terminal, police station, and traffic gardens. Meanwhile, university buildings, hotels, restaurants, and other commercial buildings are on the university side. The tree information in the study area is collected for further analysis. When inventorying vegetation, existing studies created plots of 100 meters by 100 meters in broad areas, such as national parks (Haryadi et al., 2019; Maulidiyan et al., 2019), and created belt transects of 100 m in linear areas, such as roadsides (Danniswari & Nasrullah, 2017). Therefore, we divided the 300-meter-long pedestrian corridors into three segments, 100 m-long each. The study area and the segmentation are shown in Figure 2. The field data was collected from November 2021 until February 2022.

### 2.2 Data collection

The study is conducted quantitatively. We collect data on field air temperature, relative humidity, wind speed, tree species, tree height, and canopy diameter. Air temperature, relative humidity, and wind speed measurement points are distributed along the corridors. The measurement is done three times daily at 08:00, 12:00, and 16:00 for seven days during sunny weather using a digital thermohygrometer. The pedestrian corridors have two sides, the university side and the terminal side, with a length of 300 m. We observed both corridors and

divided each corridor into three segments 100 m long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to the smaller vegetation coverage on this side.

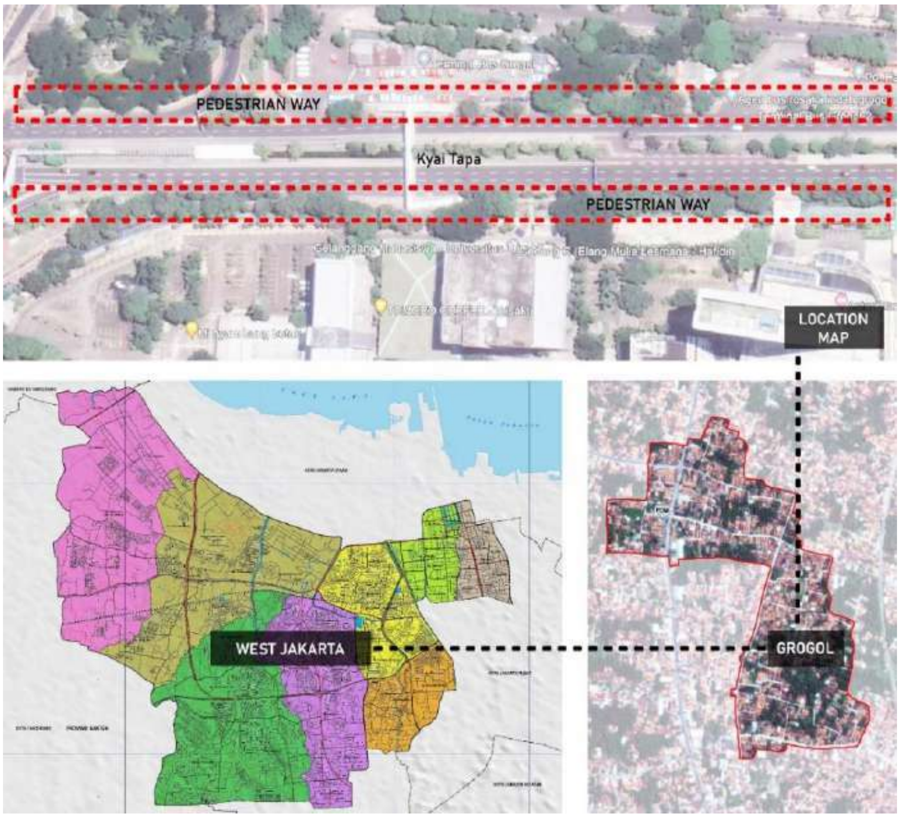


Figure. 1 Study location map


Figure. 2 Study area, the pedestrian corridors at Kyai Tapa, and the segmentation

### 2.3 Data analysis

The data are analyzed to calculate the Temperature Humidity Index. The THI is estimated to determine the equivalent temperature perceived by humans by considering the air temperature and relative humidity. This index has been widely used to measure the human body's comfort (Isnoor et al., 2021; Putri et al., 2021; Rusdayanti et al., 2021).

Table 1. Location and measurement points

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

Measured field air temperature and humidity are calculated following the THI formula by McGregor & and Nieuwolt (1998), shown in Equation 1. Where: *THI* = Temperature Humidity Index (°C), *T* = Air Temperature (°C), *RH* = Relative Humidity (%).

$$THI = 0.8\,T + (RH \times T)/500 \tag{1}$$

Table 2 shows the categories for THI values. The categories of THI used in this study follow the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), which are modified by Effendy (2007) for tropical climate use. Ideal environments perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Table 2. THI value categories

| THI value (°C) | Category |
|---|---|
| $21 \geq THI \leq 24$ | Comfortable |
| $25 \geq THI \leq 27$ | Less comfortable |
| $THI > 27$ | Not comfortable |

## 3. Results and discussions

### 3.1 The structure of vegetation

There are two sides of pedestrian corridors at Jalan Kyai Tapa: university and terminal. Each side is divided into three segments. At segment I of Jalan Kyai Tapa, university side, 30 trees comprise six species. The canopy diameter varies from 1.5 – 6.4 m, and the height varies from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are five trees of *Casuarina equisetifolia*, 2 of Artocarpus heterophyllus, and 1 of *Cerbera manghas*. The vegetation structure of segment I, the university side, is shown in Table 3.

In segment II, there are a total of 17 trees that consist of 5 different species, which are seven trees of *Ficus virens*, six trees of *Mimusops elengi*, two trees of *Cerbera mangas*, one tree of *Samanea saman*, and one tree of *Muntingia calabura*. The canopy diameter at segment II ranges from 3 – 9 m, and the tree height from 3.2 – 11.2 m. The vegetation structure of segment II is summarized in Table 4. Segment III has the highest number of trees compared to Segment I and II. There are 37 trees of 7 species with the canopy diameter varying from 3.2 – 7 m and the tree height ranging from 6 – 9 m. This segment is dominated by *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of segment III is shown in Table 5.The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to or from the terminal.

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Table 3. Vegetation structure at segment I, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| I | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

Table 4. Vegetation structure at segment II, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| II | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

At segment I of the Terminal side, there are 21 trees of 5 species whose canopy diameter varies from 3 – 5 m and the height varies from 6 – 10.8 m. This segment has 14 trees of

*Handroanthus chrysotrichus*, three trees of *Swietenia mahagoni*, one tree of *Samanea saman*, one tree of *Casuarina equisetifolia*, and one tree of *Pterocarpus indicus*.

Table 5. Vegetation structure at segment III, university side

| **Segment** | **Point** | **Tree Name** | | **Tree Size (m)** | | **Number** |
|---|---|---|---|---|---|---|
| | | **Local Name** | **Latin Name** | **Canopy Diameter** | **Height** | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| | T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| | T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| | T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

In segment II, there are only three trees: 2 of Casuarina equisetifolia and 1 of *Pterocarpus indicus*. In segment III, seven trees consist of 7 of *Pterocarpus indicus*, 2 of Casuarina equisetifolia, and 1 of *Ficus benjamina*. The canopy diameter varies from 2 – 4 m, and the height varies from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

Table 6. Vegetation structure at segment I, II, III, terminal side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| I | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| II | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| III | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

In previous studies, a more expansive tree canopy and thicker leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). Trees with wider crown diameters provided a larger shaded area, improving thermal comfort (Boukhabla & Alkama, 2012). The most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). Tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). The diameter of the tree canopy in the study area is mostly less than 5 meters. This length may not be extensive enough to improve air temperature adequately.

### 3.2 The thermal environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured at 27 points on the university side and 16 points on the terminal side. At the university side (Figure 3), the average air temperature at 08:00 ranges from 30.16-31.29°C.

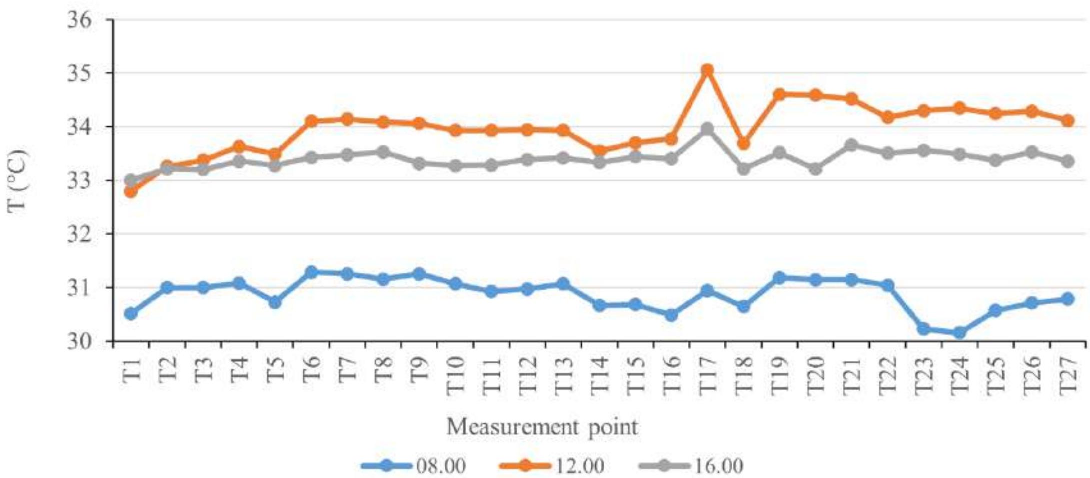


Figure. 3 The average temperature of Jalan Kyai Tapa, university side

At 08:00, the lowest air temperature is found at T24 (segment II), and the highest is found at T6 (segment I). The average air temperature at 12:00 ranges from 32.8-35.1°C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperature at 16:00 ranges from 33-34 °C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered less comfortable for human activities.

At the terminal side (Figure 4), the average air temperature at 08:00 ranges from 30.07-31.33°C. The lowest air temperature is found at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 12:00 ranges from 33.71-36.03 °C; the lowest is at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 16:00 ranges from 33.37-34.67 °C, the lowest at T1 (segment I) and the highest at T9 (segment II). Although the air temperature ranges differ in three observed times, all three segments' lowest air temperature is found at T1 and the highest at T9. Based on these values, the air temperature of the terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

Figure 5 shows the average relative humidity measured at the university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, the lowest at T26 (segment II) and the highest at T18 (segment II). This temperature is categorized as less comfortable for humans.

At 12:00, the average relative humidity ranges from 56.21 – 61.46%, the lowest at T26 (segment II) and the highest at T9 (segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%; the lowest is at T17 (segment II), and the highest is at T4 (segment I). The average relative humidity at 12:00 and 16:00 is considered comfortable for humans.

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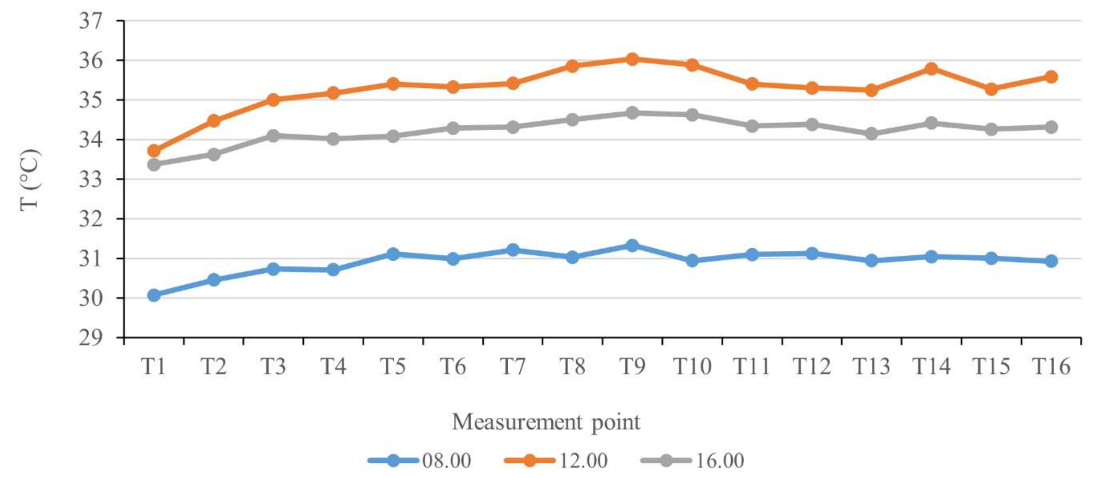


Figure. 4 The average temperature of Jalan Kyai Tapa, terminal side

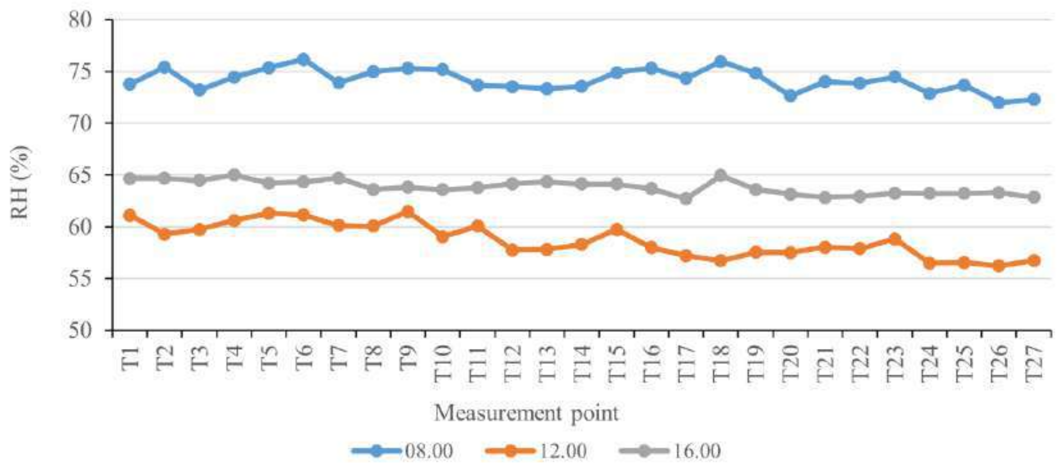


Figure. 5 Average relative humidity of Jalan Kyai Tapa, university side

The average relative humidity measured at the terminal side is shown in Figure 6. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, the lowest at T10 (segment I) and the highest at T4 (segment I). This temperature is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, the lowest at T14 (segment III) and the highest at T1 (segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, the lowest at T7 (segment II) and the highest at T1 (segment I). The average relative humidity at 12:00 and 16:00 is considered comfortable for humans.

Additionally, we measured the wind speed at the university side (Figure 7) and terminal side (Figure 8) of Jalan Kyai Tapa. Generally, the average wind speed at the terminal side is slightly higher than the university side, possibly due to fewer trees at the terminal side. At the terminal side, the average is 33.41 km/hour; at the university, the average is 32.86 km/hour.

According to the Beaufort Scale (Stewart, 2008), a 29-38 km/hour wind speed is considered a fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00, and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

In previous studies, canopy shape is essential in distributing air temperature (Fabbri et al., 2017). Shade from the tree canopy affects plant evapotranspiration, which increases relative humidity and absorbs heat energy, leading to decreased air temperature (Perini et al., 2018) and decreased soil temperature (Morakinyo et al., 2018). At T1 on the university side, although there were no trees, the average air temperature was lowest, and at T17, it was highest at 12:00 and

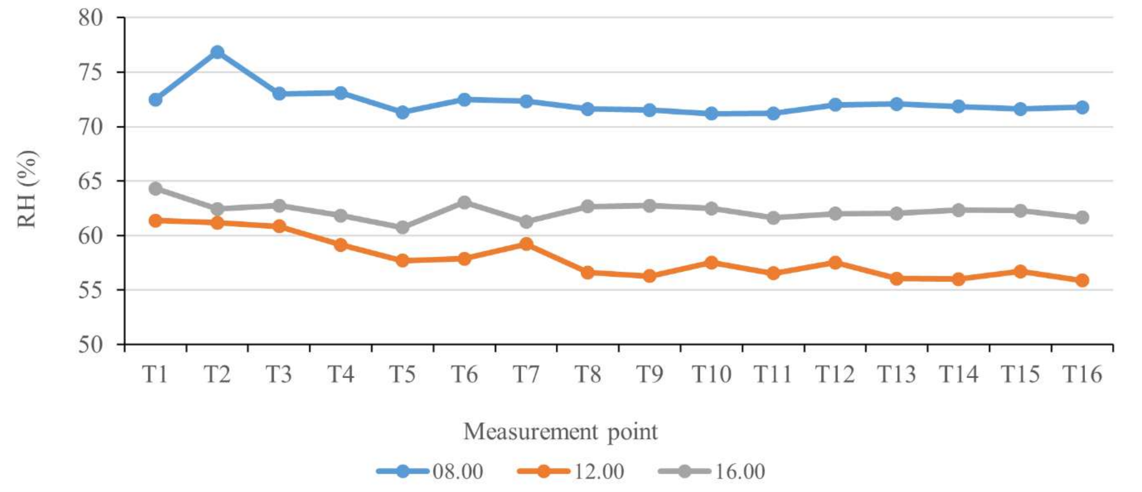


Figure. 6 Average relative humidity of Jalan Kyai Tapa, terminal side

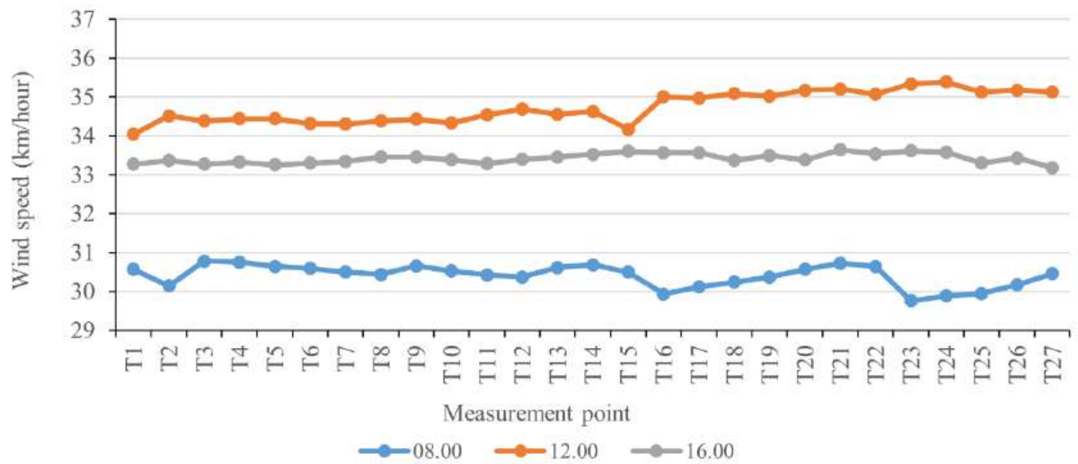


Figure. 7 Average wind speed of Jalan Kyai Tapa, university side

16:00, despite the presence of *Mimusops elengi* trees. However, at 08:00, T24 had the lowest temperature, and T6 had the highest. T6 and T24 had *Ficus virens* and *Mimusops elengi* trees nearby, but there were more trees in T24.

The different trends between the morning (08:00) and afternoon (12:00 and 16:00) observations are likely related to the evapotranspiration activity of the trees throughout the day. Evapotranspiration is driven by solar radiation, and its rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning to be more pronounced than in the afternoon (Sharmin et al., 2023).

### 3.3 Temperature heat index

We estimate the average THI at the university and terminal sides based on the measured air temperature and relative humidity in the study area. The average THI of the university side (Figure 9) at 08:00 ranges from 28.5-29.8 °C, with the lowest average THI found at T24 (segment III) and the highest at T6 (segment I). At 12:00, the average THI ranges from 30.2-31.6 °C; the lowest is T1 (segment I), and the highest is T20 (segment III). The average THI at 16:00 ranges from 30.6-31.4 °C; the lowest is T1 (segment I), and the highest is T17 (segment II). The average THI at 08:00, 12:00, and 16:00 is considered uncomfortable. The most uncomfortable time is at 12:00.

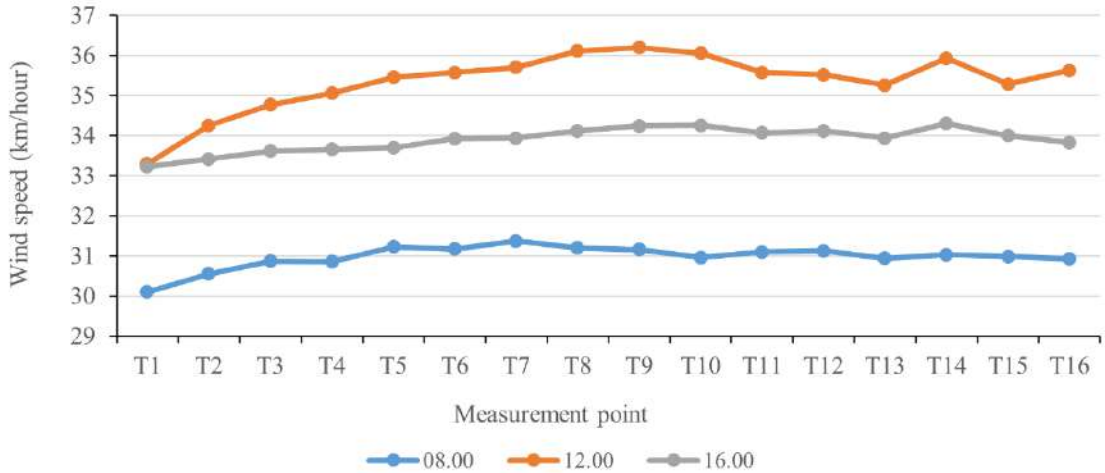


Figure. 8 Average wind speed of Jalan Kyai Tapa, terminal side

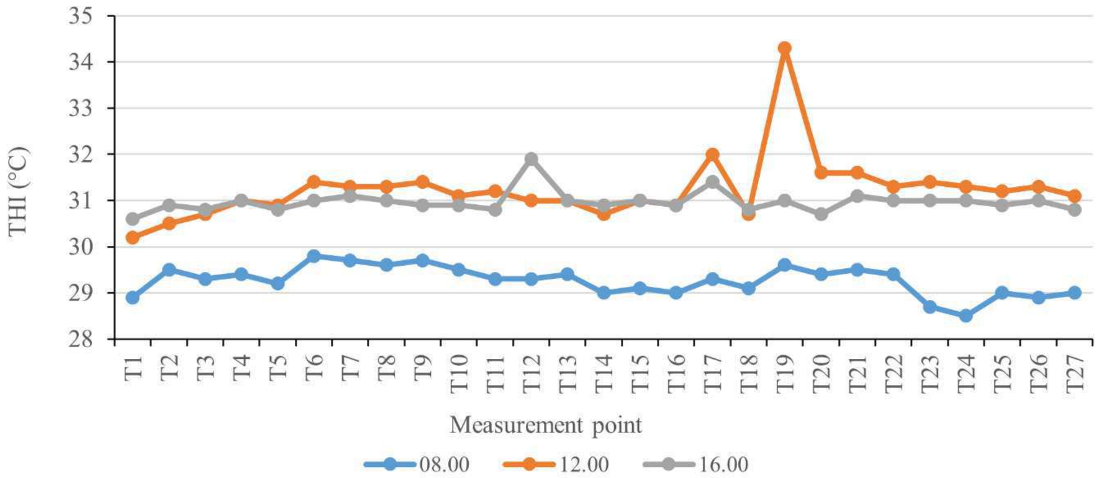


Figure. 9 The average THI on the university side

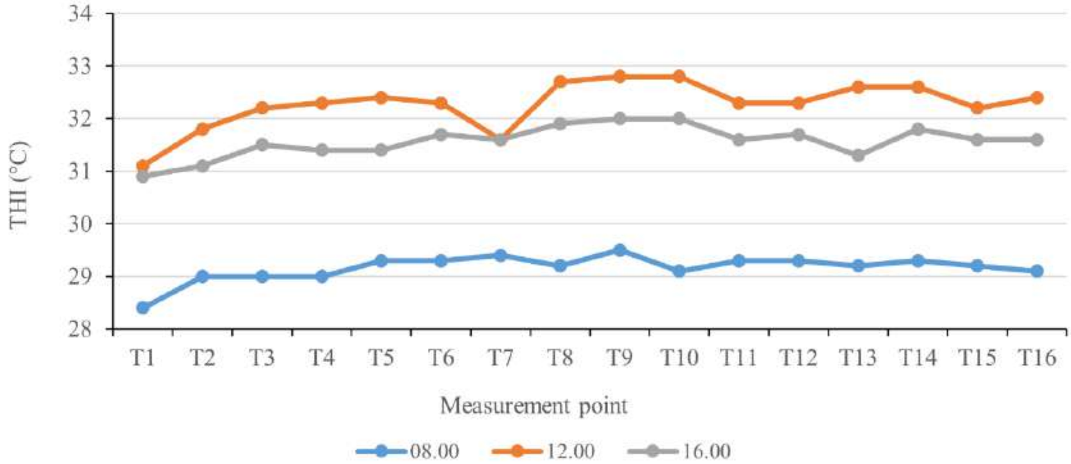


Figure. 10 The average THI at the terminal side

Figure 10 shows the average THI at the terminal side. The average THI at 08:00 ranges from 28.4-29.5 °C, with the lowest THI at T1 (segment I) and the highest at T9 (segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 16:00 ranges from 30.9-32.0 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 08:00,

12:00, and 16:00 is considered uncomfortable. Like the university side, the most uncomfortable time is at 12:00.

### 3.4 Factors that influence thermal comfort

According to the results, at the university side segments I, II, and II, there are 84 trees with varying canopy diameters from 1.5 – 9.0 m and varying heights from 3.2 – 11.2 m. Meanwhile, at the terminal side segments I, II, and II, there are 31 trees with varying canopy diameters from 2.0 – 5.0 m and varying heights from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameters. Trees with wide canopy diameters provide more expansive shaded areas, improving thermal comfort (Boukhabla & Alkama, 2012). More expansive tree canopy and denser leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

Several factors possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters: foliage shape and dimensions, trunk height, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). The shape of a tree canopy is essential in distributing air temperature (Fabbri et al., 2017). The shade from the tree canopy influences the plants' evapotranspiration, increasing relative humidity and absorbing thermal energy that decreases air temperature (Perini et al., 2018) and decreases the ground temperature (Morakinyo et al., 2018). An existing study found that the most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is a one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also essential because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely more significant than canopy diameter and tree height.

Furthermore, tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Wang & Akbari, 2016). Concerning the results of this study, the trees' canopy diameter in the study area might not be wide enough to provide adequate improvement to the air temperature, considering the majority of the tree's canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to more accurately determine the cause of uncomfortable outdoor areas.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This condition is similar to what we found during field measurement at the university side, where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. An existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that T1 has the lowest average air temperature at the university side, and T17 has the highest temperature at 12:00 and 16:00. However, there is no tree at T1. There is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has *virens* and *Mimusops elengi* nearby, but the number of trees is more significant at T24. The

different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation, and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause trees' cooling benefits in the morning to be more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the difference in tendency between morning and afternoon observations. As for the afternoon phenomenon, where T1 (no tree) has the lowest average air temperature, and T17 (with tree) has the highest, possible canopy-associated warming occurred during observations. Sharmin et al. (2023) conducted a study to determine the cooling benefits of 10 urban tree species considering the tree traits and microclimatic conditions in suburban areas. The study found that there was canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases by 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with the highest LAI has the lowest sub-canopy warming effect. The heat from nearby buildings can also cause the sub-canopy warming effect. A study by Alonzo et al. (2021) conducted in Washington DC found that trees along streets have a less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under-tree canopy and surrounding surfaces. This condition further supports that the air temperature under trees might be higher than the ambient air temperature, mainly if buildings like the study area surround the area. This condition may also explain why such a phenomenon is not found on the terminal side, considering the terminal side has fewer structures and buildings than the university side. On a side note, it is worth noting that T1 is also located near a small water body, which may also help decrease the air temperature due to water body evaporation (Chen et al., 2023).

In another case, T9 of the terminal side shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter, so we suggest it cannot provide the proper shade to cool down the air temperature. We mentioned that some spots with Casuarina equisetifolia at the university have better thermal comfort than *Mimusops elengi*. This condition indicates that vegetation species alone cannot determine thermal comfort. It is also related to the planting distance, design, and other elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the university side has better thermal comfort than the terminal side. The university side also has more trees and less pavement coverage than the terminal. Trees can improve thermal comfort, and to optimize tree function in pedestrian corridors, we should consider tree characteristics and arrangement. From the results of this study, we discussed that various factors and the trees determine the thermal comfort of pedestrian corridors' influence on microclimate, which can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during the morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically in measuring LAI and the distance between trees. Therefore, further research is required before proposing recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4. Conclusion

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01-31.54°C and the relative humidity ranges from 56.19 – 57.74%. The average air temperature

and relative humidity at Jalan Kyai Tapa are 31.2°C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52°C, which is categorized as uncomfortable. In areas with small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas with large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, they do not adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort, as we found a measurement point with no tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design for creating comfortable pedestrian corridors.

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**Author Contribution**
Conceptualization, N.I.S.; Methodology, N.I.S.; Analysis, N.I.S., D.D., R.F.; Investigation, N.I.S., R.F.; Writing – Original Draft Preparation, N.I.S.; Writing – Review & Editing, R.F., D.D., R.F.; and Funding Acquisition, N.I.S.

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

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## Abstract

The increasing number of motorized vehicles in Jakarta is causing environmental damage and can harm human health. In recent years, the Jakarta local government has the vision to focus on improving the human mobility network, including the pedestrian networks. As a heavily trafficked road, Jalan Kyai Tapa, West Jakarta, is used by many people. However, it may feel uncomfortable to walk there due to heat and sun exposure, which is compounded by extensive pavement coverage. The thermal condition of the pedestrian corridor is essential to create a comfortable walking experience. The objective of this study was to analyze the thermal comfort of the pedestrian corridors at Jalan Kyai Tapa concerning the landscape composition, including vegetation structure and pavement. This study was conducted quantitatively. This study identified the vegetation structure, including the tree species, canopy diameter, and height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate thermal comfort using the Temperature Humidity Index (THI). The results showed that the air temperature ranges from 31.01°C to 31.54°C, and the relative humidity ranges from 56.19% to 57.74%. The average THI value is 28.52 °C, which falls into the comfortable category. Despite having relatively wide canopies and providing shade, the trees in this pedestrian corridor do not seem to improve the thermal environment enough to achieve comfortable conditions for pedestrians. Interestingly, the result shows that, at certain observation times, points without trees had lower air temperatures compared to other spots with trees. Trees may not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with more expansive canopies can be less comfortable than spots near trees with smaller canopies. Tree species and the planting spacing determine the efficiency of trees to improve thermal comfort.

**Keywords**: Koridor; Pedestrian way; Thermal comfort; Vegetation.

## 1. Introduction

The urban population has kept increasing in the past few decades. The population growth in Jakarta from 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase follows the increase in motor vehicles. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, infamous for its severe traffic congestion due to overloaded motor vehicles, would suffer more. Increasing the number of motor vehicles means more emissions of air pollutants and greenhouse gases that could eventually harm human health and the environment. If the environment is damaged, pedestrians are the most

impacted group of road users, as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

A roadside greenbelt is a linear green open space formed by landscape elements, such as trees and shrubs, providing users comfort, safety, and beauty (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban areas play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (Nowak et al., 2006; Biao et al., 2010; Simangunsong et al., 2021; Simangunsong & Fitri, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spagenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin & Waryono, 2010), such as ameliorating microclimate, reducing pollutants, including particle and gas, controlling glare, producing oxygen (Simangunsong et al., 2021; Simangunsong & Fitri, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. The vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions to optimize the role of roadside vegetation. Additionally, selecting the local species would make the adaptation more accessible for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only on a micro scale but also at a city scale.

Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. The direct benefits of roadside greenbelts to humans are providing shade, user safety, and improving users' comfort, especially pedestrians and cyclists. The position of the greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if it is too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building–environment interaction, which includes various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and street width (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity directly influence THI, an index used to measure human body comfort. By paying attention to the thermal comfort of roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetics. Vegetation in roadside landscape serves as a view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, and the planting design and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etcetera). The interaction between softscape and hardscape determines thermal comfort.

Jakarta's local government initiated the concept of a Smart City in 2014 by improving the city based on six elements: Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to reduce traffic congestion, air pollution, citizen mobility, etcetera. Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infra-structure) revitalizes public facilities such as pedestrian corridors to support public

transportation. Dinas Bina Marga cooperates with the Institute for Transportation Development Policy (ITDP) Indonesia to plan a human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facilities for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road with two pedestrian corridors and green belts on the side. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Quite a lot of people use pedestrian corridors at Jalan Kyai Tapa. However, in the afternoon, it may feel uncomfortable to walk there due to heat and sunlight exposure, and significant coverages of pavements worsen that. The thermal condition of a pedestrian corridor is essential to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas but is still relatively limited in Indonesia. Existing studies have analyzed pedestrian corridors' comfort in Indonesia cities concerning its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). Only a few studies specifically focus on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). Even fewer studies exist on the thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta primarily relate to transit-oriented development concepts (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. This study analyzes the thermal comfort of pedestrian corridors at Jalan Kyai Tapa concerning its landscape composition, including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can briefly illustrate other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can help improve the pedestrian corridors in Jakarta.

## 2. Methods

### 2.1 Study area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a significant road passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot (Figure 1). There are two sides of pedestrian corridors at Jalan Kyai Tapa: (1) the terminal side (north side) and (2) the university side (south side).

The terminal side has a bus terminal, police station, and traffic gardens. Meanwhile, university buildings, hotels, restaurants, and other commercial buildings are on the university side. The tree information in the study area is collected for further analysis. When inventorying vegetation, existing studies created plots of 100 meters by 100 meters in broad areas, such as national parks (Haryadi et al., 2019; Maulidiyan et al., 2019), and created belt transects of 100 m in linear areas, such as roadsides (Danniswari & Nasrullah, 2017). Therefore, we divided the 300-meter-long pedestrian corridors into three segments, 100 m-long each. The study area and the segmentation are shown in Figure 2. The field data was collected from November 2021 until February 2022.

### 2.2 Data collection

The study is conducted quantitatively. We collect data on field air temperature, relative humidity, wind speed, tree species, tree height, and canopy diameter. Air temperature, relative humidity, and wind speed measurement points are distributed along the corridors. The measurement is done three times daily at 08:00, 12:00, and 16:00 for seven days during sunny weather using a digital thermohygrometer. The pedestrian corridors have two sides, the university side and the terminal side, with a length of 300 m. We observed both corridors and

divided each corridor into three segments 100 m long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to the smaller vegetation coverage on this side.

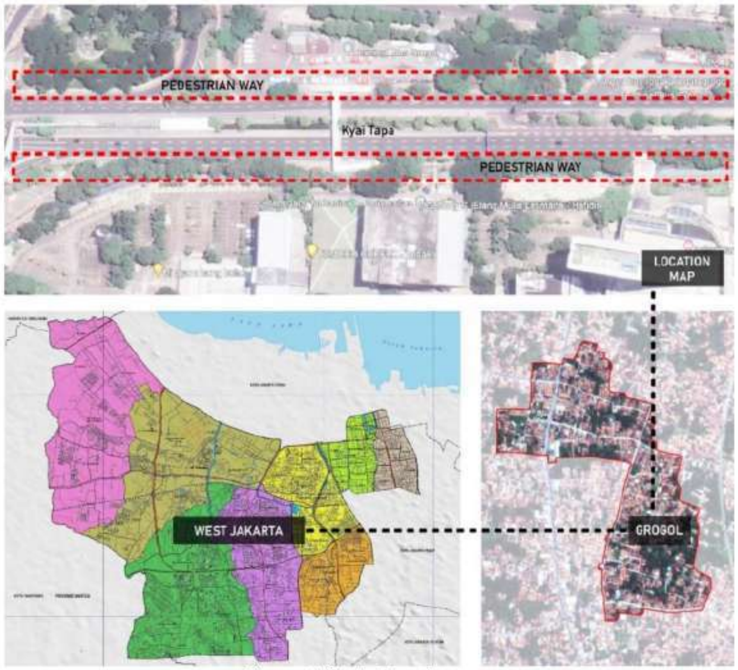

Figure. 1 Study location map

Figure. 2 Study area, the pedestrian corridors at Kyai Tapa, and the segmentation

### 2.3 Data analysis

The data are analyzed to calculate the Temperature Humidity Index. The THI is estimated to determine the equivalent temperature perceived by humans by considering the air temperature and relative humidity. This index has been widely used to measure the human body's comfort (Isnoor et al., 2021; Putri et al., 2021; Rusdayanti et al., 2021).

Table 1. Location and measurement points

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

Measured field air temperature and humidity are calculated following the THI formula by McGregor & and Nieuwolt (1998), shown in Equation 1. Where: $THI$ = Temperature Humidity Index (°C), $T$ = Air Temperature (°C), $RH$ = Relative Humidity (%).

$$THI = 0.8\,T + (RH \times T)/500 \quad (1)$$

Table 2 shows the categories for THI values. The categories of THI used in this study follow the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), which are modified by Effendy (2007) for tropical climate use. Ideal environments perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Table 2. THI value categories

| THI value (°C) | Category |
|---|---|
| $21 \geq THI \leq 24$ | Comfortable |
| $25 \geq THI \leq 27$ | Less comfortable |
| $THI > 27$ | Not comfortable |

## 3. Results and discussions

### 3.1 The structure of vegetation

There are two sides of pedestrian corridors at Jalan Kyai Tapa: university and terminal. Each side is divided into three segments. At segment I of Jalan Kyai Tapa, university side, 30 trees comprise six species. The canopy diameter varies from 1.5 – 6.4 m, and the height varies from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are five trees of *Casuarina equisetifolia*, 2 of Artocarpus heterophyllus, and 1 of *Cerbera manghas*. The vegetation structure of segment I, the university side, is shown in Table 3.

In segment II, there are a total of 17 trees that consist of 5 different species, which are seven trees of *Ficus virens*, six trees of *Mimusops elengi*, two trees of *Cerbera mangas*, one tree of *Samanea saman*, and one tree of *Muntingia calabura*. The canopy diameter at segment II ranges from 3 – 9 m, and the tree height from 3.2 – 11.2 m. The vegetation structure of segment II is summarized in Table 4. Segment III has the highest number of trees compared to Segment I and II. There are 37 trees of 7 species with the canopy diameter varying from 3.2 – 7 m and the tree height ranging from 6 – 9 m. This segment is dominated by *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of segment III is shown in Table 5.The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to or from the terminal.

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Table 3. Vegetation structure at segment I, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| I | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

Table 4. Vegetation structure at segment II, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| II | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

At segment I of the Terminal side, there are 21 trees of 5 species whose canopy diameter varies from 3 – 5 m and the height varies from 6 – 10.8 m. This segment has 14 trees of

*Handroanthus chrysotrichus*, three trees of *Swietenia mahagoni*, one tree of *Samanea saman*, one tree of *Casuarina equisetifolia*, and one tree of *Pterocarpus indicus*.

Table 5. Vegetation structure at segment III, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| III | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| | T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| | T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| | T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

In segment II, there are only three trees: 2 of Casuarina equisetifolia and 1 of *Pterocarpus indicus*. In segment III, seven trees consist of 7 of *Pterocarpus indicus*, 2 of Casuarina equisetifolia, and 1 of *Ficus benjamina*. The canopy diameter varies from 2 – 4 m, and the height varies from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

Table 6. Vegetation structure at segment I, II, III, terminal side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| I | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| II | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| III | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

In previous studies, a more expansive tree canopy and thicker leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). Trees with wider crown diameters provided a larger shaded area, improving thermal comfort (Boukhabla & Alkama, 2012). The most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). Tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). The diameter of the tree canopy in the study area is mostly less than 5 meters. This length may not be extensive enough to improve air temperature adequately.

### 3.2 The thermal environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured at 27 points on the university side and 16 points on the terminal side. At the university side (Figure 3), the average air temperature at 08:00 ranges from 30.16-31.29°C.

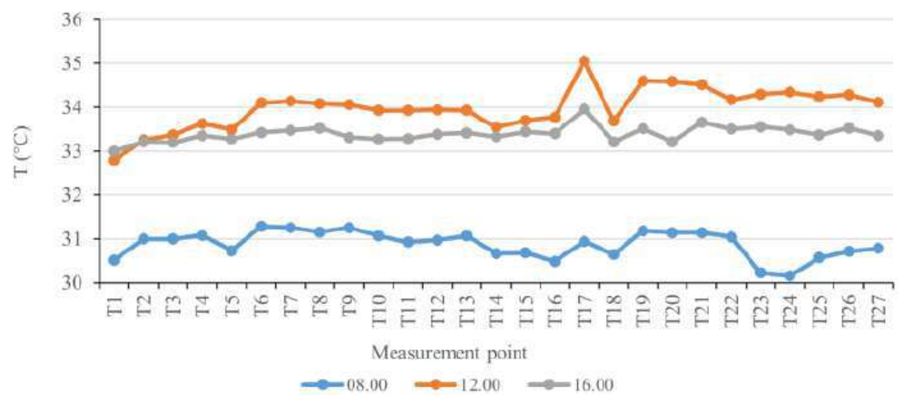


Figure. 3 The average temperature of Jalan Kyai Tapa, university side

At 08:00, the lowest air temperature is found at T24 (segment II), and the highest is found at T6 (segment I). The average air temperature at 12:00 ranges from 32.8-35.1°C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperature at 16:00 ranges from 33-34 °C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered less comfortable for human activities.

At the terminal side (Figure 4), the average air temperature at 08:00 ranges from 30.07-31.33°C. The lowest air temperature is found at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 12:00 ranges from 33.71-36.03 °C; the lowest is at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 16:00 ranges from 33.37-34.67 °C, the lowest at T1 (segment I) and the highest at T9 (segment II). Although the air temperature ranges differ in three observed times, all three segments' lowest air temperature is found at T1 and the highest at T9. Based on these values, the air temperature of the terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

Figure 5 shows the average relative humidity measured at the university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, the lowest at T26 (segment II) and the highest at T18 (segment II). This temperature is categorized as less comfortable for humans.

At 12:00, the average relative humidity ranges from 56.21 – 61.46%, the lowest at T26 (segment II) and the highest at T9 (segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%; the lowest is at T17 (segment II), and the highest is at T4 (segment I). The average relative humidity at 12:00 and 16:00 is considered comfortable for humans.

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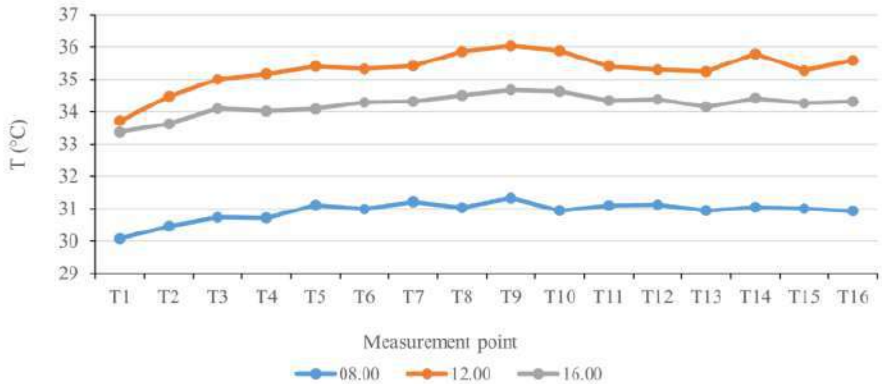


Figure . 4 The average temperature of Jalan Kyai Tapa, terminal side

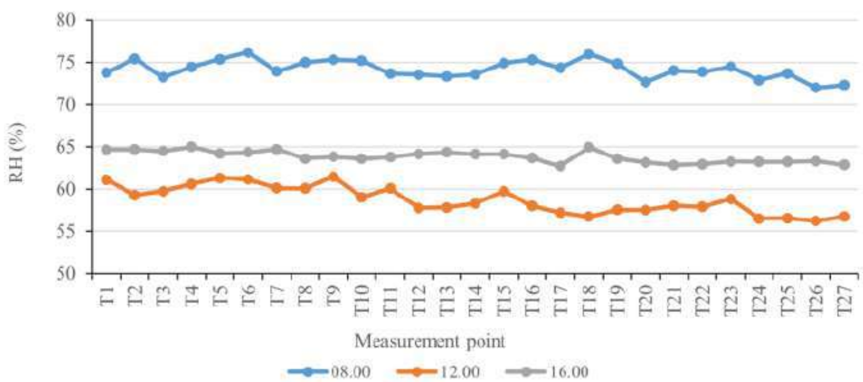


Figure. 5 Average relative humidity of Jalan Kyai Tapa, university side

The average relative humidity measured at the terminal side is shown in Figure 6. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, the lowest at T10 (segment I) and the highest at T4 (segment I). This temperature is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, the lowest at T14 (segment III) and the highest at T1 (segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, the lowest at T7 (segment II) and the highest at T1 (segment I). The average relative humidity at 12:00 and 16:00 is considered comfortable for humans.

Additionally, we measured the wind speed at the university side (Figure 7) and terminal side (Figure 8) of Jalan Kyai Tapa. Generally, the average wind speed at the terminal side is slightly higher than the university side, possibly due to fewer trees at the terminal side. At the terminal side, the average is 33.41 km/hour; at the university, the average is 32.86 km/hour.

According to the Beaufort Scale (Stewart, 2008), a 29-38 km/hour wind speed is considered a fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00, and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

In previous studies, canopy shape is essential in distributing air temperature (Fabbri et al., 2017). Shade from the tree canopy affects plant evapotranspiration, which increases relative humidity and absorbs heat energy, leading to decreased air temperature (Perini et al., 2018) and decreased soil temperature (Morakinyo et al., 2018). At T1 on the university side, although there were no trees, the average air temperature was lowest, and at T17, it was highest at 12:00 and

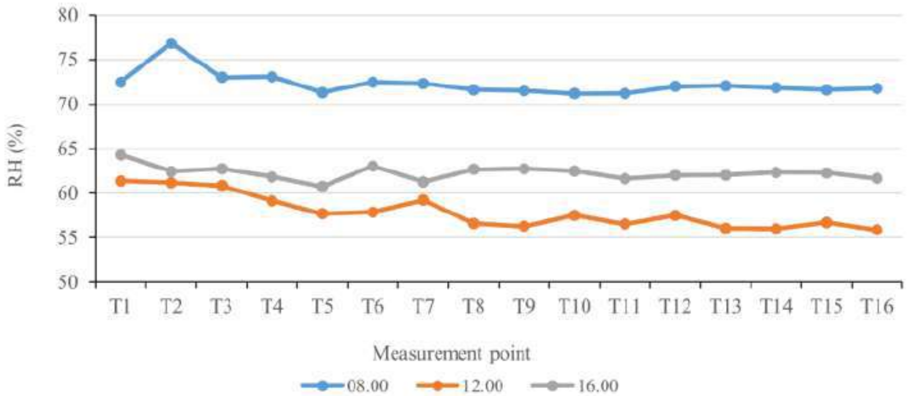


Figure. 6 Average relative humidity of Jalan Kyai Tapa, terminal side

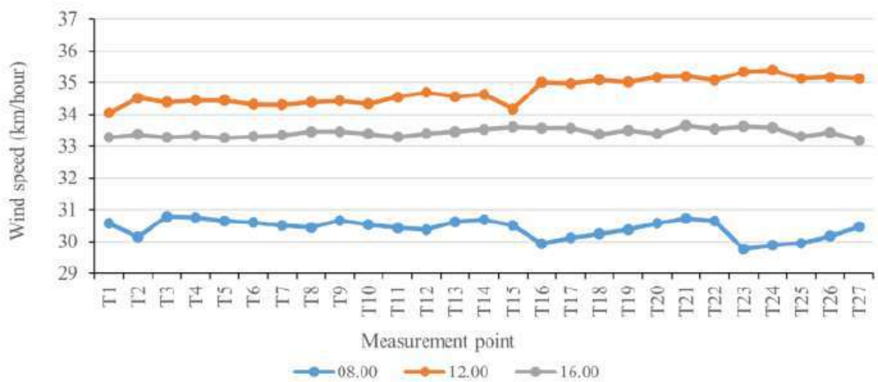


Figure. 7 Average wind speed of Jalan Kyai Tapa, university side

16:00, despite the presence of *Mimusops elengi* trees. However, at 08:00, T24 had the lowest temperature, and T6 had the highest. T6 and T24 had *Ficus virens* and *Mimusops elengi* trees nearby, but there were more trees in T24.

The different trends between the morning (08:00) and afternoon (12:00 and 16:00) observations are likely related to the evapotranspiration activity of the trees throughout the day. Evapotranspiration is driven by solar radiation, and its rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning to be more pronounced than in the afternoon (Sharmin et al., 2023).

### 3.3 Temperature heat index

We estimate the average THI at the university and terminal sides based on the measured air temperature and relative humidity in the study area. The average THI of the university side (Figure 9) at 08:00 ranges from 28.5-29.8 °C, with the lowest average THI found at T24 (segment III) and the highest at T6 (segment I). At 12:00, the average THI ranges from 30.2-31.6 °C; the lowest is T1 (segment I), and the highest is T20 (segment III). The average THI at 16:00 ranges from 30.6-31.4 °C; the lowest is T1 (segment I), and the highest is T17 (segment II). The average THI at 08:00, 12:00, and 16:00 is considered uncomfortable. The most uncomfortable time is at 12:00.

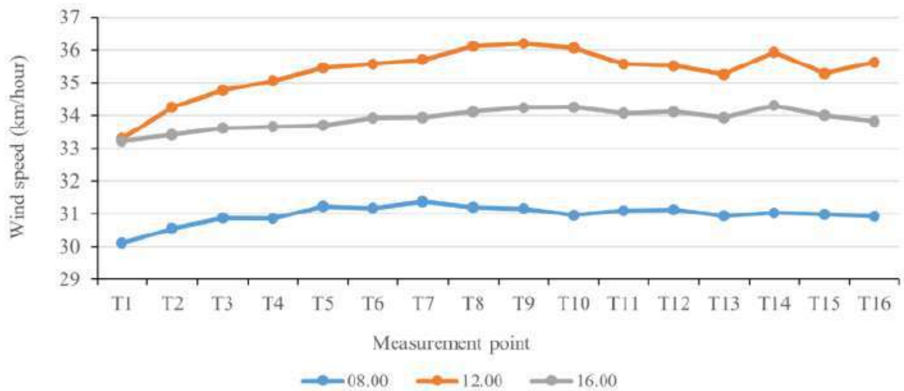


Figure. 8 Average wind speed of Jalan Kyai Tapa, terminal side

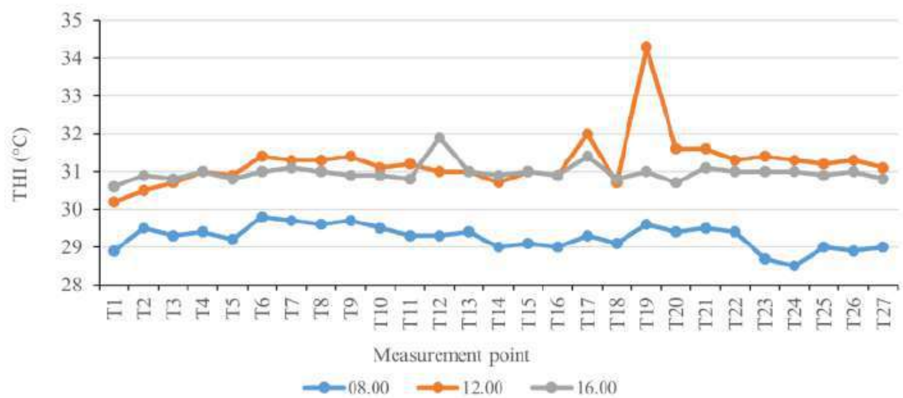


Figure. 9 The average THI on the university side

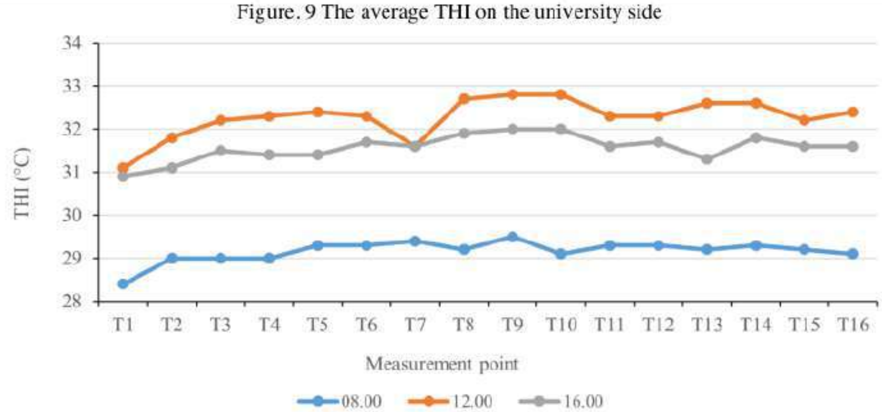


Figure. 10 The average THI at the terminal side

Figure 10 shows the average THI at the terminal side. The average THI at 08:00 ranges from 28.4-29.5 °C, with the lowest THI at T1 (segment I) and the highest at T9 (segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 16:00 ranges from 30.9-32.0 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 08:00,

12:00, and 16:00 is considered uncomfortable. Like the university side, the most uncomfortable time is at 12:00.

### 3.4 Factors that influence thermal comfort

According to the results, at the university side segments I, II, and II, there are 84 trees with varying canopy diameters from 1.5 – 9.0 m and varying heights from 3.2 – 11.2 m. Meanwhile, at the terminal side segments I, II, and II, there are 31 trees with varying canopy diameters from 2.0 – 5.0 m and varying heights from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameters. Trees with wide canopy diameters provide more expansive shaded areas, improving thermal comfort (Boukhabla & Alkama, 2012). More expansive tree canopy and denser leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

Several factors possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters: foliage shape and dimensions, trunk height, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). The shape of a tree canopy is essential in distributing air temperature (Fabbri et al., 2017). The shade from the tree canopy influences the plants' evapotranspiration, increasing relative humidity and absorbing thermal energy that decreases air temperature (Perini et al., 2018) and decreases the ground temperature (Morakinyo et al., 2018). An existing study found that the most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is a one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also essential because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely more significant than canopy diameter and tree height.

Furthermore, tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Wang & Akbari, 2016). Concerning the results of this study, the trees' canopy diameter in the study area might not be wide enough to provide adequate improvement to the air temperature, considering the majority of the tree's canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to more accurately determine the cause of uncomfortable outdoor areas.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This condition is similar to what we found during field measurement at the university side, where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. An existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that T1 has the lowest average air temperature at the university side, and T17 has the highest temperature at 12:00 and 16:00. However, there is no tree at T1. There is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has *virens* and *Mimusops elengi* nearby, but the number of trees is more significant at T24. The

different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation, and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause trees' cooling benefits in the morning to be more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the difference in tendency between morning and afternoon observations. As for the afternoon phenomenon, where T1 (no tree) has the lowest average air temperature, and T17 (with tree) has the highest, possible canopy-associated warming occurred during observations. Sharmin et al. (2023) conducted a study to determine the cooling benefits of 10 urban tree species considering the tree traits and microclimatic conditions in suburban areas. The study found that there was canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases by 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with the highest LAI has the lowest sub-canopy warming effect. The heat from nearby buildings can also cause the sub-canopy warming effect. A study by Alonzo et al. (2021) conducted in Washington DC found that trees along streets have a less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under-tree canopy and surrounding surfaces. This condition further supports that the air temperature under trees might be higher than the ambient air temperature, mainly if buildings like the study area surround the area. This condition may also explain why such a phenomenon is not found on the terminal side, considering the terminal side has fewer structures and buildings than the university side. On a side note, it is worth noting that T1 is also located near a small water body, which may also help decrease the air temperature due to water body evaporation (Chen et al., 2023).

In another case, T9 of the terminal side shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter, so we suggest it cannot provide the proper shade to cool down the air temperature. We mentioned that some spots with Casuarina equisetifolia at the university have better thermal comfort than *Mimusops elengi*. This condition indicates that vegetation species alone cannot determine thermal comfort. It is also related to the planting distance, design, and other elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the university side has better thermal comfort than the terminal side. The university side also has more trees and less pavement coverage than the terminal. Trees can improve thermal comfort, and to optimize tree function in pedestrian corridors, we should consider tree characteristics and arrangement. From the results of this study, we discussed that various factors and the trees determine the thermal comfort of pedestrian corridors' influence on microclimate, which can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during the morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically in measuring LAI and the distance between trees. Therefore, further research is required before proposing recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4. Conclusion

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01-31.54°C and the relative humidity ranges from 56.19 – 57.74%. The average air temperature

and relative humidity at Jalan Kyai Tapa are 31.2°C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52°C, which is categorized as uncomfortable. In areas with small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas with large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, they do not adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort, as we found a measurement point with no tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design for creating comfortable pedestrian corridors.

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**Author Contribution**
Conceptualization, N.I.S.; Methodology, N.I.S.; Analysis, N.I.S., D.D., R.F.; Investigation, N.I.S., R.F.; Writing – Original Draft Preparation, N.I.S.; Writing – Review & Editing, R.F., D.D., R.F.; and Funding Acquisition, N.I.S.

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Jurnal : Journal of Environmental Science and Sustainable Development

Penulis : Nur Intan Simangunsong, Reza Fauzi, Dibyanti Danniswari, Rini Fitri

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The title is:
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The keywords are:
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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

**Abstract**

The increase of motor vehicles in Jakarta leads to environmental degradation and eventually can harm human health. When the environment is damaged, pedestrians are the most impacted group of road users. In the past few years, the local government of Jakarta has a vision to focus on improving human mobility networks including pedestrian networks. As a road with busy traffic, Jalan Kyai Tapa, West Jakarta, is used by many people, but it may feel not comfortable to walk there due to heat and sun exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. This study is done quantitatively. We identify the vegetation structure of Jalan Kyai Tapa including the tree species, canopy diameter, and tree height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate the thermal comfort using Temperature Humidity Index (THI). The results show that the air temperature at Jalan Kyai Tapa ranges from 31.01 °C - 31.54 °C and the relative humidity ranges from 56.19% - 57.74%. The average THI value at Jalan Kyai Tapa is 28.52 °C, which is considered as not comfortable. Despite having relatively wide canopy and can provide shade, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the thermal environment to reach a comfortable state for pedestrians. Interestingly, the result shows that, at certain times, the spot shaded by a pedestrian bridge (hardscape structure) have lower air temperature compared to the spots shaded by trees. Trees might not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with wider canopy can be less comfortable than spots near trees with smaller canopy. Tree species and the planting spacing determine the efficiency of trees to improve the thermal comfort.

**Keywords**: corridor; pedestrian way; thermal comfort; vegetation.

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# 1 INTRODUCTION

The urban population keep increasing in the past few decades. The population growth in Jakarta 2010-2020 is about 0.92% (BPS DKI Jakarta, 2020). The population increase is followed by the increase of motor vehicle. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, that is infamous for its severe traffic congestion due to overload motor vehicles, would suffer more from this. Increasing motor vehicles means more emissions of air pollutants and greenhouse gases that eventually could harm human health and damage the environment. If the environment is damaged, pedestrians are the most impacted group of road users as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

Roadside greenbelt is a linear green open space that is formed by landscape elements, such as trees and shrubs, providing comfort, safety, and beauty for users (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban area play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (Akbari, 2001; Nowak, 2006; Lafortezza, 2009; Biao, 2010; Simangunsong, 2021 ; Simangunsong, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spangenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin, 2010), such as ameliorating microclimate, reducing pollutants including particle and gas, controlling glare, producing oxygen (Simangunsong, 2021; Simangunsong, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. To optimize the role of roadside vegetation, the vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions. Additionally, selecting the local species would make the adaptation easier for the vegetation (Syed, 2013). Vegetation at roadside greenbelts can improve the thermal environment, not only at a micro scale, but also at a city scale.

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Roadside greenbelts offer many benefits to the environment that indirectly benefits humans as well. Direct benefits of roadside greenbelts to humans are providing shades, users safety, and improving the comfortability for users, especially pedestrians and cyclists. The position of greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if too strong, but mild wind could improve users' thermal comfort, especially in a hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building – environment interaction, which include various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and width of street (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity are factors that directly influence Temperature Humidity Index (THI), an index that is used to measure human body comfort. By paying attention to the thermal comfort at roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than the thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetic. Vegetation at roadside landscape serves as view controller, physical barrier, microclimate regulator, wildlife habitat, and aesthetic function (Laurie, 1975). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, the planting design, and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etc.). The interaction between softscape and hardscape determines the thermal comfort.

Jakarta's local government initiated a concept of Smart City since 2014 by improving the city based on six elements of Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to improve traffic congestion, reduce air pollution, improve citizen mobility, etc. To support the public transportation, Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infrastructure) revitalizes public facility such as pedestrian corridors. Dinas Bina Marga cooperates with Institute for Transportation Development Policy (ITDP) Indonesia to plan human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facility for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road that has two pedestrian corridors with roadside greenbelts. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Pedestrian corridors at Jalan Kyai Tapa

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are used by quite a lot of people. However, in the afternoon, it may feel not comfortable to walk there due to heat and sun light exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, this study helps to serve an image of current pedestrian corridors in Jakarta. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can give a brief illustration of other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can be of help in improving the pedestrian corridors in Jakarta.

## 2 METHODS

### 2.1 Study Area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a major road that is passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot. There are two sides of pedestrian corridors at Jalan Kyai Tapa, (1) Terminal Side (north side) and (2) University Side (south side). At the Terminal Side, there are bus terminal, police station, and traffic gardens. Meanwhile, at the University Side, there are university buildings, hotels, restaurants, and other commercial buildings. The study area is 300 m-long and we divided it into three segments for the analysis. Each segment is 100 m-long. The study area and the segmentation are shown in Figure 1. The field data were collected in November 2021 until February 2022.


**Figure 1. Study area, the pedestrian corridors at Jalan Kyai Tapa, and the segmentation (Source: author's documentation (R.F), 2021)**

## 2.2 Data Collection

The study is conducted quantitatively. We collect data of field air temperature, relative humidity, wind speed, trees species, tree height, and canopy diameter. The measurement points for air temperature, relative humidity, and wind speed are distributed along the corridors. The measurement is done three times a day at 08:00, 12:00, and 16:00 for seven days during sunny weather using digital thermohygrometer. The pedestrian corridors have two sides, university side and terminal side, with a length of 300 m. We observe both corridors and divide each corridor into three segments of 100 m-long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to smaller vegetation coverage at this side.

**Table 1. Location and measurement points**

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

### 2.3 Data Analysis

The data are analyzed to calculate the Temperature Humidity Index (THI). THI is estimated to determine the equivalent temperature perceived by humans by considering the air temperature and relative humidity. This index is important to measure the human body's comfort. Measured field air temperature and humidity are calculated following the THI formula by Nieuwolt (1998).

$$THI = 0.8\,T + \frac{(RH \times T)}{500}$$

where:

THI = Temperature Humidity Index (°C)

T = Air Temperature (°C)

RH = Relative Humidity (%)

Table 2 shows the categories for THI values. The categories of THI used in this study follows the categories made by Nieuwolt (1998) and Emmanuel (2005), that are modified by Effendy (2007) for tropical climate use. Ideal environment that are perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie 1990).

**Tabel 2. THI Value Categories**

| THI value (°C) | Category |
|---|---|
| $21 \geq THI \leq 24$ | Comfortable |
| $25 \geq THI \leq 27$ | Less comfortable |
| $THI > 27$ | Not comfortable |

# 3 RESULTS AND DISCUSSIONS

## 3.1 The Vegetation Structure

There are two sides of pedestrian corridors at Jalan Kyai Tapa, which are University Side and Terminal Side. Each side is divided into three segments. At Segment I of Jalan Kyai Tapa University Side, there are 30 trees that consist of 6 different species. The canopy diameter varies from 1.5 – 6.4 m and the height vary from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are 5 trees of *Casuarina equisetifolia*, 2 trees of *Artocarpus heterophyllus*, and 1 tree of *Cerbera manghas*. The vegetation structure of Segment I, University Side, is shown in Table 3.

**Table 3. Vegetation Structure at Segment I, University Side**

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| **I** | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

At Segment II, there are a total of 17 trees that consist of 5 different species, which are 7 trees of *Ficus virens*, 6 trees of *Mimusops elengi*, 2 trees of *Cerbera manghas*, 1 tree of *Samanea saman*, and 1 tree of *Muntingia calabura*. The canopy diameter at Segment II ranges from 3 – 9 m and the tree height range from 3.2 – 11.2 m. The vegetation structure of Segment II is summarized in Table 4.

**Table 4. Vegetation Structure at Segment II, University Side**

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **II** | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

Segment III has the highest number of trees compared to Segment I and II. There are 37 trees that consist of 7 species with the canopy diameter vary from 3.2 – 7 m and the tree height range from 6 – 9 m. This segment is dominated with *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of Segment III is shown in Table 5.

**Table 5. Vegetation Structure at Segment III, University Side**

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to/from the terminal. At Segment I of Terminal side, there are 21 trees of 5 species with the canopy diameter varies from 3 – 5 m and the height vary from 6 – 10.8 m. This segment has 14 trees of *Handroanthus chrysotrichus*, 3 trees of *Swietenia mahagoni*, 1 tree of *Samanea saman*, 1 tree of *Casuarina equisetifolia*, and 1 tree of *Pterocarpus indicus*. At Segment II, there are only 3 trees, 2 trees of *Casuarina equisetifolia* and 1 tree of *Pterocarpus indicus*. At Segment III, there are 7 trees that consist of 7 trees of *Pterocarpus indicus*, 2 trees of *Casuarina equisetifolia*, and 1 tree of *Ficus benjamina*. The canopy diameter varies from 2 – 4 m and the height vary from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

**Table 6. Vegetation Structure at Segment I, II, III, Terminal Side**

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **I** | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| **II** | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| **III** | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

### 3.2 The Thermal Environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured on 27 points at the University Side and 16 points at the Terminal Side. At the University Side (Figure 2), the average air temperature at 08:00 ranges from 30.16 – 31.29 °C. The lowest air temperature is found at T24 (Segment II) and the highest is found at T6 (Segment I). The average air temperature at 12:00 ranges from 32.8 – 35.1 °C. The lowest air temperature is at T1 (Segment I) and the highest is at T17 (Segment II). The average air temperature at 16:00 ranges from 33 – 34 °C. The lowest air temperature is at T1 (Segment I) and the highest is at T17 (Segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered as **less comfortable** for human activities.

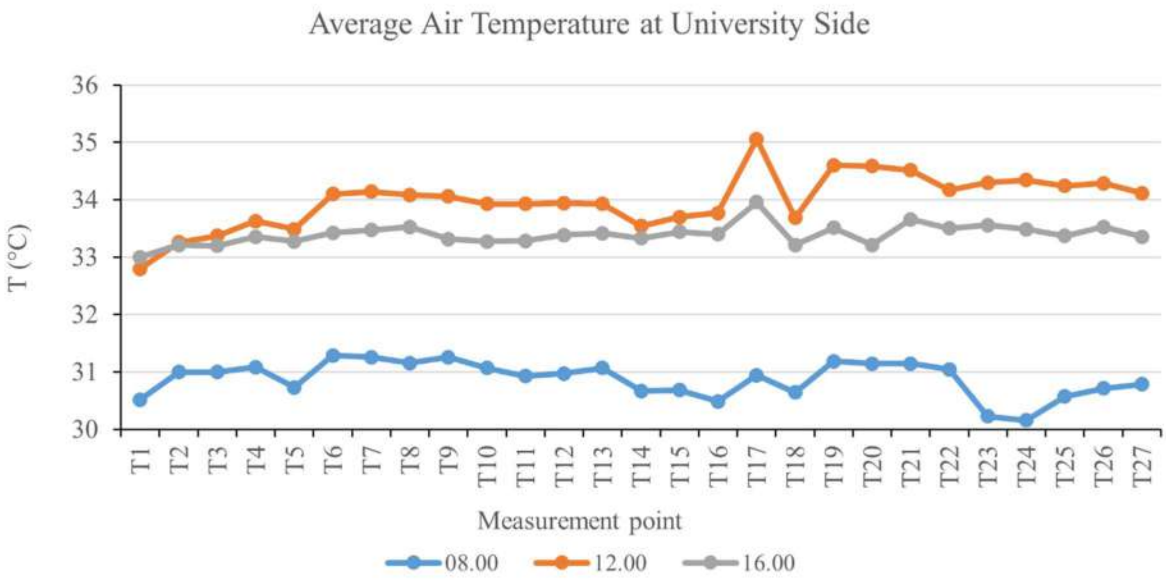


**Figure 2. Average temperature of Jalan Kyai Tapa, University Side (author's result (N.I.S), 2022)**

At the Terminal Side (Figure 3), the average air temperature at 08:00 ranges from 30.07 – 31.33 °C. The lowest air temperature is found at T1 (Segment I) and the highest is at T9 (Segment II). The average air temperature at 12:00 ranges from 33.71 – 36.03 °C, which the lowest is at T1 (Segment I) and the highest is at T9 (Segment II). The average air temperature at 16:00 ranges from 33.37 – 34.67 °C, which the lowest is at T1 (Segment I) and the highest is at T9 (Segment II). Although the air temperature ranges are different in three observed time, all three segments' lowest air temperature is found at T1 and the highest is at T9. Based on these values, the air temperature of the Terminal Side at 08:00, 12:00, and 16:00 is considered **less comfortable** for humans.

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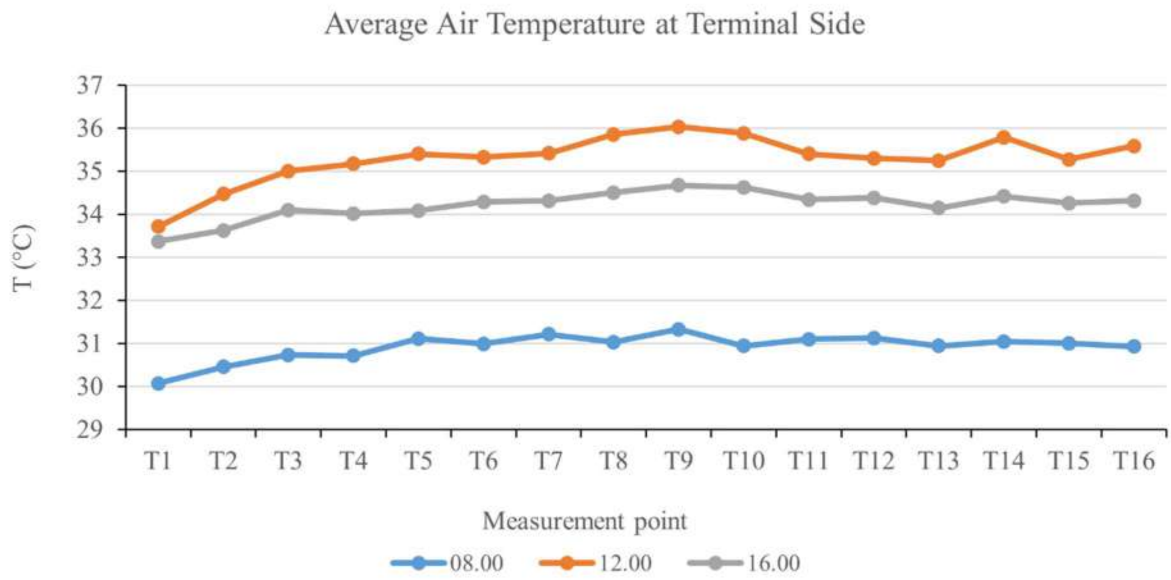


**Figure 3. Average temperature of Jalan Kyai Tapa, Terminal Side (author's result (N.I.S), 2022)**

Figure 4 shows the average relative humidity measured at the University Side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, which the lowest is at T26 (Segment II) and the highest is at T18 (Segment II). This is categorized as **less comfortable** for humans. At 12:00, the average relative humidity ranges from 56.21 – 61.46%, which the lowest is at T26 (Segment II) and the highest is at T9 (Segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%, which the lowest is at T17 (Segment II) and the highest is at T4 (Segment I). The average relative humidity at 12:00 and 16:00 are categorized as **comfortable** for humans.

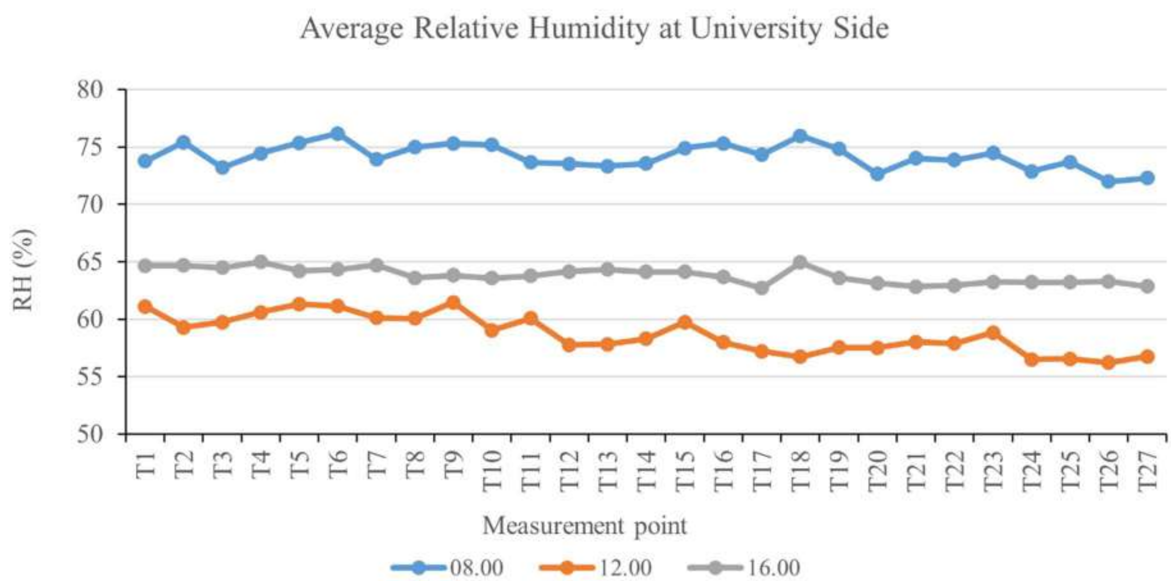


**Figure 4. Average relative humidity of Jalan Kyai Tapa, University Side (author's result (N.I.S), 2022)**

The average relative humidity measured at the Terminal Side is shown in Figure 5. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, which the lowest is at T10 (Segment I) and the highest is at T4 (Segment I). This is categorized as **less comfortable** for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, which the lowest is at T14 (Segment III) and the highest is at T1 (Segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, which the lowest is at T7 (Segment II) and the highest is at T1 (Segment I). The average relative humidity at 12:00 and 16:00 are categorized as **comfortable** for humans.

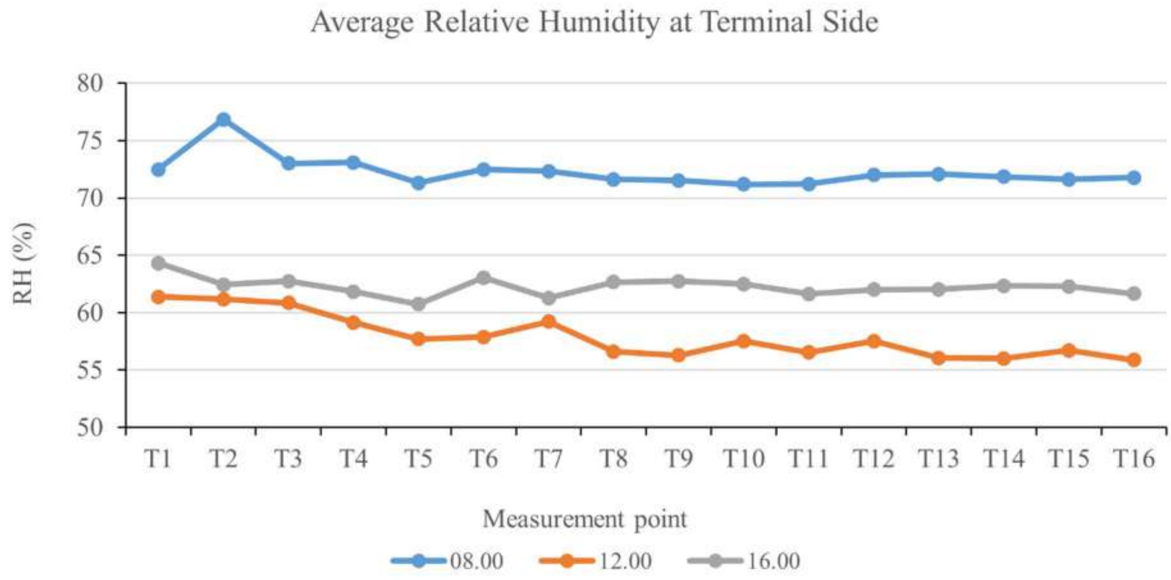


**Figure 5. Average relative humidity of Jalan Kyai Tapa, Terminal Side (author's result (N.I.S), 2022)**

Additionally, we measured the wind speed at the University Side (Figure 6) and Terminal Side (Figure 7) of Jalan Kyai Tapa. Generally, the average wind speed at the Terminal Side is slightly higher than the University Side, possibly due to fewer trees at the Terminal Side. At the Terminal Side, the average is 33.41 km/hour and at the University Side, the average is 32.86 km/hour. According to the Beaufort Scale (Stewart, 2008), wind speed of 29 – 38 km/hour is considered as fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00 and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

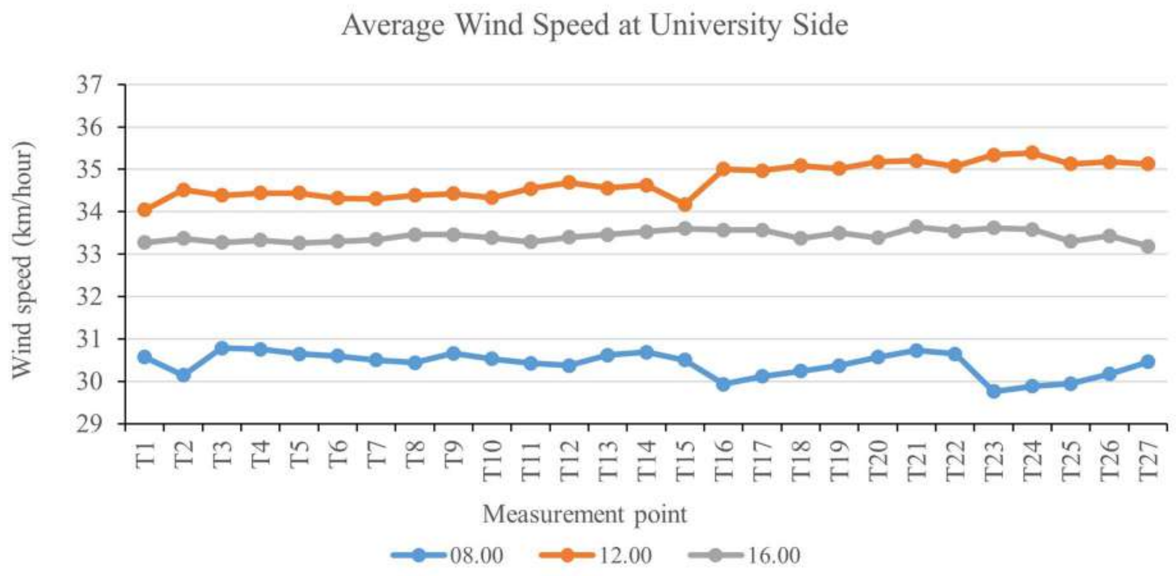


**Figure 6. Average wind speed of Jalan Kyai Tapa, University Side (author's result (N.I.S), 2022)**

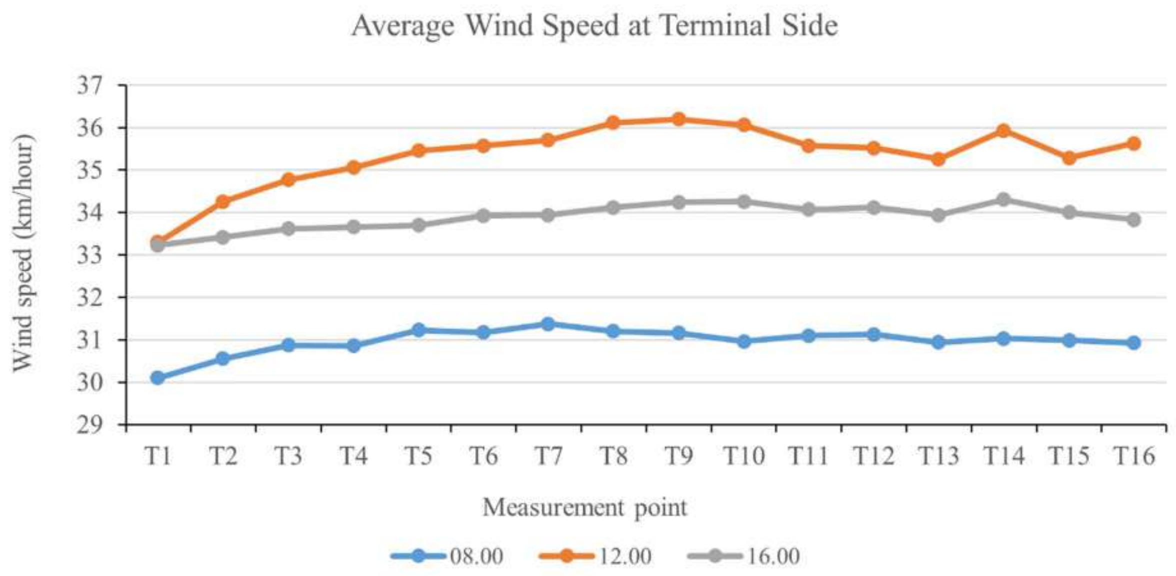


**Figure 7. Average wind speed of Jalan Kyai Tapa, Terminal Side (author's result (N.I.S), 2022)**

### 3.3 Temperature Heat Index (THI)

Based on the measured air temperature and relative humidity at the study area, we estimate the average THI at the University Side and the Terminal Side. The average THI of the University Side (Figure 8) at 08:00 ranges from 28.5 – 29.8 °C, which the lowest average THI is found at T24 (Segment III) and the highest is at T6 (Segment I). At 12:00, the average THI ranges from 30.2 – 31.6 °C, which the lowest is at T1 (Segment I) and the highest is at T20 (Segment III). The average THI at 16:00 ranges from 30.6 – 31.4 °C, which the lowest is at T1 (Segment I) and the highest is at T17

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(Segment II). The average THI at 08:00, 12:00, and 16:00 are considered as **not comfortable**. The most not comfortable time is at 12:00.

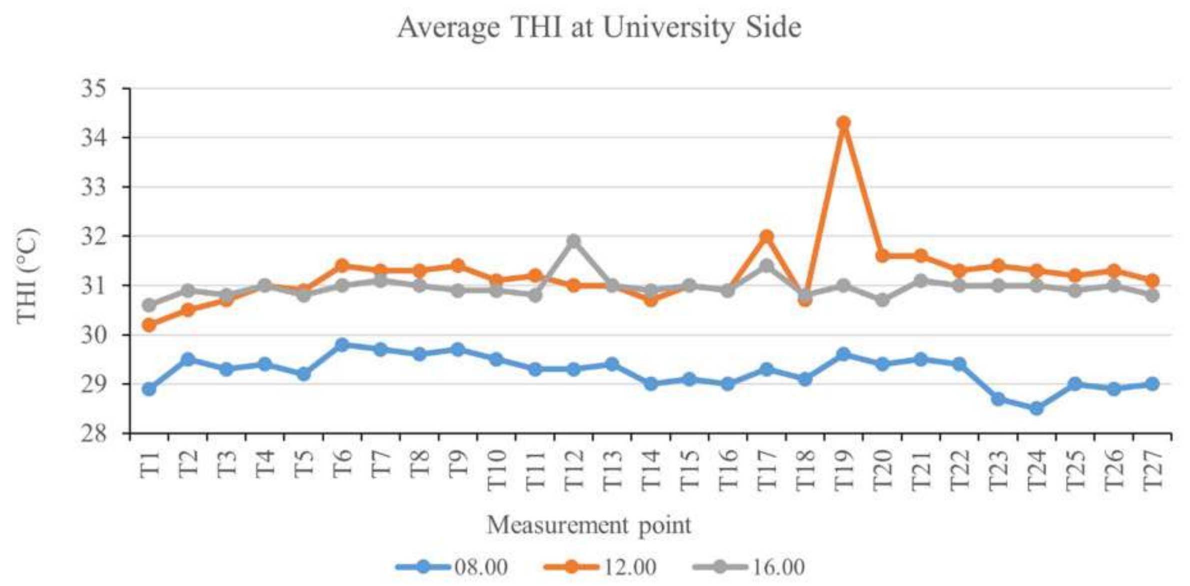

**Figure 8. The average THI at the University Side**

Figure 9 shows the average THI at the Terminal Side. The average THI at 08:00 ranges from 28.4 – 29.5 °C, which the lowest THI is at T1 (Segment I) and the highest is at T9 (Segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C, which the lowest is at T1 (Segment I) and the highest is at T9 and T10 (Segment II). The average THI at 16:00 ranges from 30.9 – 32.0 °C, which the lowest is at T1 (Segment I) and the highest is at T9 and T10 (Segment II). The average THI at 08:00, 12:00, and 16:00 are considered as **not comfortable**. Similar to the University Side, the most not comfortable time is at 12:00.

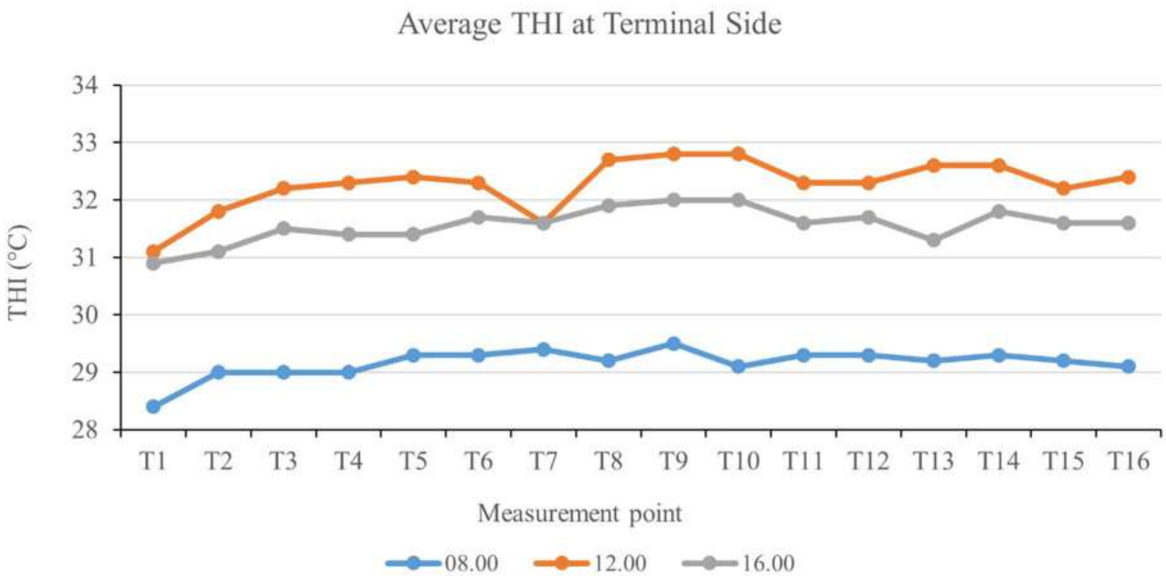


**Figure 9. The average THI at the Terminal Side**

### 3.4 Factors that Influence Thermal Comfort

According to the results, at the University Side Segment I, II, and II, there are 84 trees with varying canopy diameter from 1.5 – 9.0 m and varying height from 3.2 – 11.2 m. Meanwhile at the Terminal Side Segment I, II, and II, there are 31 trees with varying canopy diameter from 2.0 – 5.0 m and varying height from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameter. Trees with wide canopy diameter are known to give wider shaded areas, which should improve the thermal comfort (Boukhabla & Alkama, 2012). Wider tree canopy and denser leaves can help reducing air temperature and improving microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all trees are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This is similar to what we found during field measurement at the University Side where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. Although an existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that T1 of the University Side has the lowest average air temperature at 12:00 and 16:00, although there is no tree at T1. We would assume that the spot with the lowest air temperature would be the spot under a shaded tree, however, that is not always the case. Although there is no tree at T1 of the University Side, T1 is located close to a pedestrian bridge. We suggest that at 08:00, T1 is shaded by the pedestrian bridge, but at 12:00 and 16:00 the sun direction has moved so T1 is exposed to the heat. This shows that there are more factors that influence human thermal comfort other than vegetation. Hardscape structure could provide better shade than vegetation, although it depends on the sun direction, especially at an east-west road like Jalan Kyai Tapa. This finding is supported by existing research that found when street trees are planted closer to a building, the thermal comfort becomes better (Yang et al., 2018).

At another case, T9 of the Terminal Side that is shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 m. Furthermore, the planting distance between trees in that area is larger than the canopy diameter so we suggest it cannot give proper shade to cool down the air temperature. We mentioned that at the University Side, some spots with *Casuarina equisetifolia* have better thermal comfort than *Mimusops elengi*, this indicates that vegetation species alone cannot determine the thermal comfort, it is also related to the planting distance, design, and other trees close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the University Side has better thermal comfort than the Terminal Side. The University Side also has more trees and less pavement coverage than the Terminal Side. Trees can improve the thermal comfort. To optimize the tree function at pedestrian corridors, we should consider aspects like species, size, and planting distance. Further research is required to analyze the recommended planting design and plant selection that can improve people’s thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4 CONCLUSION

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01 – 31.54 °C and the relative humidity ranges from 56.19 – 57.74%. Average air temperature and relative humidity at Jalan Kyai Tapa are 31.2 °C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52 °C, which is categorized as not comfortable. In areas that have small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas that have large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopy, the trees do not seem to adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort as we found a measurement point that does not have any tree have the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design in creating comfortable pedestrian corridors.

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**Author Contribution**

Conceptualization, N.I.S.; Methodology, R.F.[1]; Analysis, X.X.; Investigation, X.X.; Writing – Original Draft Preparation, N.I.S.; Writing – Review & Editing, R.F.[1], R.F.[2], D.D.; Visualization, D.D.; and Funding Acquisition, X.X.

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**2. Bukti konfirmasi review dan hasil review (12 Juli 2023)**

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# Manuscript 1201-Request to Revised Article (Round 2)- Journal of Environmental Science and Sustainable Development

2 messages

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**Dibyanti Danniswari** <dibyanti@trisakti.ac.id> Tue, Jul 18, 2023 at 10:47 AM
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Dear Editor in Chief of JESSD UI,
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Thank you for the reviewer comments.
We revised our manuscript accordingly and we also follow the author guidelines.
All changes are tracked and marked automatically in the manuscript. The changes can be shown by clicking the red line on the left side of the text.

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# List of Revisions

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD


## Abstract

The increase of motor vehicles in Jakarta leads to environmental degradation and eventually can harm human health. When the environment is damaged, pedestrians are the most impacted group of road users. In the past few years, the local government of Jakarta has a vision to focus on improving human mobility networks including pedestrian networks. As a road with busy traffic, Jalan Kyai Tapa, West Jakarta, is used by many people, but it may feel not comfortable to walk there due to heat and sun exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. This study is done quantitatively. We identify the vegetation structure of Jalan Kyai Tapa including the tree species, canopy diameter, and tree height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate the thermal comfort using Temperature Humidity Index (THI). The results show that the air temperature at Jalan Kyai Tapa ranges from 31.01 °C - 31.54 °C and the relative humidity ranges from 56.19% - 57.74%. The average THI value at Jalan Kyai Tapa is 28.52 °C, which is considered as not comfortable. Despite having relatively wide canopy and can provide shade, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the thermal environment to reach a comfortable state for pedestrians. Interestingly, the result shows that, at certain observation times, the spot that has no tree have lower air temperature compared to other spots with trees. Trees might not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with wider canopies can be less comfortable than spots near trees with smaller canopies. Tree species and the planting spacing determine the efficiency of trees to improve the thermal comfort.


**Keywords**: Corridor; Pedestrian way; Thermal comfort; Vegetation.

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# 1 INTRODUCTION

The urban population keep increasing in the past few decades. The population growth in Jakarta 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase is followed by the increase of motor vehicle. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, that is infamous for its severe traffic congestion due to overload motor vehicles, would suffer more from this. Increasing motor vehicles means more emissions of air pollutants and greenhouse gases that eventually could harm human health and damage the environment. If the environment is damaged, pedestrians are the most impacted group of road users as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

Roadside greenbelt is a linear green open space that is formed by landscape elements, such as trees and shrubs, providing comfort, safety, and beauty for users (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban area play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (~~Akbari et al., 2001~~; Biao et al., 2010; ~~Lafortezza et al., 2009~~; Nowak et al., 2006; Simangunsong et al., 2021; Simangunsong & Fitri, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spagenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin & Waryono, 2010), such as ameliorating microclimate, reducing pollutants including particle and gas, controlling glare, producing oxygen (Simangunsong et al., 2021; Simangunsong & Fitri, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. To optimize the role of roadside vegetation, the vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions. Additionally, selecting the local species would make the adaptation easier for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only ~~at~~on a micro scale, but also at a city scale.

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Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. Direct benefits of roadside greenbelts to humans are providing shades, users safety, and improving the comfortability for users, especially pedestrians and cyclists. The position of greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building – environment interaction, which include various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and width of street (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity are factors that directly influence Temperature Humidity Index (THI), an index that is used to measure human body comfort. By paying attention to the thermal comfort at roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetic. Vegetation at roadside landscape serves as view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). ~~(Laurie, 1975).~~ To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, the planting design, and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etc.). The interaction between softscape and hardscape determines the thermal comfort.

Jakarta's local government initiated a concept of Smart City since 2014 by improving the city based on six elements of Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to improve traffic congestion, reduce air pollution, improve citizen mobility, etc. To support public transportation, Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infrastructure) revitalizes public ~~facility~~facilities such as pedestrian corridors. Dinas Bina Marga cooperates with Institute for Transportation Development Policy (ITDP) Indonesia to plan human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facility for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road that has two pedestrian corridors with roadside greenbelts. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Pedestrian corridors at Jalan Kyai Tapa are used by quite a lot of people. However, in the afternoon, it may feel not comfortable to walk there due to heat and sun light exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas, but it is still rather limited in Indonesia. Existing studies has analyzed pedestrian corridors comfort in Indonesia cities, in relation to its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). There are only few studies that specifically focuses on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). There are even fewer studies on thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta are mostly related to transit oriented development concept (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. ~~this study helps to serve an image of current pedestrian corridors in Jakarta.~~ The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can give a brief illustration of other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can be of help in improving the pedestrian corridors in Jakarta.

## 2 METHODS

### 2.1 Study Area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a major road that is passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot. There are two sides of pedestrian corridors at Jalan Kyai Tapa, (1) ~~Terminal Side~~terminal side (north side) and (2) ~~University Side~~university side (south side). At the ~~Terminal Side~~terminal side, there are bus terminal, police station, and traffic gardens. Meanwhile, at the ~~University Side~~university side, there are university buildings, hotels, restaurants, and other commercial buildings. The tree information in the study area is collected for further analysis. When inventorying vegetation, existing studies created plots of

100 meters by 100 meters in wide areas, such as national parks (Haryadi et al., 2019; Maulidiyan et al., 2019), and created belt transects of 100 m in linear areas, such as roadsides (Danniswari & Nasrullah, 2017). Therefore, ~~The study area is 300 m-long and~~ we divided the 300 meters-long pedestrian corridors~~it~~ into three segments, ~~for the analysis. Each segment is~~ 100 m-long each. The study area and the segmentation are shown in Figure 1. The field data were collected in November 2021 until February 2022.


Figure 1. Study area, the pedestrian corridors at Jalan Kyai Tapa, and the segmentation (Source: author's documentation, 2021)

## 2.2 Data Collection

The study is conducted quantitatively. We collect data of field air temperature, relative humidity, wind speed, trees species, tree height, and canopy diameter. The measurement points for air temperature, relative humidity, and wind speed are distributed along the corridors. The measurement is done three times a day at 08:00, 12:00, and 16:00 for seven days during sunny weather using digital thermohygrometer. The pedestrian corridors have two sides, university side and terminal side, with a length of 300 m. We observe both corridors and divide each corridor into three segments of 100 m-long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to smaller vegetation coverage at this side.

Table 1. Location and measurement points

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

### 2.3 Data Analysis

The data are analyzed to calculate the Temperature Humidity Index (THI). THI is estimated to determine the equivalent temperature perceived by humans, by considering the air temperature and relative humidity. This index ~~is important~~has been widely used to measure the human body's comfort (Isnoor et al., 2021; Pertiwi & Paski, 2021; Putri et al., 2021; Rusdayanti et al., 2021). Measured field air temperature and humidity are calculated following the THI formula by McGregor & Nieuwolt (1998) shown in Equation 1.

(1)

where:

THI = Temperature Humidity Index (°C),

T = Air Temperature (°C),

RH = Relative Humidity (%)

Table 2 shows the categories for THI values. The categories of THI used in this study follows the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), that are modified by Effendy (2007) for tropical climate use. Ideal environments that are perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Tab~~e~~le 2. THI ~~Value~~ value ~~Categories~~categories

| THI value (°C) | Category |
|---|---|
| 21 ≥ THI ≤ 24 | Comfortable |
| 25 ≥ THI ≤ 27 | Less comfortable |
| THI > 27 | Not comfortable |

## 3 RESULTS AND DISCUSSIONS

### 3.1 The Vegetation Structure

There are two sides of pedestrian corridors at Jalan Kyai Tapa, which are u~~U~~niversity s~~S~~ide and t~~T~~erminal s~~S~~ide. Each side is divided into three segments. At ~~Segment~~segment I of Jalan Kyai Tapa u~~U~~niversity s~~S~~ide, there are 30 trees that consist of 6 different species. The canopy diameter varies from 1.5 – 6.4 m and the height vary from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are 5 trees of *Casuarina equisetifolia*, 2 trees of *Artocarpus heterophyllus*, and 1 tree of *Cerbera manghas*. The vegetation structure of ~~Segment~~ segment I, ~~U~~university s~~S~~ide, is shown in Table 3.

Table 3. Vegetation ~~Structure~~ structure at ~~Segment~~ segment I, ~~University~~ university ~~Side~~side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| **I** | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

At ~~Segment~~ segment II, there are a total of 17 trees that consist of 5 different species, which are 7 trees of *Ficus virens*, 6 trees of *Mimusops elengi*, 2 trees of *Cerbera manghas*, 1 tree of *Samanea saman*, and 1 tree of *Muntingia calabura*. The canopy diameter at ~~Segment~~ segment II ranges from 3 – 9 m and the tree height range from 3.2 – 11.2 m. The vegetation structure of ~~Segment~~ segment II is summarized in Table 4.

Table 4. Vegetation ~~Structure~~ structure at ~~Segment~~ segment II, ~~University~~ university ~~Side~~side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **II** | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

Segment III has the highest number of trees compared to ~~Segment~~segment I and II. There are 37 trees that consist of 7 species with the canopy diameter vary from 3.2 – 7 m and the tree height range from 6 – 9 m. This segment is dominated with *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of ~~Segment~~segment III is shown in Table 5.

Table 5. Vegetation ~~Structure~~ structure at ~~Segment~~ segment III, ~~University~~ university s~~S~~ide

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| | T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| | T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| | T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to/from the terminal. At ~~Segment~~segment I of Terminal side, there are 21 trees of 5 species with the canopy diameter varies from 3 – 5 m and the height vary from 6 – 10.8 m. This segment has 14 trees of *Handroanthus chrysotrichus*, 3 trees of *Swietenia mahagoni*, 1 tree of *Samanea saman*, 1 tree of *Casuarina equisetifolia*, and 1 tree of *Pterocarpus indicus*. At ~~Segment~~segment II, there are only 3 trees, 2 trees of *Casuarina equisetifolia* and 1 tree of *Pterocarpus indicus*. At

~~Segment~~segment III, there are 7 trees that consist of 7 trees of *Pterocarpus indicus*, 2 trees of *Casuarina equisetifolia*, and 1 tree of *Ficus benjamina.* The canopy diameter varies from 2 – 4 m and the height vary from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

Table 6. Vegetation ~~Structure~~ structure at ~~S~~segment I, II, III, ~~Terminal~~ terminal s~~S~~ide

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **I** | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| **II** | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| **III** | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

### 3.2 The Thermal Environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured on 27 points at the ~~University~~ university ~~Side~~ side and 16 points at the ~~Terminal Side~~terminal side. At the ~~University~~ university ~~Side~~ side (Figure 2), the average air temperature at 08:00 ranges from 30.16 – 31.29 °C. The lowest air temperature is found at T24 (~~Segment~~segment II) and the highest is found at T6 (~~Segment~~segment I). The average air temperature at 12:00 ranges from 32.8 – 35.1 °C. The lowest air temperature is at T1 (~~Segment~~segment I) and the highest is at T17 (~~Segment~~segment II). The average air temperature at 16:00 ranges from 33 – 34 °C. The lowest air temperature is at T1 (~~Segment~~segment I) and the highest is at T17 (~~Segment~~segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered as **less comfortable** for human activities.

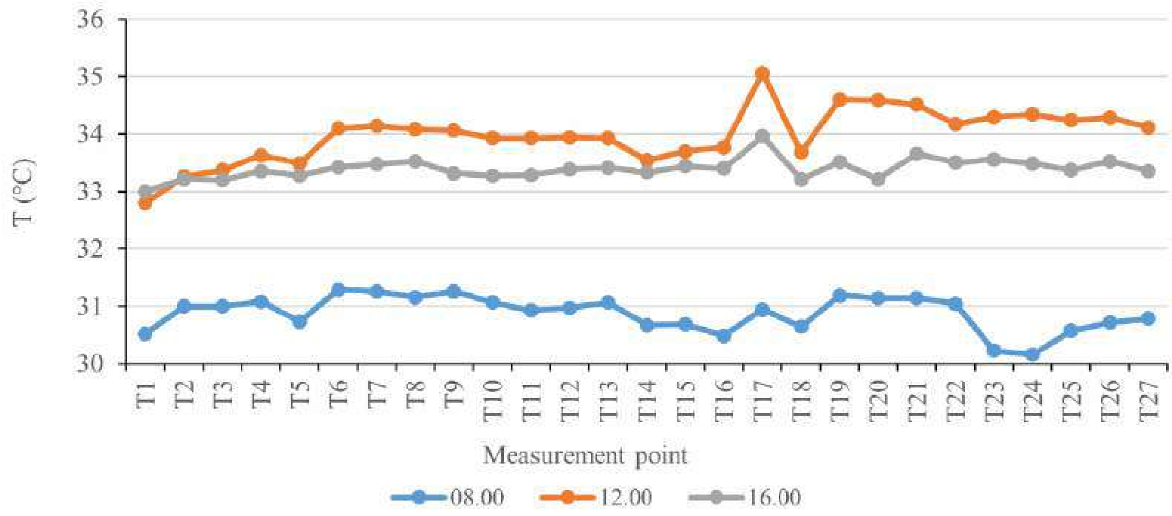


Figure 2. Average temperature of Jalan Kyai Tapa, ~~University Side~~university side

At the ~~Terminal Side~~terminal side (Figure 3), the average air temperature at 08:00 ranges from 30.07 – 31.33 °C. The lowest air temperature is found at T1 (~~Segment~~segment I) and the highest is at T9 (~~Segment~~segment II). The average air temperature at 12:00 ranges from 33.71 – 36.03 °C, which the lowest is at T1 (~~Segment~~segment I) and the highest is at T9 (~~Segment~~segment II). The average air temperature at 16:00 ranges from 33.37 – 34.67 °C, which the lowest is at T1 (~~Segment~~segment I) and the highest is at T9 (~~Segment~~segment II). Although the air temperature ranges are different in three observed time, all three segments' lowest air temperature is found at T1 and the highest is at T9. Based on these values, the air temperature of the ~~Terminal Side~~terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

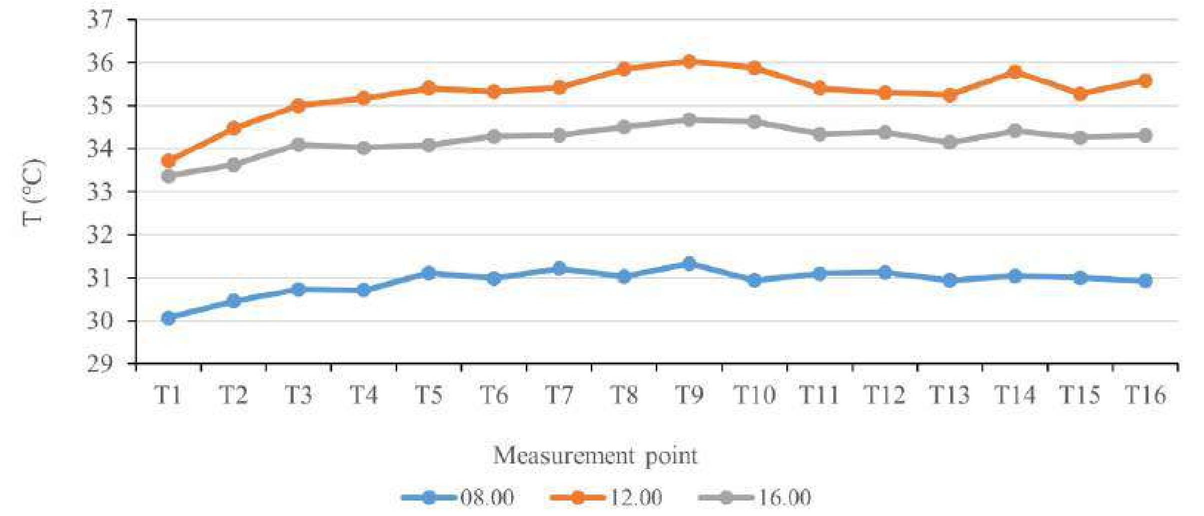


Figure 3. Average temperature of Jalan Kyai Tapa, ~~Terminal Side~~terminal side

Figure 4 shows the average relative humidity measured at the ~~University Side~~university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, which the lowest is at T26 (~~Segment~~segment II) and the highest is at T18 (~~Segment~~segment II). This is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.21 – 61.46%, which the lowest is at T26 (~~Segment~~segment II) and the highest is at T9 (~~Segment~~segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%, which the lowest is at T17 (~~Segment~~segment II) and the highest is at T4 (~~Segment~~segment I). The average relative humidity at 12:00 and 16:00 are categorized as comfortable for humans.

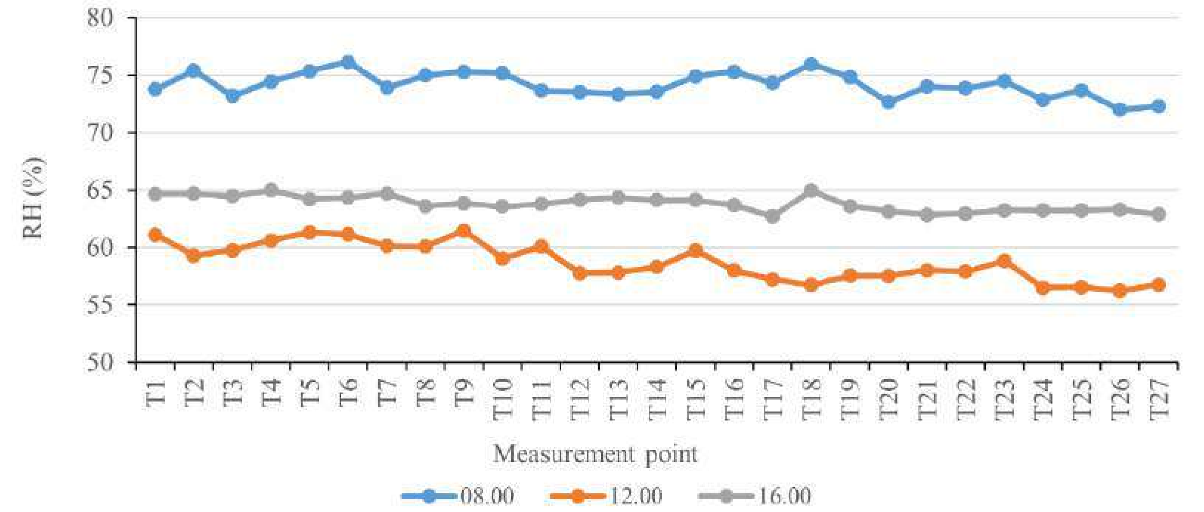


Figure 4. Average relative humidity of Jalan Kyai Tapa, ~~University Side~~university side

DOI: https://doi.org/XX.XXXXX/jessd.xxxx.xxxx

The average relative humidity measured at the ~~Terminal Side~~terminal side is shown in Figure 5. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, which the lowest is at T10 (~~Segment~~segment I) and the highest is at T4 (~~Segment~~segment I). This is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, which the lowest is at T14 (~~Segment~~segment III) and the highest is at T1 (~~Segment~~segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, which the lowest is at T7 (~~Segment~~segment II) and the highest is at T1 (~~Segment~~segment I). The average relative humidity at 12:00 and 16:00 are categorized as comfortable for humans.

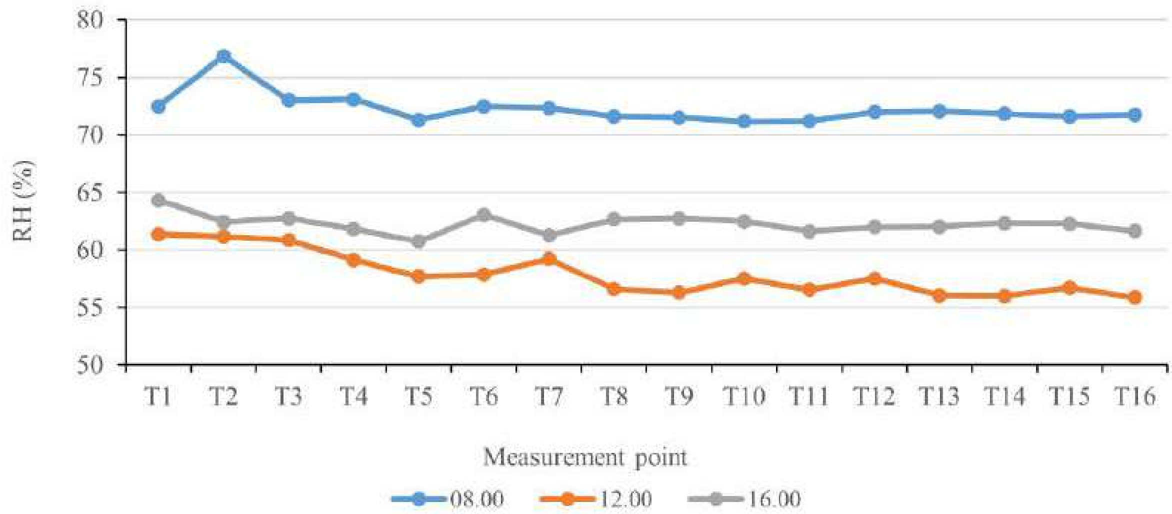


Figure 5. Average relative humidity of Jalan Kyai Tapa, ~~Terminal Side~~terminal side

Additionally, we measured the wind speed at the ~~University Side~~university side (Figure 6) and ~~Terminal Side~~terminal side (Figure 7) of Jalan Kyai Tapa. Generally, the average wind speed at the ~~Terminal Side~~terminal side is slightly higher than the ~~University Side~~university side, possibly due to fewer trees at the ~~Terminal Side~~terminal side. At the ~~Terminal Side~~terminal side, the average is 33.41 km/hour and at the ~~University Side~~university side, the average is 32.86 km/hour. According to the Beaufort Scale (Stewart, 2008), wind speed of 29 – 38 km/hour is considered as fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00 and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

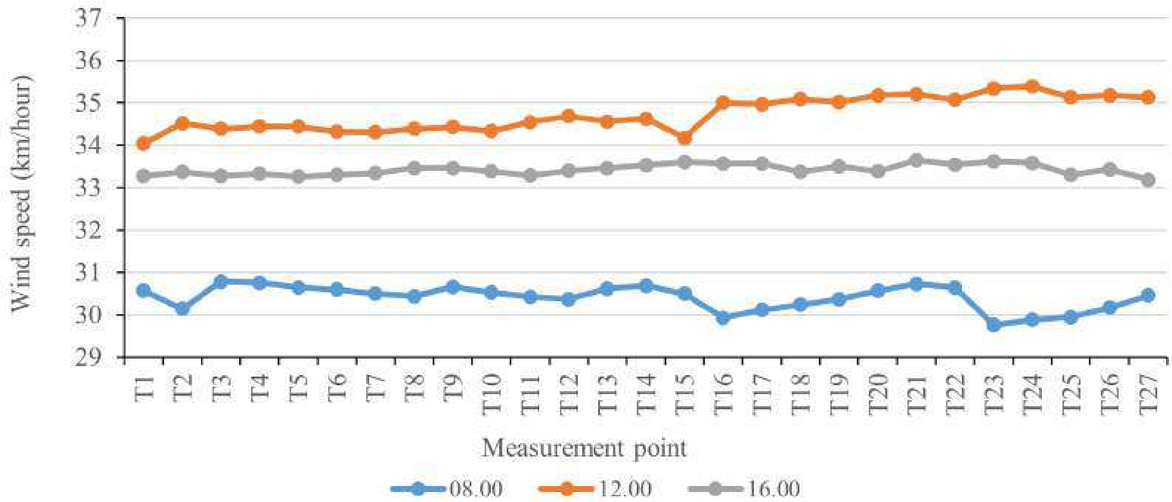


Figure 6. Average wind speed of Jalan Kyai Tapa, ~~University Side~~university side

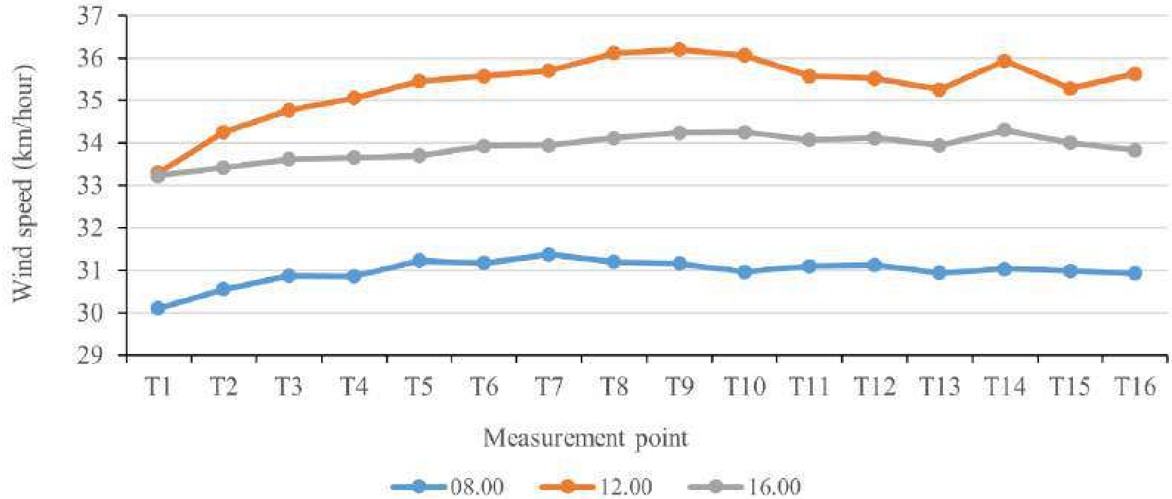


Figure 7. Average wind speed of Jalan Kyai Tapa, ~~Terminal Side~~terminal side (author's result, 2022)

### 3.3 Temperature Heat Index (THI)

Based on the measured air temperature and relative humidity at the study area, we estimate the average THI at the ~~University Side~~university side and the ~~Terminal Side~~terminal side. The average THI of the ~~University Side~~university side (Figure 8) at 08:00 ranges from 28.5 – 29.8 °C, which the lowest average THI is found at T24 (~~Segment~~segment III) and the highest is at T6 (~~Segment~~segment I). At 12:00, the average THI ranges from 30.2 – 31.6 °C, which the lowest is at T1 (~~Segment~~segment I) and the highest is at T20 (~~Segment~~segment III). The average THI at 16:00 ranges from 30.6 – 31.4 °C, which the lowest is at T1 (~~Segment~~segment I) and the highest is at T17

(Segmentsegment II). The average THI at 08:00, 12:00, and 16:00 are considered as **not comfortable**. The most not comfortable time is at 12:00.

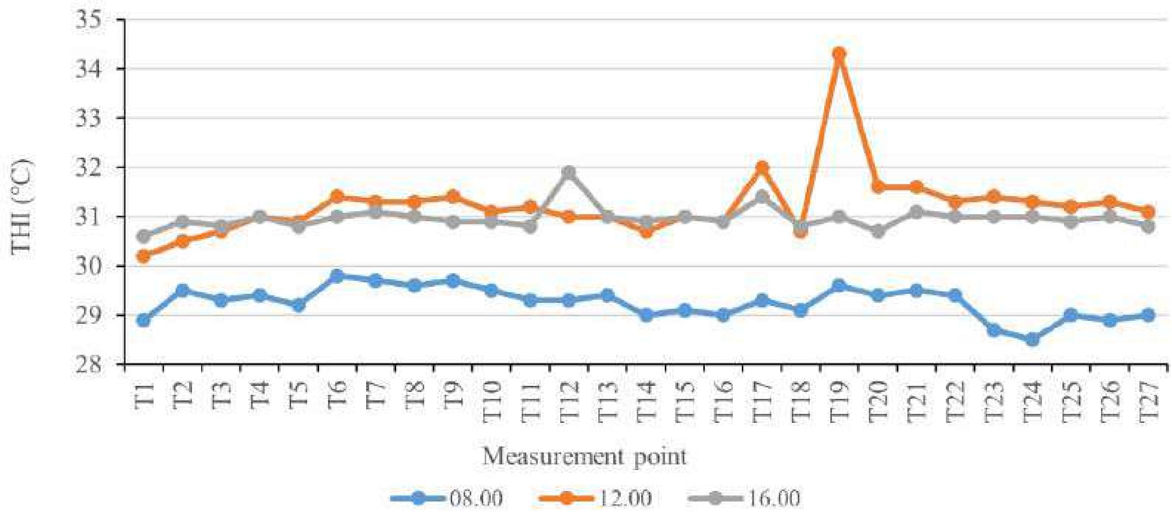


Figure 8. The average THI at the University Sideuniversity side

Figure 9 shows the average THI at the Terminal Sideterminal side. The average THI at 08:00 ranges from 28.4 – 29.5 °C, which the lowest THI is at T1 (Segmentsegment I) and the highest is at T9 (Segmentsegment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C, which the lowest is at T1 (Segmentsegment I) and the highest is at T9 and T10 (Segmentsegment II). The average THI at 16:00 ranges from 30.9 – 32.0 °C, which the lowest is at T1 (Segmentsegment I) and the highest is at T9 and T10 (Segmentsegment II). The average THI at 08:00, 12:00, and 16:00 are considered as not comfortable. Similar to the University Sideuniversity side, the most not comfortable time is at 12:00.

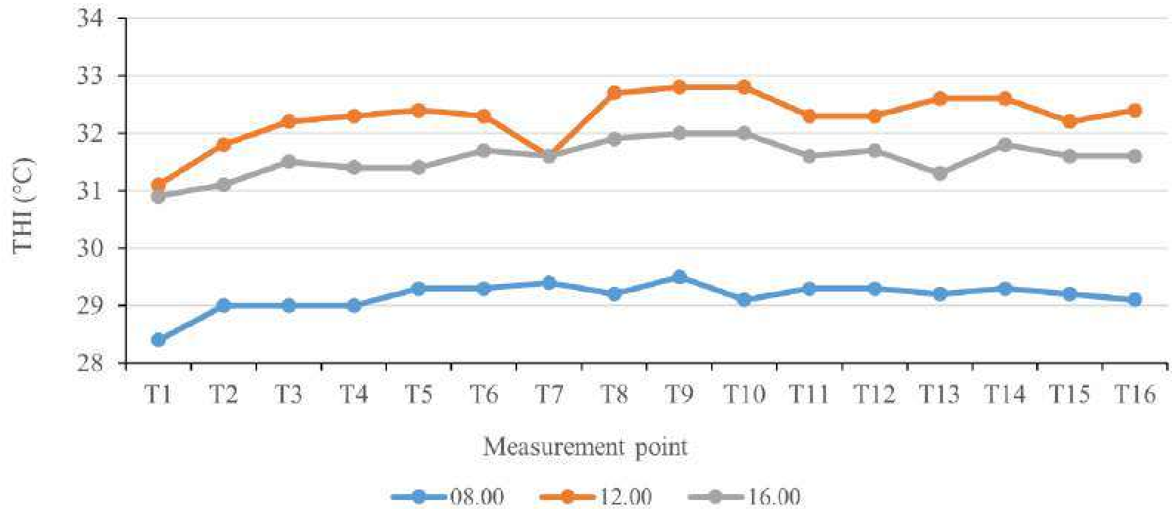


Figure 9. The average THI at the Terminal Sideterminal side

### 3.4 Factors that Influence Thermal Comfort

According to the results, at the ~~University Side~~university side ~~Segment~~segment I, II, and II, there are 84 trees with varying canopy diameter from 1.5 – 9.0 m and varying height from 3.2 – 11.2 m. Meanwhile at the ~~Terminal Side~~terminal side ~~Segment~~segment I, II, and II, there are 31 trees with varying canopy diameter from 2.0 – 5.0 m and varying height from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameter. Trees with wide canopy diameter are known to give wider shaded areas, which should improve the thermal comfort (Boukhabla & Alkama, 2012). Wider tree canopy and denser leaves can help reducing air temperature and improving microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

There are several factors that possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters, which are the foliage shape and dimensions, height of trunk, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). Tree canopy shape is an important variable in distributing air temperature (Fabbri et al., 2017). The shade from tree canopy influences the plants evapotranspiration, which increases relative humidity and absorbs thermal energy that leads to air temperature decrease (Perini et al., 2018) and ground temperature decrease (Morakinyo et al., 2018). An existing study found that the most influential parameter in affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is defined as one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also important because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely to be more significant than canopy diameter and tree height. Furthermore, tall trees with a large leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees for improving outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Wang & Akbari, 2016). In relation to the results of this study, the trees canopy diameter in the study area might be not wide enough to provide adequate improvement to the air temperature, considering majority of the trees canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to determine the cause of uncomfortable outdoor areas more accurately.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all trees are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This is similar to what we found during field measurement at the ~~University Side~~university side where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. Although an existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that ~~T1 of~~at the ~~University~~ university ~~Side~~ side, T1 has the lowest average air temperature and T17 has the highest temperature at 12:00 and 16:00, although there is no tree at T1 and there is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has the lowest temperature and T6 has the highest temperature. T6 and T24 similarly have *Ficus virens* and *Mimusops elengi* nearby, but the number of trees is bigger at T24. The different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning is more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the different tendency between morning and afternoon observations. As for the afternoon phenomenon where T1 (no tree) has the lowest average air temperature and T17 (with tree) has the highest, there is possibly canopy-associated warming that occurred during observations. ~~(~~Sharmin et al., (2023) conducted a study to determine cooling benefits of 10 urban trees species considering the tree traits and microclimatic conditions in suburban areas. The study found that there is canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with highest LAI has the lowest sub-canopy warming effect. The sub-canopy warming effect can also be caused by the heat from nearby buildings. A study by (Alonzo et al., (2021) that was conducted in Washington DC found that trees located along streets has less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under tree canopy and surrounding surfaces. This further supports that the air temperature under trees might be higher than the ambient air temperature, particularly if the area is surrounded by buildings like the study area. This also may explain why such phenomenon is not found at the terminal side considering the terminal side has fewer structures and buildings than the university side. On a side note, However, T1 of the University Side is located nearby a big shade tree. We suggest that at 12:00 and 16:00, T1 is shaded by a nearby tree, but it is not shaded at 08:00. This shows that a nearby tree shadow could lower the air temperature, although it depends on the time and sun's direction. Iit is worth to note that T1 is also located near a small water body which may also affect help to decrease the air temperature due to water body evaporation (Chen et al., 2023).

At another case, T9 of the Terminal Sideterminal side that is shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter so we suggest it cannot give proper shade to cool down the air temperature. We mentioned that at the University Sideuniversity side, some spots with *Casuarina equisetifolia* have better thermal comfort than *Mimusops elengi*, this indicates that vegetation species alone cannot determine the thermal comfort, it is also related to the planting distance, design, and other trees elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the University Sideuniversity side has better thermal comfort than the Terminal Sideterminal side. The University Sideuniversity side also has more trees and less pavement coverage than the Terminal Sideterminal side. Trees can improve the thermal comfort and . Tto optimize the tree function at pedestrian corridors, we should consider aspects like species, size, and planting distancethe tree characteristics and the tree arrangement. From the results of this study, we discussed that thermal comfort of pedestrian corridors is determined by various factors and the trees influence on microclimate can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically on measuring LAI and the distance between trees. Therefore, Ffurther research is required to analyzeprior to proposing the recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4 CONCLUSION

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01 – 31.54 °C and the relative humidity ranges from 56.19 – 57.74%. Average air temperature and relative humidity at Jalan Kyai Tapa are 31.2 °C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52 °C, which is categorized as not comfortable. In areas that have small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas that have large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, the trees do not seem to adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort as we found a measurement point that does not have any tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design in creating comfortable pedestrian corridors.

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**3. Bukti konfirmasi submit revisi, respon kepada reviewer, dan artikel yang di resubmit (18 Juli2023)**

Intan Mangunsong <nurintan@trisakti.ac.id>

# Manuscript 1201-Request to Revised Article (Round 2)- Journal of Environmental Science and Sustainable Development

**Dibyanti Danniswari** <dibyanti@trisakti.ac.id> Tue, Jul 18, 2023 at 10:47 AM
To: JESSD UI <jessd@ui.ac.id>
Cc: nurintan@trisakti.ac.id, reza.fauzi@trisakti.ac.id, rini.fitri@trisakti.ac.id, jessd.sil.ui@gmail.com

Dear Editor in Chief of JESSD UI,
(cc: fellow authors)

Thank you for the reviewer comments.
We revised our manuscript accordingly and we also follow the author guidelines.
All changes are tracked and marked automatically in the manuscript. The changes can be shown by clicking the red line on the left side of the text.

In this email, we attached the revised manuscript and the filled template of the revision list.
Thank you very much.

Best regards,
Dibyanti Danniswari

[Quoted text hidden]

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Journal of Environmental Science and Sustainable Development

List of Revisions

I. **Details of Manuscript**

| | |
|---|---|
| Manuscript ID | 1201 |
| Type of Manuscript | Original research article |
| Title | ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD |

II. **List of Improvements**

| **No.** | **Reviewers Comments per Section** | **Improvements** | **Page(s) of Improvements** |
|---|---|---|---|
| *Please rewrite all reviewers comments based on the manuscript sections and further list the detail improvements made in your revised manuscript:* | | | |
| 1. | Abstract:<br>Abstract with no more than 300 words should be supplied to reflect the content of the paper. A concise and factual abstract is required (IMRAD Model) - Read our guidelines,<br>An abstract is often presented separately from the article, so it must be able to stand-alone. For this reason, References should be avoided. Also, non-standard or uncommon abbreviations should be avoided, but if essential they must be defined at their first mention in the abstract itself. In | The word count is reduced to 299. We did not include any references. We use an abbreviation, THI, since it is essential for understanding our study, but we already defined it at its first mention as an index we used to evaluate the thermal comfort. We improved the abstract and followed the IMRAD model stated in the author guidelines, including Introduction, Methods, Results, Discussions, and Conclusion. | |

| | | | |
|---|---|---|---|
| | the end of this section, please also briefly state the structure of paper, starting from Title up to References. | For the above reasons, the abstract is able to stand-alone. | |
| 2. | Introduction:<br>a) Is there any relevant references?<br>b) Just include the references were published within 3-5 years<br>c) We recommend that you to replace this abbreviation. | a) References are added to support the statements.<br>b) The references are changed.<br>c) It is removed for clarity | |
| 3. | Method:<br>a) Why don't just state north side and south side instead of terminal side and university side?<br>b) Metres? state the abbreviation in its first appears. Metres (m) | a) We decided to still use "terminal side" and "university side" because it portrays the study area better than "north side" and "south side". We want the readers to easily recognize the different conditions of the roadsides. We removed "north side" and "south side" to avoid confusion.<br>b) We stated the abbreviation (m).<br>Note: We keep the spelling "meter" instead of "metre" because we follow the American English spelling, as suggested in the Author Guideline. | |

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| | c) Please input the clearer resolution of this picture. We recommend that you to use same size of picture below the main segment picture. It might be more organized. Notice the typos of SEGMEN. Is it SEGMENT?<br>d) State clearer meaning of sunny weather.<br>e) Please consistent of using capital letters.<br>f) Formula 1. | However, if reviewers suggest that “metre” is correct, we allow the editor to revise the text.<br>c) We replaced it with a new picture with clearer resolution and rearranged the photos. We fixed the typos as well (SEGMEN 1 to SEGMENT I).<br>d) We added "when there are no clouds blocking the sunlight" for a clearer explanation.<br>e) We corrected the capital letters in all tables.<br>f) We changed “Equation 1” to “Formula 1”. | |
| 4. | Results and Discussion:<br>a) In any part of mentioning segment, IT MUST BE CONSISTENT WITH THE WAY YOU STATE IN METHOD.<br>b) the most uncomfortable time | a) We changed the method part. All body texts use “segment” with roman numerals, e.g., “segment I”.<br>b) We decided to keep “the most not comfortable time” to keep the consistency because “not comfortable” is a category | |

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| | | we stated in the Method. | |
| 5. | Conclusion:<br>(none) | | |
| 6. | References:<br>(none) | | |
| 7. | Overall Substances: | | |
| 8. | Others: | | |

III. **Form Submission**

Thank you for revising your manuscript based on the valuable comments provided by peer reviewers. If you have any question or concern, please do not hesitate to contact us by email to jessd@ui.ac.id.

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**ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD**


**Abstract**

The increase of motor vehicles in Jakarta leads to environmental degradation and eventually can harm human health. When the environment is damaged, pedestrians are the most impacted group of road users. In the past few years, the local government of Jakarta has a vision to focus on improving human mobility networks including pedestrian networks. As a road with busy traffic, Jalan Kyai Tapa, West Jakarta, is used by many people, but it may feel not comfortable to walk there due to heat and sun exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. This study is done quantitatively. We identify the vegetation structure of Jalan Kyai Tapa including the tree species, canopy diameter, and tree height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate the thermal comfort using Temperature Humidity Index (THI). The results show that common tree species found at Jalan Kyai Tapa include *Mimusops elengi*, *Ficus virens*, and *Casuarina equisetifolia*. The tree height ranges from 3.7 to 11.2 meters and the canopy diameter ranges from 1.5 to 9.0 meters. The results show that tThe air temperature at Jalan Kyai Tapa ranges from 31.01 °C - 31.54 °C and the relative humidity ranges from 56.19% - 57.74%. The average THI value at Jalan Kyai Tapa is 28.52 °C, which is considered as not comfortable. Despite having having relatively wide canopy and can providethe ability to provide shade, the trees at Jalan Kyai Tapa's pedestrian corridors study area do not seem to adequately improve the thermal environment to reach a comfortable state for pedestrians. Interestingly, the result shows that, at certain observation times, the spot that has no tree have lower air temperature compared to other spots with trees. Trees might not be the most influential factor in improving pedestrian thermal comfort. Furthermore,This study found the spots near trees with wider canopies can be less comfortable than spots near trees with smaller canopies. Trees species and size might not be the most influential factor in improving pedestrian thermal comfort. Tree species and the planting spacing determine the efficiency of trees to improve the thermal comfort.


**Keywords**: Corridor; Pedestrian way; Thermal comfort; Vegetation.

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# 1 INTRODUCTION

The urban population keep increasing in the past few decades. The population growth in Jakarta 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase is followed by the increase of motor vehicle. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, that is infamous for its severe traffic congestion due to overload motor vehicles, would suffer more from this. Increasing motor vehicles means more emissions of air pollutants and greenhouse gases that eventually could harm human health and damage the environment (Lin et al., 2020; Xu & Qin, 2023). If the environment is damaged, pedestrians are the most impacted group of road users as they are directly exposed to the environment (B. Wang et al., 2022). Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment (Sukmaningrum et al., 2020; Xi et al., 2023).

Roadside greenbelt is a linear green open space that is formed by landscape elements, such as trees and shrubs, providing comfort, safety, and beauty for users (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban area play important~~a~~ roles in microclimate amelioration (Meili, Manoli, et al., 2021), air quality improvement (Eisenman et al., 2019), carbon dioxide reduction (Meidiana et al., 2021), oxygen production (Simangunsong & Fitri, 2021), ecological function (Simangunsong et al., 2021), and city's water supply protection (Berland et al., 2017; Scholz, 2019)~~ (Akbari et al., 2001; Biao et al., 2010; Lafortezza et al., 2009; Nowak et al., 2006; Simangunsong et al., 2021; Simangunsong & Fitri, 2021)~~. Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Xi et al., 2023). Roadside greenbelts offer various benefits to improve urban environment quality~~ (Samsoedin & Waryono, 2010)~~, such as ameliorating microclimate, reducing pollutants including particle and gas (Jung & Yoon, 2022), controlling glare (Huang et al., 2019), producing oxygen (Simangunsong & Fitri, 2021), reducing noise (Liu et al., 2023), controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. To optimize the role of roadside vegetation, the vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions. Additionally, selecting the local species would make the adaptation easier for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only on a micro scale, but also at a city scale.

Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. Direct benefits of roadside greenbelts to humans are providing shades, users safety, and improving the comfortability for users, especially pedestrians and cyclists. The position of greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building – environment interaction, which include various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and width of street (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity are factors that directly influence Temperature Humidity Index (THI), an index that is used to measure human body comfort. By paying attention to the thermal comfort at roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetic. Vegetation at roadside landscape serves as view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, the planting design, and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etc.). The interaction between softscape and hardscape determines the thermal comfort.

Jakarta's local government initiated a concept of Smart City since 2014 by improving the city based on six elements of Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to improve traffic congestion, reduce air pollution, and improve citizen mobility~~, etc.~~ To support public transportation, Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infrastructure) revitalizes public facilities such as pedestrian corridors. Dinas Bina Marga cooperates with Institute for Transportation Development Policy (ITDP)

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Indonesia to plan human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facility for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road that has two pedestrian corridors with roadside greenbelts. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Pedestrian corridors at Jalan Kyai Tapa are used by quite a lot of people. However, in the afternoon, it may feel not comfortable to walk there due to heat and sun light exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas, but it is still rather limited in Indonesia. Existing studies has analyzed pedestrian corridors comfort in Indonesia cities, in relation to its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). There are only few studies that specifically focuses on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). There are even fewer studies on thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta are mostly related to transit oriented development concept (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can give a brief illustration of other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can be of help in improving the pedestrian corridors in Jakarta.

## 2 METHODS

### 2.1 Study Area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a major road that is passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot. There are two sides of pedestrian corridors at Jalan Kyai Tapa, (1) terminal side ~~(north side)~~ and (2) university side ~~(south side)~~. At the terminal side, there are bus terminal, police station, and traffic gardens. Meanwhile, at the

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university side, there are university buildings, hotels, restaurants, and other commercial buildings. The tree information in the study area is collected for further analysis. When inventorying vegetation, existing studies created plots of 100 meters (m) by 100 m~~eters~~ in wide areas, such as national parks (Haryadi et al., 2019; Maulidiyan et al., 2019), and created belt transects of 100 m in linear areas, such as roadsides (Danniswari & Nasrullah, 2017). Therefore, we divided the 300 meters-long pedestrian corridors into three segments, 100 m-long each. The study area and the segmentation are shown in Figure 1. The field data were collected in November 2021 until February 2022.

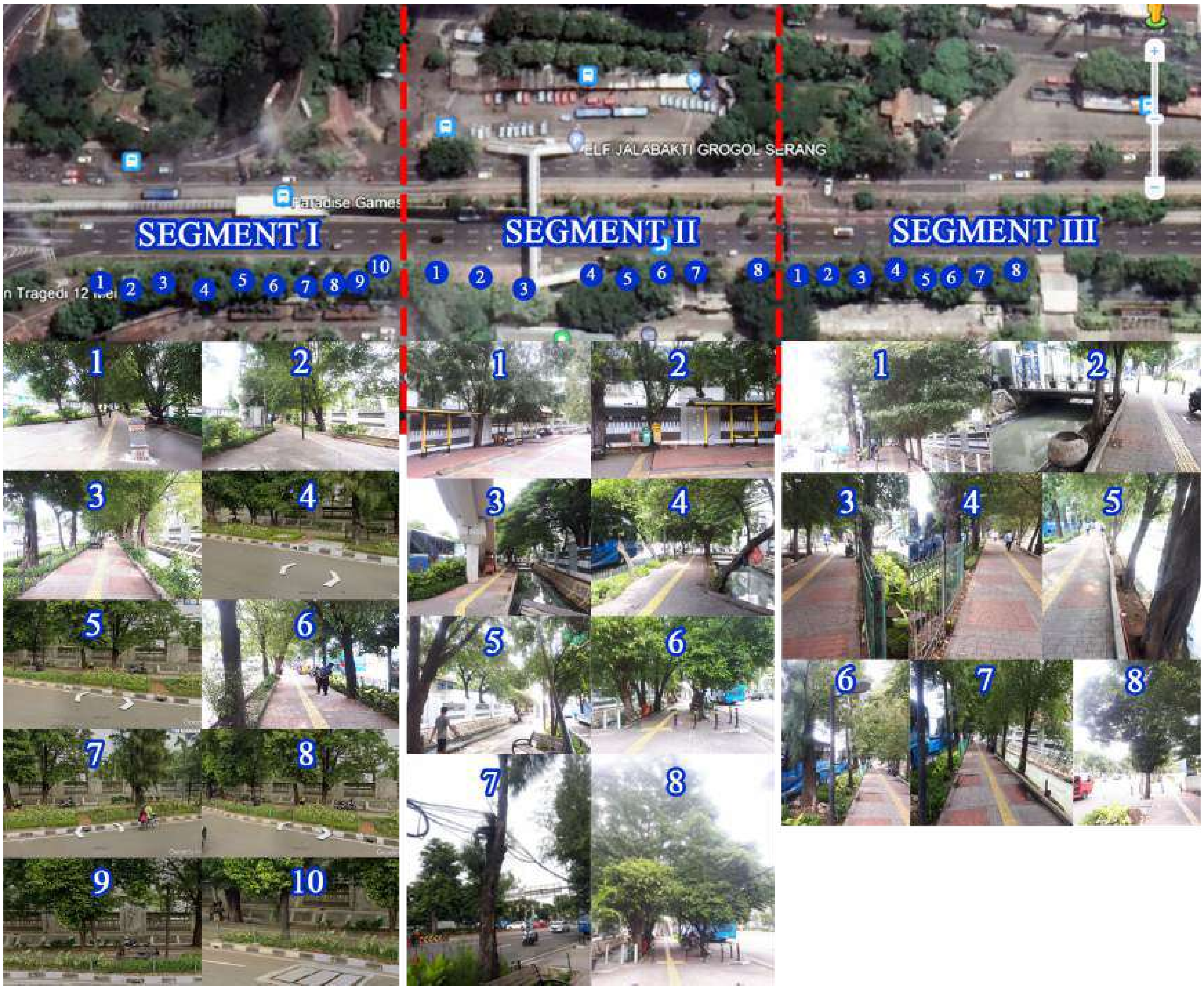


Figure 1. Study area, the pedestrian corridors at Jalan Kyai Tapa, and the segmentation (Source: author's documentation, 2021)

## 2.2 Data Collection

The study is conducted quantitatively. We collect data of field air temperature, relative humidity, wind speed, trees species, tree height, and canopy diameter. The measurement points for air temperature, relative humidity, and wind speed are distributed along the corridors. The measurement is done three times a day at 08:00, 12:00, and 16:00 for seven days during sunny weather when there are no clouds blocking the sunlight, using digital thermohygrometer. The pedestrian corridors have two sides, university side and terminal side, with a length of 300 m. We observe both corridors and divide each corridor into three segments of 100 m-long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to smaller vegetation coverage at this side.

Table 1. Location and measurement points

| **Pedestrian corridor side** | **Location** | **Total lLength (m)** | **Segment length (m)** | **Total measurement points** | **Measurement points per segment** |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

## 2.3 Data Analysis

The data are analyzed to calculate the Temperature Humidity Index (THI). THI is estimated to determine the equivalent temperature perceived by humans, by considering the air temperature and relative humidity. This index has been widely used to measure the human body's comfort (Isnoor et al., 2021; Pertiwi & Paski, 2021; Putri et al., 2021; Rusdayanti et al., 2021). Measured field air temperature and humidity are calculated following the THI formula by McGregor & Nieuwolt (1998) shown in Equation Formula 1.

(1)

where: THI = Temperature Humidity Index (°C), T = Air Temperature (°C), RH = Relative Humidity (%)

Table 2 shows the categories for THI values. The categories of THI used in this study follows the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), that are modified by Effendy (2007) for tropical climate use. Ideal environments that are perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Table 2. THI value categories

| THI value (°C) | Category |
|---|---|
| 21 ≥ THI ≤ 24 | Comfortable |
| 25 ≥ THI ≤ 27 | Less comfortable |
| THI > 27 | Not comfortable |

## 3 RESULTS AND DISCUSSIONS

### 3.1 The Vegetation Structure

There are two sides of pedestrian corridors at Jalan Kyai Tapa, which are university side and terminal side. Each side is divided into three segments. At segment I of Jalan Kyai Tapa university side, there are 30 trees that consist of 6 different species. The canopy diameter varies from 1.5 – 6.4 m and the height vary from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are 5 trees of *Casuarina equisetifolia*, 2 trees of *Artocarpus heterophyllus*, and 1 tree of *Cerbera manghas*. The vegetation structure of segment I, university side, is shown in Table 3.

Table 3. Vegetation structure at segment I, university side

| Segment | Point | Tree n~~N~~ame | | Tree s~~S~~ize (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local n~~N~~ame | Scientific n~~N~~ame | Canopy ~~D~~diameter | Height | |
| **I** | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |

 

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

At segment II, there are a total of 17 trees that consist of 5 different species, which are 7 trees of *Ficus virens*, 6 trees of *Mimusops elengi*, 2 trees of *Cerbera manghas*, 1 tree of *Samanea saman*, and 1 tree of *Muntingia calabura*. The canopy diameter at segment II ranges from 3 – 9 m and the tree height range from 3.2 – 11.2 m. The vegetation structure of segment II is summarized in Table 4.

Table 4. Vegetation structure at segment II, university side

| **Segment** | **Point** | **Tree ~~N~~name** | | **Tree ~~S~~size (m)** | | **Number** |
|---|---|---|---|---|---|---|
| | | **Local ~~Name~~name** | **~~Latin~~ Scientific n~~N~~ame** | **Canopy ~~D~~diameter** | **Height** | |
| **II** | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

Segment III has the highest number of trees compared to segment I and II. There are 37 trees that consist of 7 species with the canopy diameter vary from 3.2 – 7 m and the tree height range from 6 – 9 m. This segment is dominated with *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of segment III is shown in Table 5.

Table 5. Vegetation structure at segment III, university side

| **Segment** | **Point** | **Tree n~~N~~ame** | | **Tree s~~S~~ize (m)** | | **Number** |
|---|---|---|---|---|---|---|
| | | **Local n~~N~~ame** | **Scientific~~Latin~~ n~~N~~ame** | **Canopy ~~D~~diameter** | **Height** | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| | T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| | T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| | T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to/from the terminal. At segment I of Terminal side, there are 21 trees of 5 species with the canopy diameter varies from 3 – 5 m and the height vary from 6 – 10.8 m. This segment has 14 trees of *Handroanthus chrysotrichus*, 3 trees of *Swietenia mahagoni*, 1 tree of *Samanea saman*, 1 tree of *Casuarina equisetifolia*, and 1 tree of *Pterocarpus indicus*. At segment II, there are only 3 trees, 2 trees of *Casuarina equisetifolia* and 1 tree of *Pterocarpus indicus*. At segment III, there are 7 trees that consist of 7 trees of *Pterocarpus indicus*, 2 trees of *Casuarina equisetifolia*, and 1 tree of *Ficus benjamina.* The canopy diameter varies from 2 – 4 m and the height vary from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

Table 6. Vegetation structure at segment I, II, III, terminal side

| Segment | Point | Tree nName | | Tree Ssize (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Nname | Scientific Latin nName | Canopy dDiameter | Height | |
| **I** | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| **II** | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| **III** | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

### 3.2 The Thermal Environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured on 27 points at the university side and 16 points at the terminal side. At the university side (Figure 2), the average air temperature at 08:00 ranges from 30.16 – 31.29 °C. The lowest air temperature is found at T24 (segment II) and the highest is found at T6 (segment I). The average air temperature at 12:00 ranges from 32.8 – 35.1 °C. The lowest air temperature is at T1 (segment I) and the highest is at T17 (segment II). The average air temperature at 16:00 ranges from 33 – 34 °C. The lowest air temperature is at T1 (segment I) and the highest is at T17 (segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered as **less comfortable** for human activities.

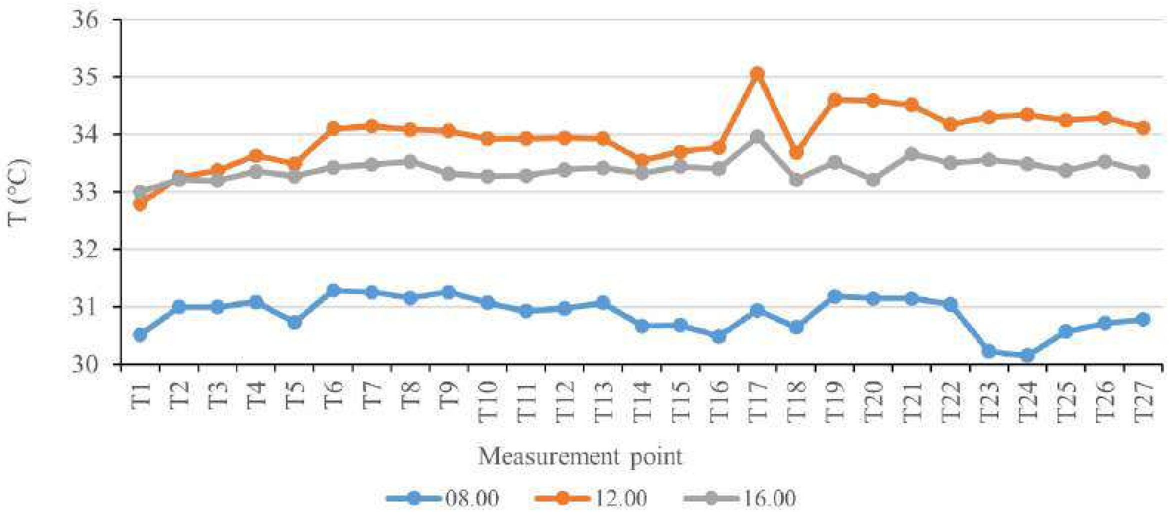


Figure 2. Average temperature of Jalan Kyai Tapa, university side

At the terminal side (Figure 3), the average air temperature at 08:00 ranges from 30.07 – 31.33 °C. The lowest air temperature is found at T1 (segment I) and the highest is at T9 (segment II). The average air temperature at 12:00 ranges from 33.71 – 36.03 °C, which the lowest is at T1 (segment I) and the highest is at T9 (segment II). The average air temperature at 16:00 ranges from 33.37 – 34.67 °C, which the lowest is at T1 (segment I) and the highest is at T9 (segment II). Although the air temperature ranges are different in three observed time, all three segments' lowest air temperature is found at T1 and the highest is at T9. Based on these values, the air temperature of the terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

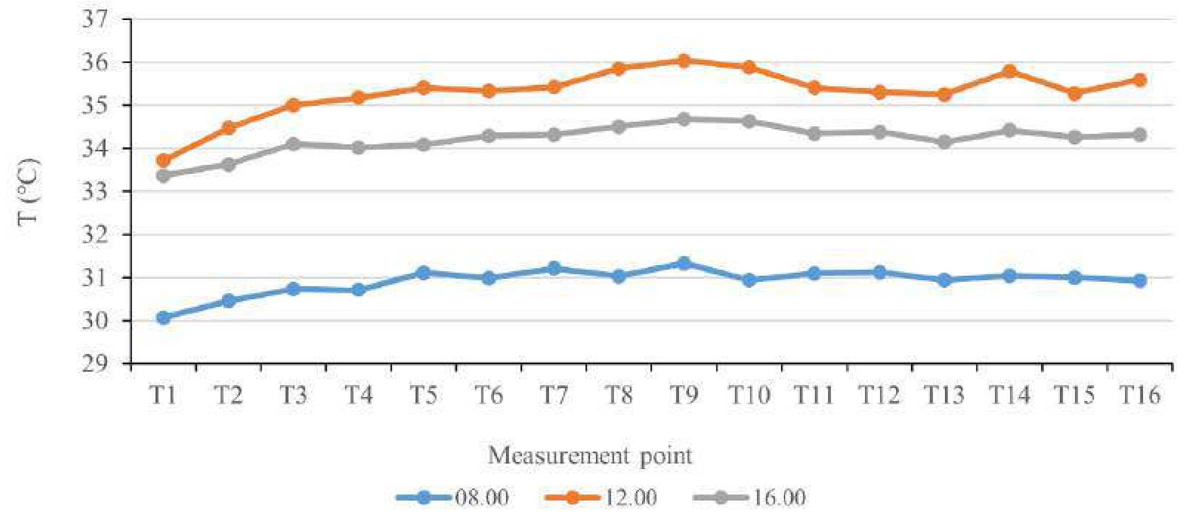


Figure 3. Average temperature of Jalan Kyai Tapa, terminal side

Figure 4 shows the average relative humidity measured at the university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, which the lowest is at T26 (segment II) and the highest is at T18 (segment II). This is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.21 – 61.46%, which the lowest is at T26 (segment II) and the highest is at T9 (segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%, which the lowest is at T17 (segment II) and the highest is at T4 (segment I). The average relative humidity at 12:00 and 16:00 are categorized as comfortable for humans.

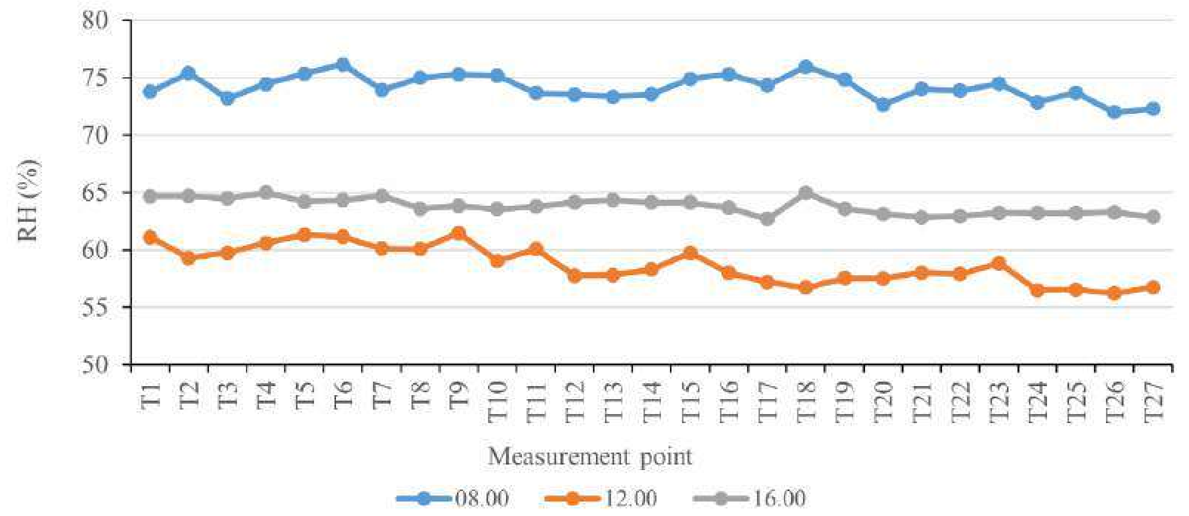


Figure 4. Average relative humidity of Jalan Kyai Tapa, university side

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The average relative humidity measured at the terminal side is shown in Figure 5. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, which the lowest is at T10 (segment I) and the highest is at T4 (segment I). This is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, which the lowest is at T14 (segment III) and the highest is at T1 (segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, which the lowest is at T7 (segment II) and the highest is at T1 (segment I). The average relative humidity at 12:00 and 16:00 are categorized as comfortable for humans.

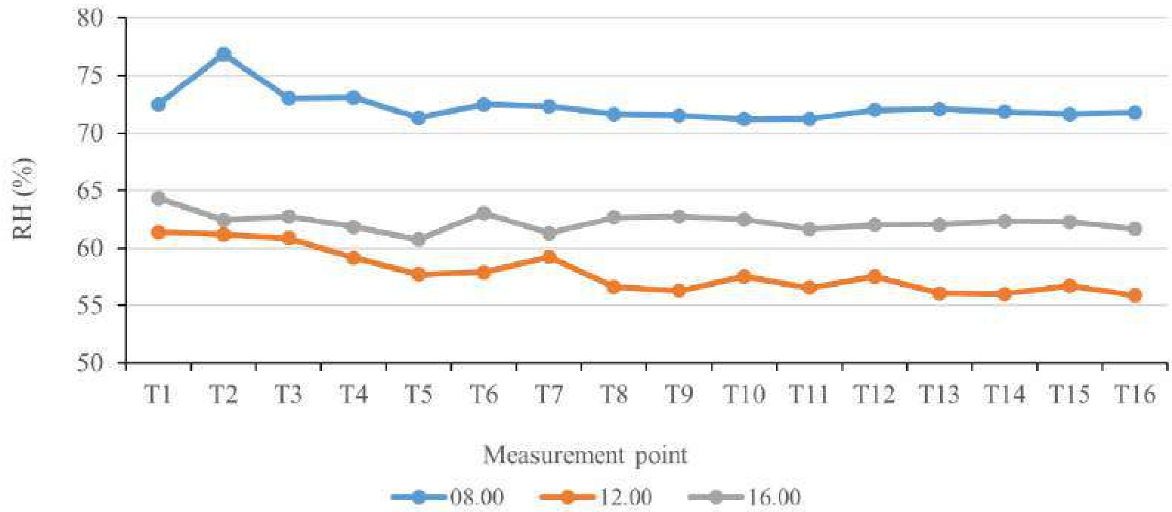


Figure 5. Average relative humidity of Jalan Kyai Tapa, terminal side

Additionally, we measured the wind speed at the university side (Figure 6) and terminal side (Figure 7) of Jalan Kyai Tapa. Generally, the average wind speed at the terminal side is slightly higher than the university side, possibly due to fewer trees at the terminal side. At the terminal side, the average is 33.41 km/hour and at the university side, the average is 32.86 km/hour. According to the Beaufort Scale (Stewart, 2008), wind speed of 29 – 38 km/hour is considered as fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00 and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

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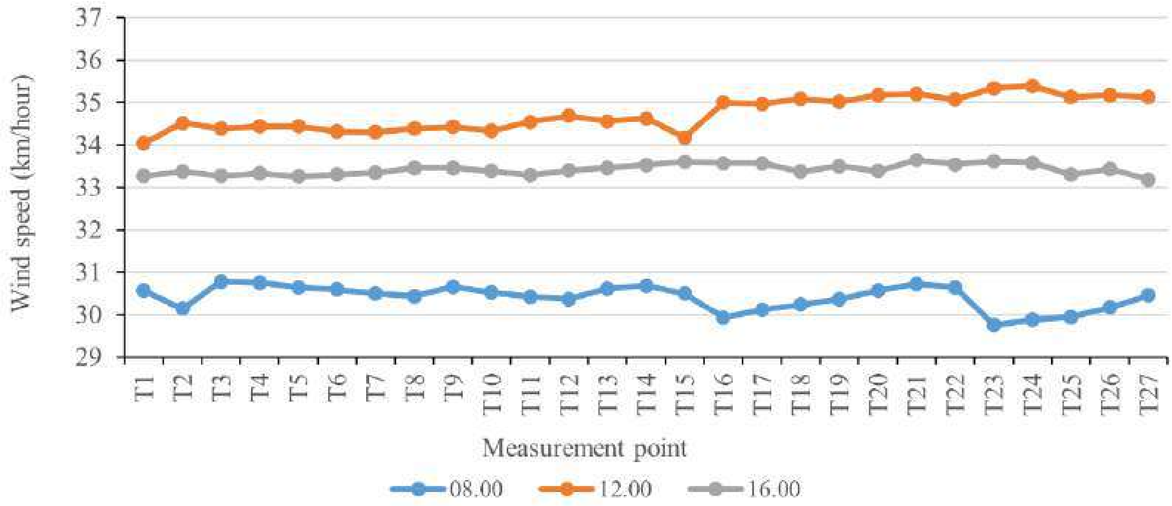


Figure 6. Average wind speed of Jalan Kyai Tapa, university side

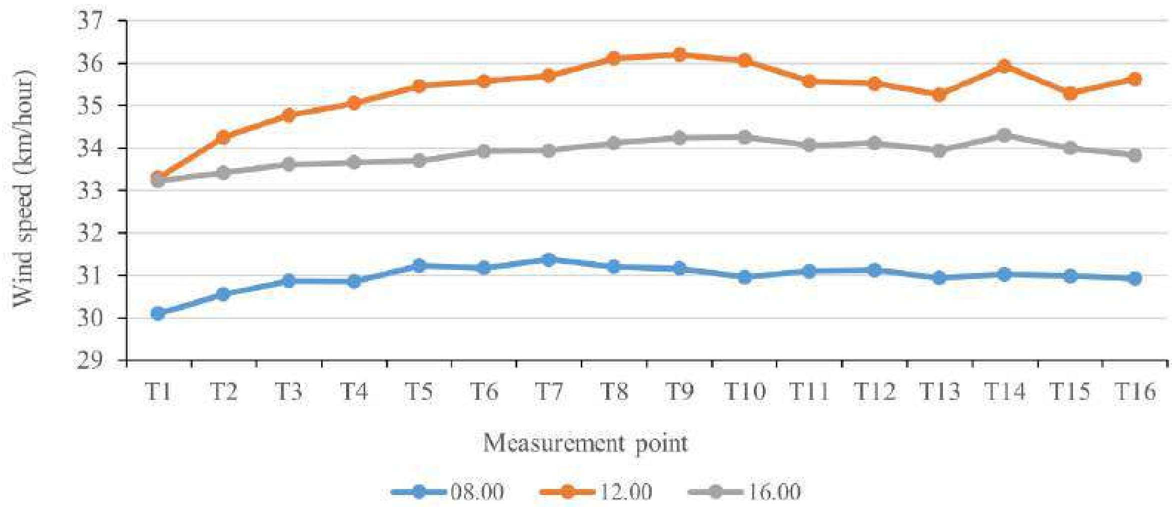


Figure 7. Average wind speed of Jalan Kyai Tapa, terminal side (author's result, 2022)

### 3.3 Temperature Heat Index (THI)

Based on the measured air temperature and relative humidity at the study area, we estimate the average THI at the university side and the terminal side. The average THI of the university side (Figure 8) at 08:00 ranges from 28.5 – 29.8 °C, which the lowest average THI is found at T24 (segment III) and the highest is at T6 (segment I). At 12:00, the average THI ranges from 30.2 – 31.6 °C, which the lowest is at T1 (segment I) and the highest is at T20 (segment III). The average THI at 16:00 ranges from 30.6 – 31.4 °C, which the lowest is at T1 (segment I) and the highest is at T17 (segment II). The average THI at 08:00, 12:00, and 16:00 are considered as **not comfortable**. The most not comfortable time is at 12:00.

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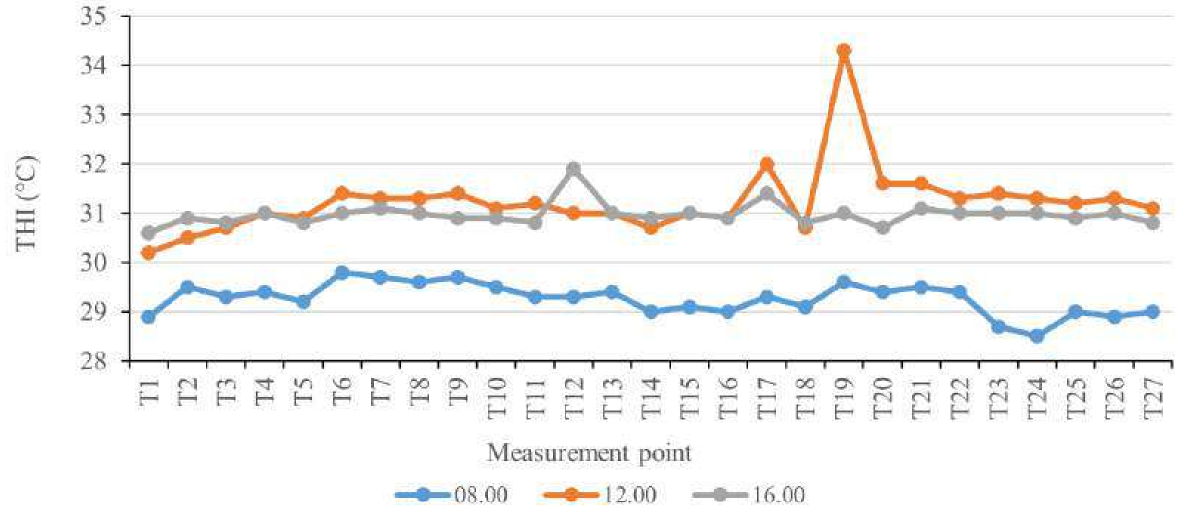


Figure 8. The average THI at the university side

Figure 9 shows the average THI at the terminal side. The average THI at 08:00 ranges from 28.4 – 29.5 °C, which the lowest THI is at T1 (segment I) and the highest is at T9 (segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C, which the lowest is at T1 (segment I) and the highest is at T9 and T10 (segment II). The average THI at 16:00 ranges from 30.9 – 32.0 °C, which the lowest is at T1 (segment I) and the highest is at T9 and T10 (segment II). The average THI at 08:00, 12:00, and 16:00 are considered as not comfortable. Similar to the university side, the most not comfortable time is at 12:00.

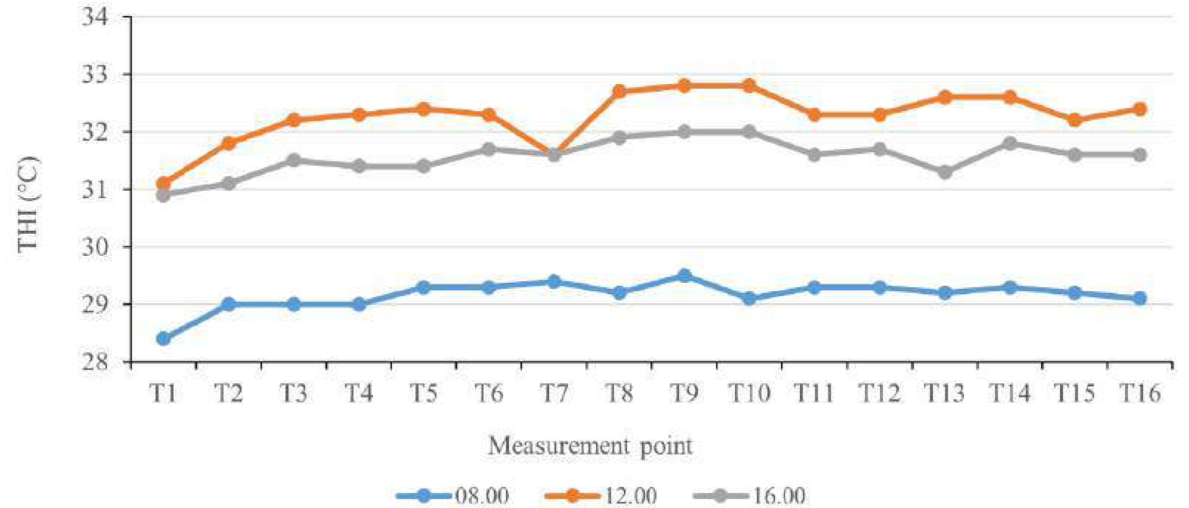


Figure 9. The average THI at the terminal side

### 3.4 Factors that Influence Thermal Comfort

According to the results, at the university side segment I, II, and II, there are 84 trees with varying canopy diameter from 1.5 – 9.0 m and varying height from 3.2 – 11.2 m. Meanwhile at the terminal side segment I, II, and II, there are 31 trees with varying canopy diameter from 2.0 – 5.0 m and varying height from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameter. Trees with wide canopy diameter are known to give wider shaded areas, which should improve the thermal comfort (Boukhabla & Alkama, 2012). Wider tree canopy and denser leaves can help reducing air temperature and improving microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

There are several factors that possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters, which are the foliage shape and dimensions, height of trunk, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). Tree canopy shape is an important variable in distributing air temperature (Fabbri et al., 2017). The shade from tree canopy influences the plants evapotranspiration, which increases relative humidity and absorbs thermal energy that leads to air temperature decrease (Perini et al., 2018) and ground temperature decrease (Morakinyo et al., 2018). An existing study found that the most influential parameter in affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is defined as one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also important because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely to be more significant than canopy diameter and tree height. Furthermore, tall trees with a large leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees for improving outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Y. Wang & Akbari, 2016). In relation to the results of this study, the trees canopy diameter in the study area might be not wide enough to provide adequate improvement to the air temperature, considering majority of the trees canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to determine the cause of uncomfortable outdoor areas more accurately.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all trees are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort

(Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This is similar to what we found during field measurement at the university side where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. Although an existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that at the university side, T1 has the lowest average air temperature and T17 has the highest temperature at 12:00 and 16:00, although there is no tree at T1 and there is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has the lowest temperature and T6 has the highest temperature. T6 and T24 similarly have *Ficus virens* and *Mimusops elengi* nearby, but the number of trees is bigger at T24. The different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning is more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the different tendency between morning and afternoon observations. As for the afternoon phenomenon where T1 (no tree) has the lowest average air temperature and T17 (with tree) has the highest, there is possibly canopy-associated warming that occurred during observations. Sharmin et al., (2023) conducted a study to determine cooling benefits of 10 urban trees species considering the tree traits and microclimatic conditions in suburban areas. The study found that there is canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with highest LAI has the lowest sub-canopy warming effect. The sub-canopy warming effect can also be caused by the heat from nearby buildings. A study by Alonzo et al., (2021) that was conducted in Washington DC found that trees located along streets has less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under tree canopy and surrounding surfaces. This further supports that the air temperature under trees might be higher than the ambient air temperature, particularly if the area is surrounded by buildings like the study area. This also may explain why such phenomenon is not found at the terminal side considering the terminal side has fewer structures and buildings than the university side. On a side note, it is worth to note that T1 is also located near a small water body which may also help to decrease the air temperature due to water body evaporation (Chen et al., 2023).

At another case, T9 of the terminal side that is shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter so we suggest it cannot give proper shade to cool down the air temperature. We mentioned that at the university side, some spots with *Casuarina equisetifolia* have better thermal comfort than *Mimusops elengi*, this indicates that vegetation species alone cannot determine the thermal comfort, it is also related to the planting distance, design, and other elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili, Acero, et al., 2021).

Generally, the university side has better thermal comfort than the terminal side. The university side also has more trees and less pavement coverage than the terminal side. Trees can improve the thermal comfort and to optimize the tree function at pedestrian corridors, we should consider the tree characteristics and the tree arrangement. From the results of this study, we discussed that thermal comfort of pedestrian corridors is determined by various factors and the trees influence on microclimate can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically on measuring LAI and the distance between trees. Therefore, further research is required prior to proposing recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4 CONCLUSION

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01 – 31.54 °C and the relative humidity ranges from 56.19 – 57.74%. Average air temperature and relative humidity at Jalan Kyai Tapa are 31.2 °C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52 °C, which is categorized as not comfortable. In areas that have small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas that have large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, the trees do not seem to adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort as we found a measurement point that does not have any tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design in creating comfortable pedestrian corridors.

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

## Abstract

The increase of motor vehicles in Jakarta leads to environmental degradation and eventually can harm human health. When the environment is damaged, pedestrians are the most impacted group of road users. In the past few years, the local government of Jakarta has a vision to focus on improving human mobility networks including pedestrian networks. As a road with busy traffic, Jalan Kyai Tapa, West Jakarta, is used by many people, but it may feel not comfortable to walk there due to heat and sun exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. This study is done quantitatively. We identify the vegetation structure of Jalan Kyai Tapa including the tree species, canopy diameter, and tree height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate the thermal comfort using Temperature Humidity Index (THI). The results show that the air temperature at Jalan Kyai Tapa ranges from 31.01 °C - 31.54 °C and the relative humidity ranges from 56.19% - 57.74%. The average THI value at Jalan Kyai Tapa is 28.52 °C, which is considered as not comfortable. Despite having relatively wide canopy and can provide shade, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the thermal environment to reach a comfortable state for pedestrians. Interestingly, the result shows that, at certain observation times, the spot that has no tree have lower air temperature compared to other spots with trees. Trees might not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with wider canopies can be less comfortable than spots near trees with smaller canopies. Tree species and the planting spacing determine the efficiency of trees to improve the thermal comfort.

**Keywords**: Corridor; Pedestrian way; Thermal comfort; Vegetation.

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## 1 INTRODUCTION

The urban population keep increasing in the past few decades. The population growth in Jakarta 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase is followed by the increase of motor vehicle. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, that is infamous for its severe traffic congestion due to overload motor vehicles, would suffer more from this. Increasing motor vehicles means more emissions of air pollutants and greenhouse gases that eventually could harm human health and damage the environment. If the environment is damaged, pedestrians are the most impacted group of road users as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

Roadside greenbelt is a linear green open space that is formed by landscape elements, such as trees and shrubs, providing comfort, safety, and beauty for users (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban area play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (Akbari et al., 2001; Biao et al., 2010; Lafortezza et al., 2009; Nowak et al., 2006; Simangunsong et al., 2021; Simangunsong & Fitri, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spagenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin & Waryono, 2010), such as ameliorating microclimate, reducing pollutants including particle and gas, controlling glare, producing oxygen (Simangunsong et al., 2021; Simangunsong & Fitri, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. To optimize the role of roadside vegetation, the vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions. Additionally, selecting the local species would make the adaptation easier for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only on a micro scale, but also at a city scale.

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Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. Direct benefits of roadside greenbelts to humans are providing shades, users safety, and improving the comfortability for users, especially pedestrians and cyclists. The position of greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building – environment interaction, which include various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and width of street (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity are factors that directly influence Temperature Humidity Index (THI), an index that is used to measure human body comfort. By paying attention to the thermal comfort at roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetic. Vegetation at roadside landscape serves as view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, the planting design, and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etc.). The interaction between softscape and hardscape determines the thermal comfort.

Jakarta's local government initiated a concept of Smart City since 2014 by improving the city based on six elements of Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to improve traffic congestion, reduce air pollution, improve citizen mobility, etc. To support public transportation, Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infrastructure) revitalizes public facilities such as pedestrian corridors. Dinas Bina Marga cooperates with Institute for Transportation Development Policy (ITDP) Indonesia to plan human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facility for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road that has two pedestrian corridors with roadside greenbelts. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several

Transjakarta bus routes and is connected to other major roads. Pedestrian corridors at Jalan Kyai Tapa are used by quite a lot of people. However, in the afternoon, it may feel not comfortable to walk there due to heat and sun light exposure, that is worsened by large coverages of pavements. The thermal condition of a pedestrian corridor is an important factor to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas, but it is still rather limited in Indonesia. Existing studies has analyzed pedestrian corridors comfort in Indonesia cities, in relation to its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). There are only few studies that specifically focuses on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). There are even fewer studies on thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta are mostly related to transit oriented development concept (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. The objective of this study is to analyze the thermal comfort of pedestrian corridors at Jalan Kyai Tapa in relation to its landscape composition including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can give a brief illustration of other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can be of help in improving the pedestrian corridors in Jakarta.

## 2 METHODS

### 2.1 Study Area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a major road that is passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot. There are two sides of pedestrian corridors at Jalan Kyai Tapa, (1) terminal side (north side) and (2) university side (south side). At the terminal side, there are bus terminal, police station, and traffic gardens. Meanwhile, at the university side, there are university buildings, hotels, restaurants, and other commercial buildings. The study area is 300 m-long and we divided the 300 meters-long pedestrian corridors into three segments, 100 m-long each. The study area and the segmentation are shown in Figure 1. The field data were collected in November 2021 until February 2022.

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Figure 1. Study area, the pedestrian corridors at Jalan Kyai Tapa, and the segmentation (Source: author's documentation, 2021)

## 2.2 Data Collection

The study is conducted quantitatively. We collect data of field air temperature, relative humidity, wind speed, trees species, tree height, and canopy diameter. The measurement points for air temperature, relative humidity, and wind speed are distributed along the corridors. The measurement is done three times a day at 08:00, 12:00, and 16:00 for seven days during sunny weather using digital thermohygrometer. The pedestrian corridors have two sides, university side and terminal side, with a length of 300 m. We observe both corridors and divide each corridor into three segments of 100 m-long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to smaller vegetation coverage at this side.

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Table 1. Location and measurement points

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

### 2.3 Data Analysis

The data are analyzed to calculate the Temperature Humidity Index (THI). THI is estimated to determine the equivalent temperature perceived by humans, by considering the air temperature and relative humidity. This index has been widely used to measure the human body's comfort (Isnoor et al., 2021; Pertiwi & Paski, 2021; Putri et al., 2021; Rusdayanti et al., 2021). Measured field air temperature and humidity are calculated following the THI formula by McGregor & Nieuwolt (1998) shown in Equation 1.

$$THI = 0.8\,T + (RH \times T)/500 \quad (1)$$

where: THI = Temperature Humidity Index (°C), T = Air Temperature (°C), RH = Relative Humidity (%)

Table 2 shows the categories for THI values. The categories of THI used in this study follows the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), that are modified by Effendy (2007) for tropical climate use. Ideal environments that are perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Table 2. THI value categories

| THI value (°C) | Category |
|---|---|
| 21 ≥ THI ≤ 24 | Comfortable |
| 25 ≥ THI ≤ 27 | Less comfortable |
| THI > 27 | Not comfortable |

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# 3 RESULTS AND DISCUSSIONS

## 3.1 The Vegetation Structure

There are two sides of pedestrian corridors at Jalan Kyai Tapa, which are university side and terminal side. Each side is divided into three segments. At segment I of Jalan Kyai Tapa university side, there are 30 trees that consist of 6 different species. The canopy diameter varies from 1.5 – 6.4 m and the height vary from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are 5 trees of *Casuarina equisetifolia*, 2 trees of *Artocarpus heterophyllus*, and 1 tree of *Cerbera manghas*. The vegetation structure of segment I, university side, is shown in Table 3.

Table 3. Vegetation structure at segment I, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| **I** | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

At segment II, there are a total of 17 trees that consist of 5 different species, which are 7 trees of *Ficus virens*, 6 trees of *Mimusops elengi*, 2 trees of *Cerbera manghas*, 1 tree of *Samanea saman*, and

1 tree of *Muntingia calabura*. The canopy diameter at segment II ranges from 3 – 9 m and the tree height range from 3.2 – 11.2 m. The vegetation structure of segment II is summarized in Table 4.

Table 4. Vegetation structure at segment II, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **II** | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

Segment III has the highest number of trees compared to segment I and II. There are 37 trees that consist of 7 species with the canopy diameter vary from 3.2 – 7 m and the tree height range from 6 – 9 m. This segment is dominated with *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of segment III is shown in Table 5.

Table 5. Vegetation structure at segment III, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to/from the terminal. At segment I of Terminal side, there are 21 trees of 5 species with the canopy diameter varies from 3 – 5 m and the height vary from 6 – 10.8 m. This segment has 14 trees of *Handroanthus chrysotrichus*, 3 trees of *Swietenia mahagoni*, 1 tree of *Samanea saman*, 1 tree of *Casuarina equisetifolia*, and 1 tree of *Pterocarpus indicus*. At segment II, there are only 3 trees, 2 trees of *Casuarina equisetifolia* and 1 tree of *Pterocarpus indicus*. At segment III, there are 7 trees that consist of 7 trees of *Pterocarpus indicus*, 2 trees of *Casuarina equisetifolia*, and 1 tree of *Ficus benjamina*. The canopy diameter varies from 2 – 4 m and the height vary from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

Table 6. Vegetation structure at segment I, II, III, terminal side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **I** | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| **II** | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |

| | | | | | | |
|---|---|---|---|---|---|---|
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| **III** | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

### 3.2 The Thermal Environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured on 27 points at the university side and 16 points at the terminal side. At the university side (Figure 2), the average air temperature at 08:00 ranges from 30.16 – 31.29 °C. The lowest air temperature is found at T24 (segment II) and the highest is found at T6 (segment I). The average air temperature at 12:00 ranges from 32.8 – 35.1 °C. The lowest air temperature is at T1 (segment I) and the highest is at T17 (segment II). The average air temperature at 16:00 ranges from 33 – 34 °C. The lowest air temperature is at T1 (segment I) and the highest is at T17 (segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered as **less comfortable** for human activities.

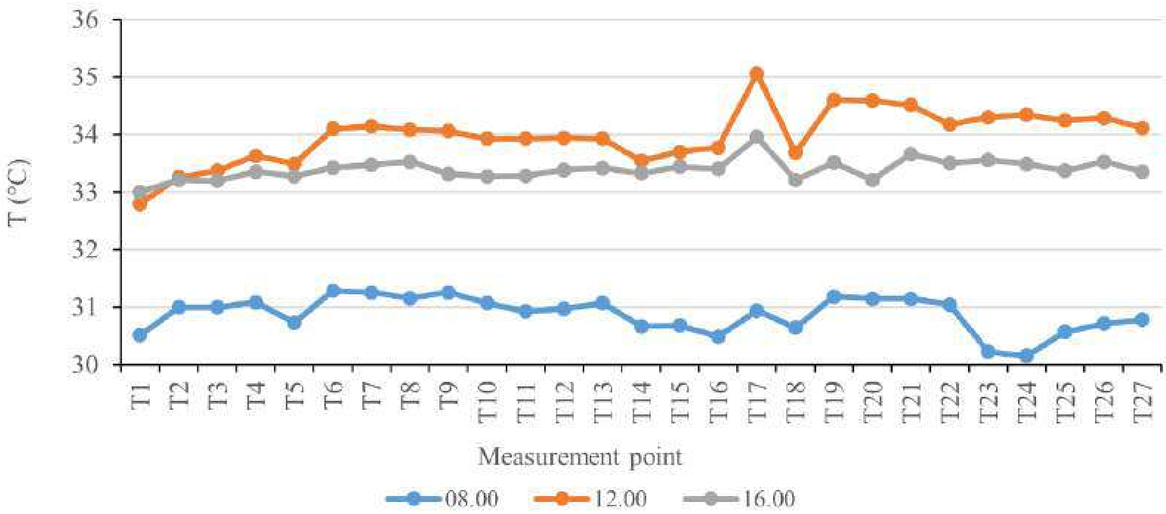


Figure 2. Average temperature of Jalan Kyai Tapa, university side

At the terminal side (Figure 3), the average air temperature at 08:00 ranges from 30.07 – 31.33 °C. The lowest air temperature is found at T1 (segment I) and the highest is at T9 (segment II). The average air temperature at 12:00 ranges from 33.71 – 36.03 °C, which the lowest is at T1 (segment I) and the highest is at T9 (segment II). The average air temperature at 16:00 ranges from 33.37 – 34.67

°C, which the lowest is at T1 (segment I) and the highest is at T9 (segment II). Although the air temperature ranges are different in three observed time, all three segments' lowest air temperature is found at T1 and the highest is at T9. Based on these values, the air temperature of the terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

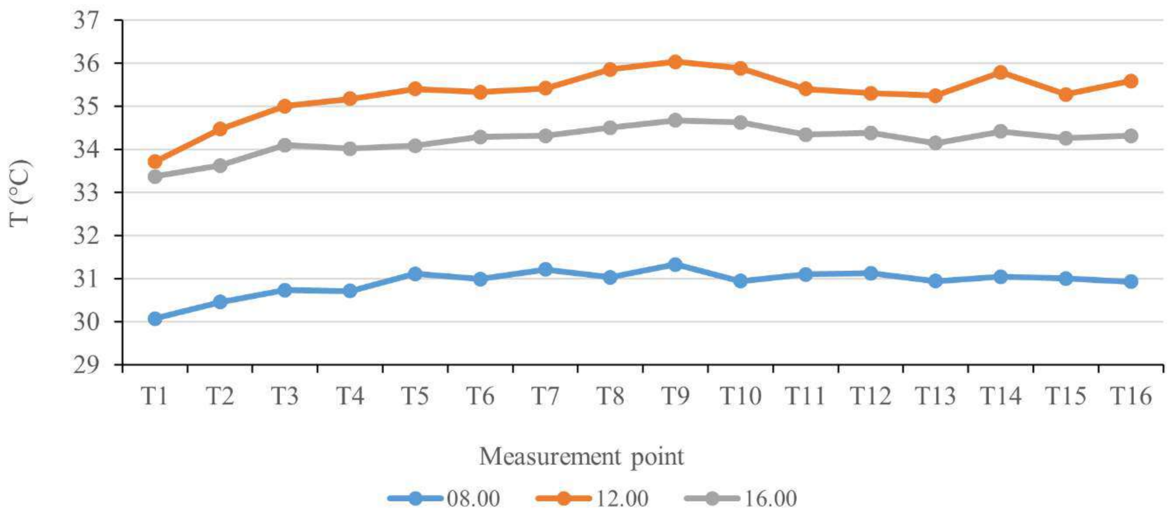


Figure 3. Average temperature of Jalan Kyai Tapa, terminal side

Figure 4 shows the average relative humidity measured at the university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, which the lowest is at T26 (segment II) and the highest is at T18 (segment II). This is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.21 – 61.46%, which the lowest is at T26 (segment II) and the highest is at T9 (segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%, which the lowest is at T17 (segment II) and the highest is at T4 (segment I). The average relative humidity at 12:00 and 16:00 are categorized as comfortable for humans.

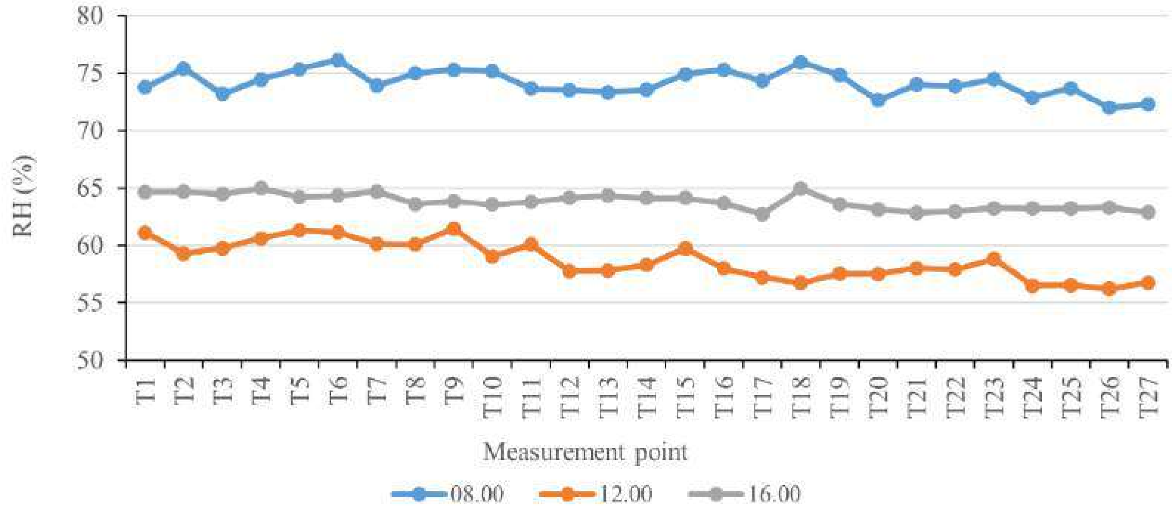


Figure 4. Average relative humidity of Jalan Kyai Tapa, university side

The average relative humidity measured at the terminal side is shown in Figure 5. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, which the lowest is at T10 (segment I) and the highest is at T4 (segment I). This is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, which the lowest is at T14 (segment III) and the highest is at T1 (segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, which the lowest is at T7 (segment II) and the highest is at T1 (segment I). The average relative humidity at 12:00 and 16:00 are categorized as comfortable for humans.

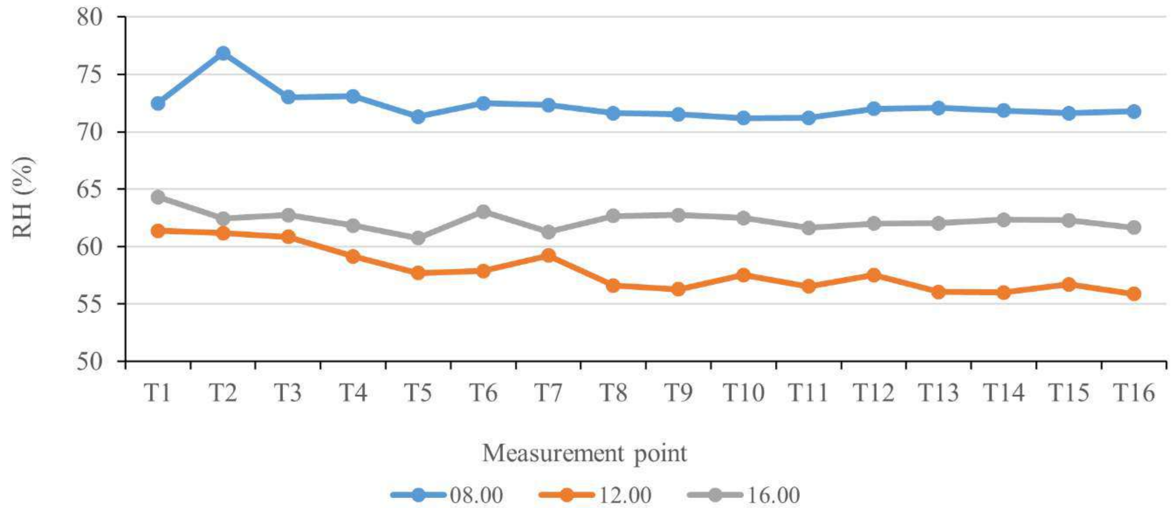


Figure 5. Average relative humidity of Jalan Kyai Tapa, terminal side

Additionally, we measured the wind speed at the university side (Figure 6) and terminal side (Figure 7) of Jalan Kyai Tapa. Generally, the average wind speed at the terminal side is slightly higher than the university side, possibly due to fewer trees at the terminal side. At the terminal side, the average is 33.41 km/hour and at the university side, the average is 32.86 km/hour. According to the Beaufort Scale (Stewart, 2008), wind speed of 29 – 38 km/hour is considered as fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00 and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

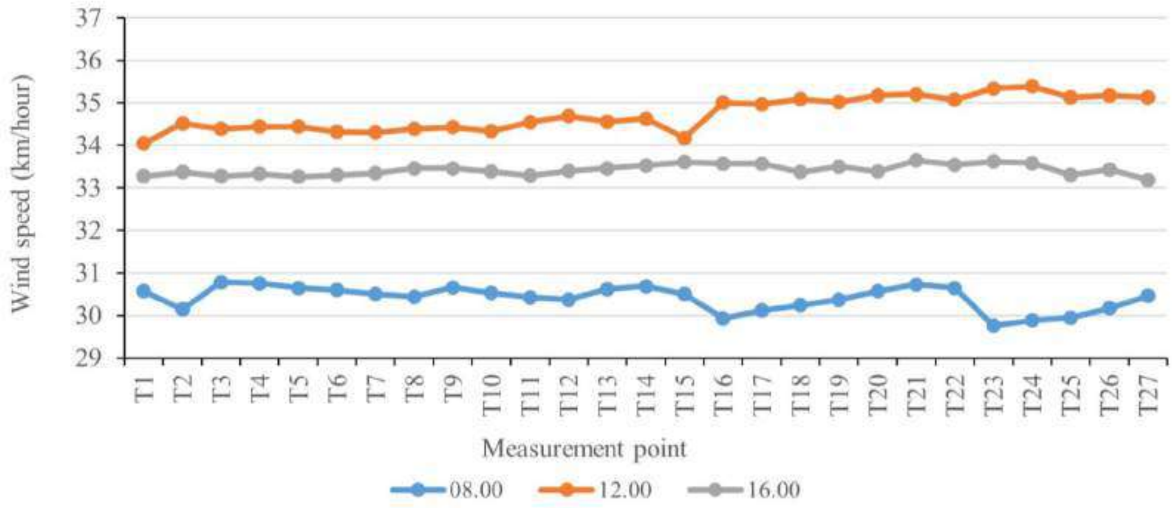


Figure 6. Average wind speed of Jalan Kyai Tapa, university side

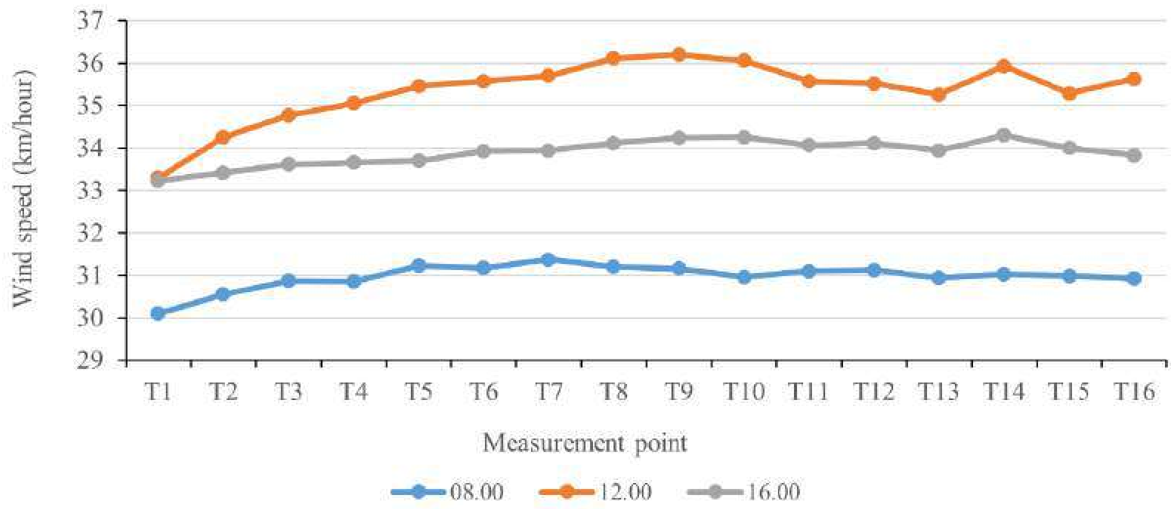


Figure 7. Average wind speed of Jalan Kyai Tapa, terminal side (author's result, 2022)

### 3.3 Temperature Heat Index (THI)

Based on the measured air temperature and relative humidity at the study area, we estimate the average THI at the university side and the terminal side. The average THI of the university side (Figure 8) at 08:00 ranges from 28.5 – 29.8 °C, which the lowest average THI is found at T24 (segment III) and the highest is at T6 (segment I). At 12:00, the average THI ranges from 30.2 – 31.6 °C, which the lowest is at T1 (segment I) and the highest is at T20 (segment III). The average THI at 16:00 ranges from 30.6 – 31.4 °C, which the lowest is at T1 (segment I) and the highest is at T17 (segment II). The average THI at 08:00, 12:00, and 16:00 are considered as **not comfortable**. The most not comfortable time is at 12:00.

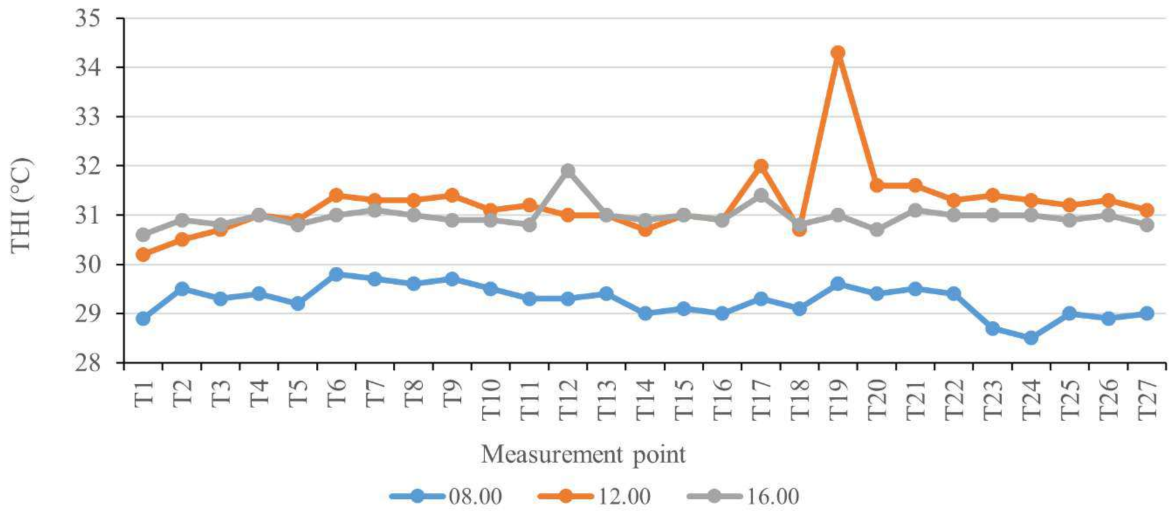


Figure 8. The average THI at the university side

Figure 9 shows the average THI at the terminal side. The average THI at 08:00 ranges from 28.4 – 29.5 °C, which the lowest THI is at T1 (segment I) and the highest is at T9 (segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C, which the lowest is at T1 (segment I) and the highest is at T9 and T10 (segment II). The average THI at 16:00 ranges from 30.9 – 32.0 °C, which the lowest is at T1 (segment I) and the highest is at T9 and T10 (segment II). The average THI at 08:00, 12:00, and 16:00 are considered as not comfortable. Similar to the university side, the most not comfortable time is at 12:00.

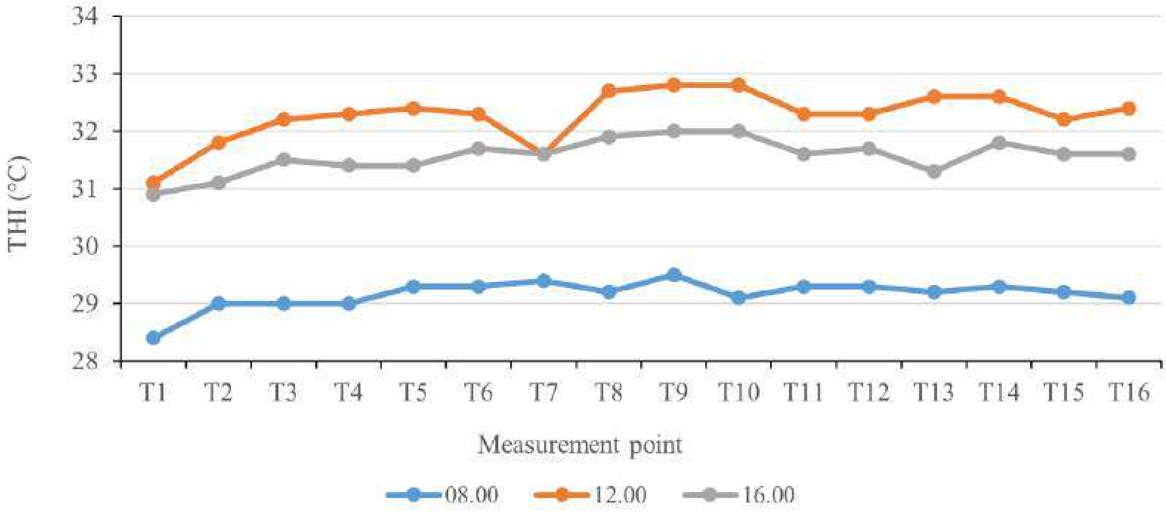


Figure 9. The average THI at the terminal side

### 3.4 Factors that Influence Thermal Comfort

According to the results, at the university side segment I, II, and II, there are 84 trees with varying canopy diameter from 1.5 – 9.0 m and varying height from 3.2 – 11.2 m. Meanwhile at the terminal side segment I, II, and II, there are 31 trees with varying canopy diameter from 2.0 – 5.0 m and varying height from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameter. Trees with wide canopy diameter are known to give wider shaded areas, which should improve the thermal comfort (Boukhabla & Alkama, 2012). Wider tree canopy and denser leaves can help reducing air temperature and improving microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

There are several factors that possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters, which are the foliage shape and dimensions, height of trunk, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). Tree canopy shape is an important variable in distributing air temperature (Fabbri et al., 2017). The shade from tree canopy influences the plants evapotranspiration, which increases relative humidity and absorbs thermal energy that leads to air temperature decrease (Perini et al., 2018) and ground temperature decrease (Morakinyo et al., 2018). An existing study found that the most influential parameter in affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is defined as one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also important because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely to be more significant than canopy diameter and tree height. Furthermore, tall trees with a large leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees for improving outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Wang & Akbari, 2016). In relation to the results of this study, the trees canopy diameter in the study area might be not wide enough to provide adequate improvement to the air temperature, considering majority of the trees canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to determine the cause of uncomfortable outdoor areas more accurately.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all trees are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This is similar to what we found during field measurement at the university side where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. Although an existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that at the university side, T1 has the lowest average air temperature and T17 has the highest temperature at 12:00 and 16:00, although there is no tree at T1 and there is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has the lowest temperature and T6 has the highest temperature. T6 and T24 similarly have *Ficus virens* and *Mimusops elengi* nearby, but the number of trees is bigger at T24. The different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning is more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the different tendency between morning and afternoon observations. As for the afternoon phenomenon where T1 (no tree) has the lowest average air temperature and T17 (with tree) has the highest, there is possibly canopy-associated warming that occurred during observations. Sharmin et al., (2023) conducted a study to determine cooling benefits of 10 urban trees species considering the tree traits and microclimatic conditions in suburban areas. The study found that there is canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with highest LAI has the lowest sub-canopy warming effect. The sub-canopy warming effect can also be caused by the heat from nearby buildings. A study by Alonzo et al., (2021) that was conducted in Washington DC found that trees located along streets has less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under tree canopy and surrounding surfaces. This further supports that the air temperature under trees might be higher than the ambient air temperature, particularly if the area is surrounded by buildings like the study area. This also may explain why such phenomenon is not found at the terminal side considering the terminal side has fewer structures and buildings than the university side. On a side note, it is worth to note that T1 is also located near a small water body which may also help to decrease the air temperature due to water body evaporation (Chen et al., 2023).

At another case, T9 of the terminal side that is shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter so we suggest it cannot give proper shade to cool down the air temperature. We mentioned that at the university side, some spots with *Casuarina equisetifolia* have better thermal comfort than *Mimusops elengi*, this indicates that vegetation species alone cannot determine the thermal comfort, it is also related to the planting distance, design, and other elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the university side has better thermal comfort than the terminal side. The university side also has more trees and less pavement coverage than the terminal side. Trees can improve the thermal comfort and to optimize the tree function at pedestrian corridors, we should consider the tree characteristics and the tree arrangement. From the results of this study, we discussed that thermal comfort of pedestrian corridors is determined by various factors and the trees influence on microclimate can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically on measuring LAI and the distance between trees. Therefore, further research is required prior to proposing recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4 CONCLUSION

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01 – 31.54 °C and the relative humidity ranges from 56.19 – 57.74%. Average air temperature and relative humidity at Jalan Kyai Tapa are 31.2 °C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52 °C, which is categorized as not comfortable. In areas that have small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas that have large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, the trees do not seem to adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort as we found a measurement point that does not have any tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design in creating comfortable pedestrian corridors.

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1 message

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

**Abstract**

The increasing number of motorized vehicles in Jakarta is causing environmental damage and can harm human health. In recent years, the Jakarta local government has the vision to focus on improving the human mobility network, including the pedestrian networks. As a heavily trafficked road, Jalan Kyai Tapa, West Jakarta, is used by many people. However, it may feel uncomfortable to walk there due to heat and sun exposure, which is compounded by extensive pavement coverage. The thermal condition of the pedestrian corridor is essential to create a comfortable walking experience. The objective of this study was to analyze the thermal comfort of the pedestrian corridors at Jalan Kyai Tapa concerning the landscape composition, including vegetation structure and pavement. This study was conducted quantitatively. This study identified the vegetation structure, including the tree species, canopy diameter, and height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate thermal comfort using the Temperature Humidity Index (THI). The results showed that the air temperature ranges from 31.01°C to 31.54°C, and the relative humidity ranges from 56.19% to 57.74%. The average THI value is 28.52 °C, which falls into the comfortable category. Despite having relatively wide canopies and providing shade, the trees in this pedestrian corridor do not seem to improve the thermal environment enough to achieve comfortable conditions for pedestrians. Interestingly, the result shows that, at certain observation times, points without trees had lower air temperatures compared to other spots with trees. Trees may not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with more expansive canopies can be less comfortable than spots near trees with smaller canopies. Tree species and the planting spacing determine the efficiency of trees to improve thermal comfort.

**Keywords**: Corridor; Pedestrian way; Thermal comfort; Vegetation.

## 1. Introduction

The urban population has kept increasing in the past few decades. The population growth in Jakarta from 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase follows the increase in motor vehicles. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, infamous for its severe traffic congestion due to overloaded motor vehicles, would suffer more. Increasing the number of motor vehicles means more emissions of air pollutants and greenhouse gases that could eventually harm human health and the environment. If the environment is damaged, pedestrians are the most impacted group of road users as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

A roadside greenbelt is a linear green open space formed by landscape elements, such as trees and shrubs, providing users comfort, safety, and beauty (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban areas play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (Nowak et al., 2006; Biao et al., 2010; Simangunsong et al., 2021; Simangunsong & Fitri, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

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In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spagenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin & Waryono, 2010), such as ameliorating microclimate, reducing pollutants, including particle and gas, controlling glare, producing oxygen (Simangunsong et al., 2021; Simangunsong & Fitri, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. The vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions to optimize the role of roadside vegetation. Additionally, selecting the local species would make the adaptation more accessible for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only on a micro scale but also at a city scale.

Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. The direct benefits of roadside greenbelts to humans are providing shade, user safety, and improving users' comfort, especially pedestrians and cyclists. The position of the greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if it is too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building–environment interaction, which includes various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and street width (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity directly influence THI, an index used to measure human body comfort. By paying attention to the thermal comfort of roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetics. Vegetation in roadside landscape serves as a view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, and the planting design and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etcetera). The interaction between softscape and hardscape determines thermal comfort.

Jakarta's local government initiated the concept of a Smart City in 2014 by improving the city based on six elements: Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to reduce traffic congestion, air pollution, citizen mobility, etcetera. Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infrastructure) revitalizes public facilities such as pedestrian corridors to support public transportation. Dinas Bina Marga cooperates with the Institute for Transportation Development Policy (ITDP) Indonesia to plan a human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facilities for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road with two pedestrian corridors and green belts on the side. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Quite a lot of people use pedestrian corridors at Jalan Kyai Tapa. However, in the afternoon, it may feel uncomfortable to walk there due to heat and sunlight exposure, and significant coverages of pavements worsen that. The thermal condition of a pedestrian corridor is essential to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas but is still relatively limited in Indonesia. Existing studies have analyzed pedestrian corridors' comfort in Indonesia cities concerning its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). Only a few studies specifically focus on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). Even fewer studies exist on the thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta primarily relate to transit-oriented development concepts (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. This study analyzes the thermal comfort of pedestrian corridors at Jalan Kyai Tapa concerning its landscape composition, including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can briefly illustrate other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can help improve the pedestrian corridors in Jakarta.

## 2. Methods

### 2.1 Study area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a significant road passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot (Figure 1). There are two sides of pedestrian corridors at Jalan Kyai Tapa: (1) the terminal side (north side) and (2) the university side (south side).

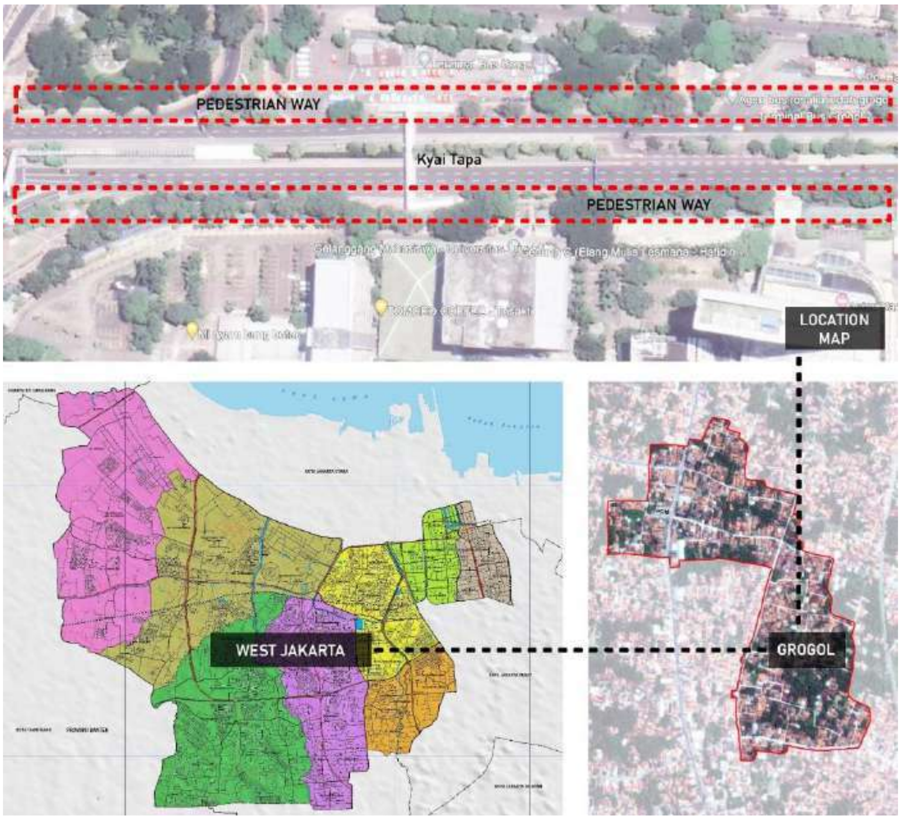


Figure. 1 Study location map

The terminal side has a bus terminal, police station, and traffic gardens. Meanwhile, university buildings, hotels, restaurants, and other commercial buildings are on the university side. The tree information in the study area is collected for further analysis. When inventorying vegetation, existing studies created plots of 100 meters by 100 meters in broad areas, such as national parks (Haryadi et al., 2019; Maulidiyan et al., 2019), and created belt transects of 100 m in linear areas, such as roadsides (Danniswari & Nasrullah, 2017). Therefore, we divided the 300-meter-long pedestrian corridors into three segments, 100 m-long each. The study area and the segmentation are shown in Figure 2. The field data was collected from November 2021 until February 2022.


Figure. 2 Study area, the pedestrian corridors at Kyai Tapa, and the segmentation

## 2.2 Data collection

The study is conducted quantitatively. We collect data on field air temperature, relative humidity, wind speed, tree species, tree height, and canopy diameter. Air temperature, relative humidity, and wind speed measurement points are distributed along the corridors. The measurement is done three times daily at 08:00, 12:00, and 16:00 for seven days during sunny weather using a digital thermohygrometer. The pedestrian corridors have two sides, the university side and the terminal side, with a length of 300 m. We observed both corridors and divided each corridor into three segments 100 m long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to the smaller vegetation coverage on this side.

Table 1. Location and measurement points

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

### 2.3 Data analysis

The data are analyzed to calculate the Temperature Humidity Index. The THI is estimated to determine the equivalent temperature perceived by humans by considering the air temperature and relative humidity. This index has been widely used to measure the human body's comfort (Isnoor et al., 2021; Putri et al., 2021; Rusdayanti et al., 2021). Measured field air temperature and humidity are calculated following the THI formula by McGregor & and Nieuwolt (1998), shown in Equation 1. Where: *THI* = Temperature Humidity Index (°C), *T* = Air Temperature (°C), *RH* = Relative Humidity (%).

$$THI = 0.8\,T + (RH \times T)/500 \quad (1)$$

Table 2 shows the categories for THI values. The categories of THI used in this study follow the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), which are modified by Effendy (2007) for tropical climate use. Ideal environments perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Table 2. THI value categories

| THI value (°C) | Category |
|---|---|
| $21 \geq THI \leq 24$ | Comfortable |
| $25 \geq THI \leq 27$ | Less comfortable |
| $THI > 27$ | Not comfortable |

## 3. Results and discussions

### 3.1 The structure of vegetation

There are two sides of pedestrian corridors at Jalan Kyai Tapa: university and terminal. Each side is divided into three segments. At segment I of Jalan Kyai Tapa, university side, 30 trees comprise six species. The canopy diameter varies from 1.5 – 6.4 m, and the height varies from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are five trees of *Casuarina equisetifolia*, 2 of Artocarpus heterophyllus, and 1 of *Cerbera manghas*. The vegetation structure of segment I, the university side, is shown in Table 3.

In segment II, there are a total of 17 trees that consist of 5 different species, which are seven trees of *Ficus virens*, six trees of *Mimusops elengi*, two trees of *Cerbera mangas*, one tree of *Samanea saman*, and one tree of *Muntingia calabura*. The canopy diameter at segment II ranges from 3 – 9 m, and the tree height from 3.2 – 11.2 m. The vegetation structure of segment II is summarized in Table 4.

Table 3. Vegetation structure at segment I, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| **I** | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

Table 4. Vegetation structure at segment II, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **II** | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

Segment III has the highest number of trees compared to Segment I and II. There are 37 trees of 7 species with the canopy diameter varying from 3.2 – 7 m and the tree height ranging from 6 – 9 m. This segment is dominated by *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of segment III is shown in Table 5.

Table 5. Vegetation structure at segment III, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| | T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| | T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| | T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to/from the terminal. At segment I of the Terminal side, there are 21 trees of 5 species whose canopy diameter varies from 3 – 5 m and the height varies from 6 – 10.8 m. This segment has 14 trees of *Handroanthus chrysotrichus*, three trees of *Swietenia mahagoni*, one tree of *Samanea saman*, one tree of *Casuarina equisetifolia*, and one tree of *Pterocarpus indicus*. In segment II, there are only three trees: 2 of Casuarina equisetifolia and 1 of *Pterocarpus indicus*. In segment III, seven trees consist of 7 of *Pterocarpus indicus*, 2 of Casuarina equisetifolia, and 1 of *Ficus benjamina*. The canopy diameter varies from 2 – 4 m, and the height varies from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

In previous studies, a more expansive tree canopy and thicker leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). Trees with wider crown diameters provided a larger shaded area, improving thermal comfort (Boukhabla & Alkama, 2012). The most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). Tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). The diameter of the tree canopy in the study area is mostly less than 5 meters. This length may not be extensive enough to improve air temperature adequately.

Table 6. Vegetation structure at segment I, II, III, terminal side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| **I** | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| **II** | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| **III** | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

### 3.2 The thermal environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured at 27 points on the university side and 16 points on the terminal side. At the university side (Figure 3), the average air temperature at 08:00 ranges from 30.16-31.29°C.

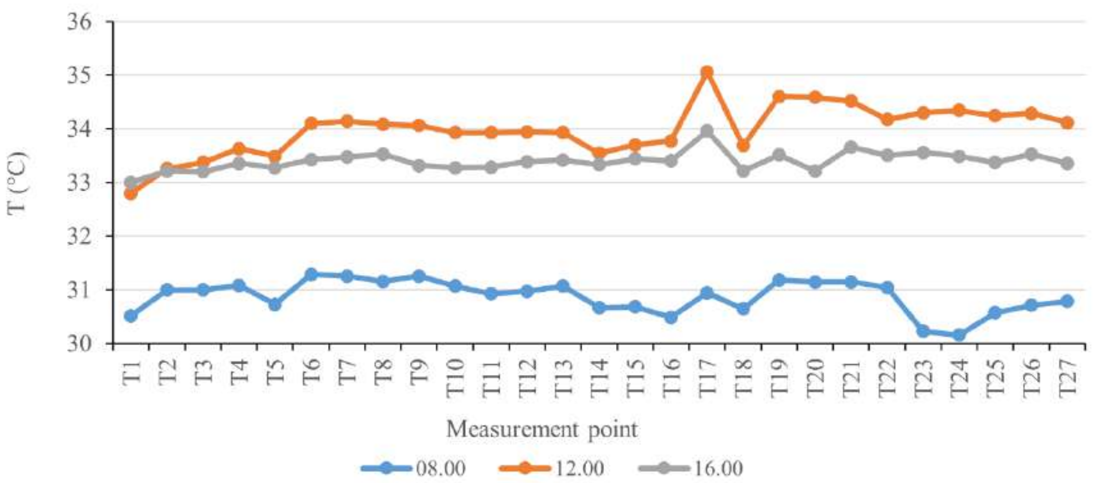


Figure. 3 The average temperature of Jalan Kyai Tapa, university side

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At 08:00, the lowest air temperature is found at T24 (segment II), and the highest is found at T6 (segment I). The average air temperature at 12:00 ranges from 32.8-35.1°C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperature at 16:00 ranges from 33-34 °C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered less comfortable for human activities.

At the terminal side (Figure 4), the average air temperature at 08:00 ranges from 30.07-31.33°C. The lowest air temperature is found at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 12:00 ranges from 33.71-36.03 °C; the lowest is at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 16:00 ranges from 33.37-34.67 °C, the lowest at T1 (segment I) and the highest at T9 (segment II). Although the air temperature ranges differ in three observed times, all three segments' lowest air temperature is found at T1 and the highest at T9. Based on these values, the air temperature of the terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

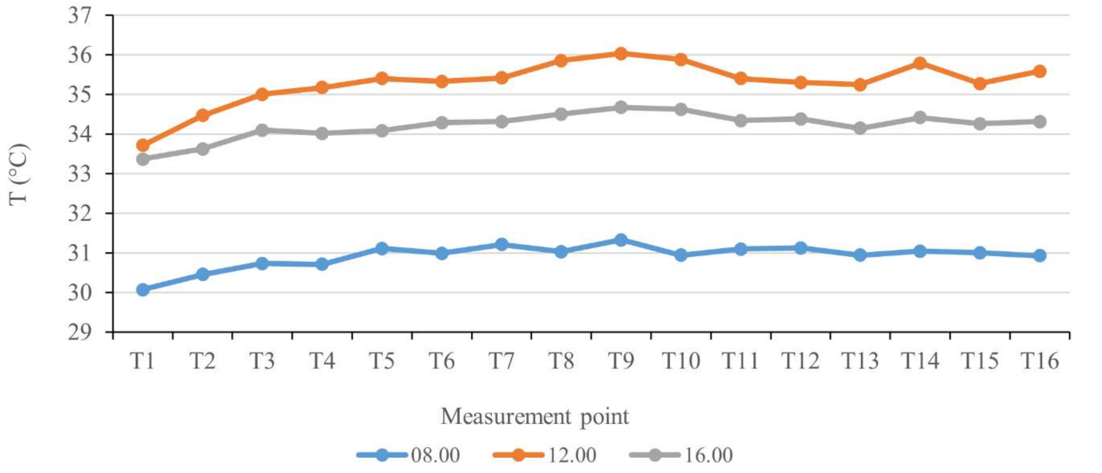


Figure. 4 The average temperature of Jalan Kyai Tapa, terminal side

Figure 5 shows the average relative humidity measured at the university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, the lowest at T26 (segment II) and the highest at T18 (segment II). This temperature is categorized as less comfortable for humans.

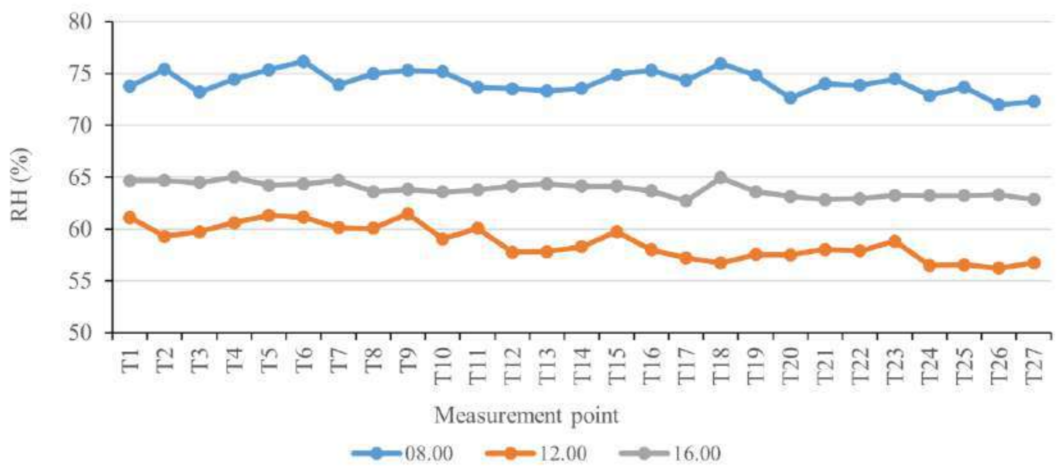


Figure. 5 Average relative humidity of Jalan Kyai Tapa, university side

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At 12:00, the average relative humidity ranges from 56.21 – 61.46%, the lowest at T26 (segment II) and the highest at T9 (segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%; the lowest is at T17 (segment II), and the highest is at T4 (segment I). The average relative humidity at 12:00 and 16:00 are considered comfortable for humans.

The average relative humidity measured at the terminal side is shown in Figure 6. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, the lowest at T10 (segment I) and the highest at T4 (segment I). This temperature is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, the lowest at T14 (segment III) and the highest at T1 (segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, the lowest at T7 (segment II) and the highest at T1 (segment I). The average relative humidity at 12:00 and 16:00 are considered comfortable for humans.

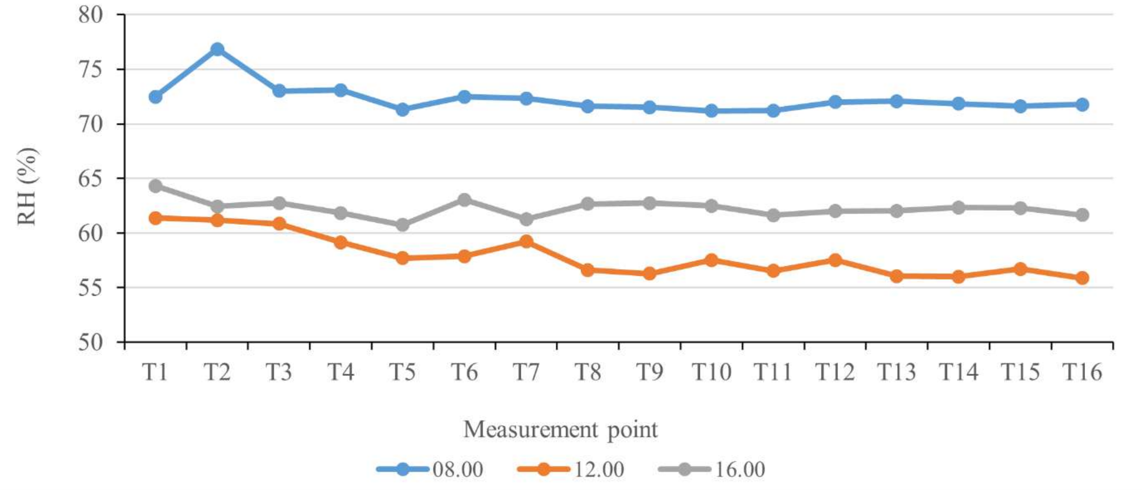


Figure. 6 Average relative humidity of Jalan Kyai Tapa, terminal side

Additionally, we measured the wind speed at the university side (Figure 7) and terminal side (Figure 8) of Jalan Kyai Tapa. Generally, the average wind speed at the terminal side is slightly higher than the university side, possibly due to fewer trees at the terminal side. At the terminal side, the average is 33.41 km/hour; at the university, the average is 32.86 km/hour.

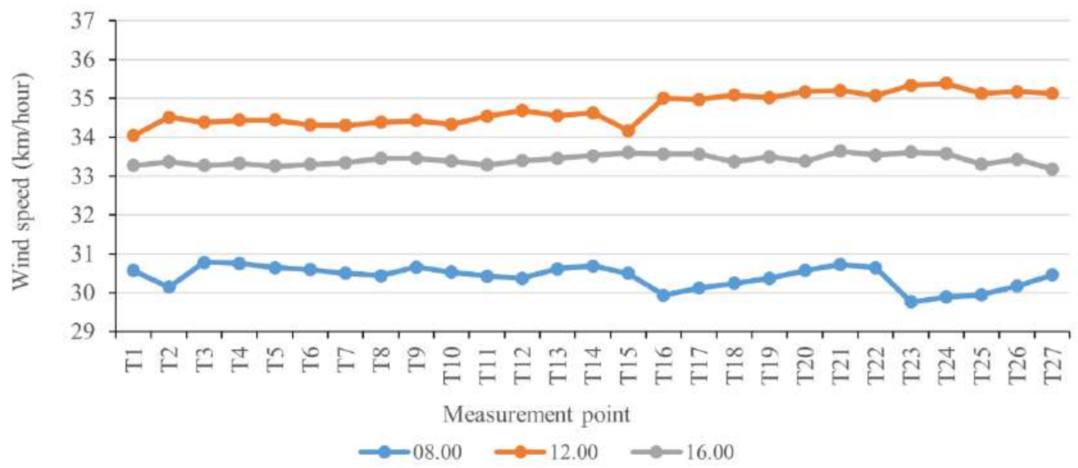


Figure. 7 Average wind speed of Jalan Kyai Tapa, university side

According to the Beaufort Scale (Stewart, 2008), a 29-38 km/hour wind speed is considered a fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00, and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

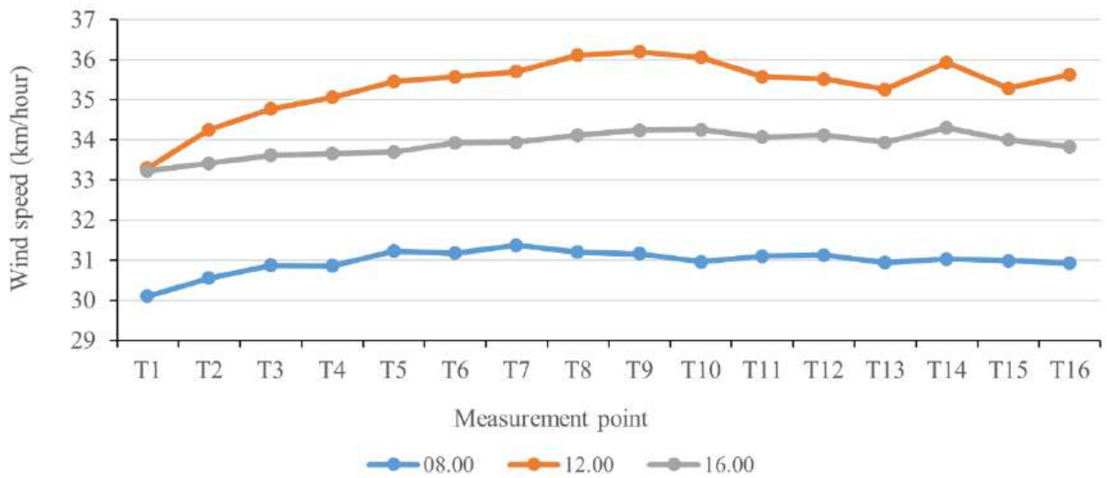


Figure. 8 Average wind speed of Jalan Kyai Tapa, terminal side

In previous studies, canopy shape is essential in distributing air temperature (Fabbri et al., 2017). Shade from the tree canopy affects plant evapotranspiration, which increases relative humidity and absorbs heat energy, leading to decreased air temperature (Perini et al., 2018) and decreased soil temperature (Morakinyo et al., 2018). At T1 on the university side, although there were no trees, the average air temperature was lowest, and at T17, it was highest at 12:00 and 16:00, despite the presence of *Mimusops elengi* trees. However, at 08:00, T24 had the lowest temperature, and T6 had the highest. T6 and T24 had *Ficus virens* and *Mimusops elengi* trees nearby, but there were more trees in T24. The different trends between the morning (08:00) and afternoon (12:00 and 16:00) observations are likely related to the evapotranspiration activity of the trees throughout the day. Evapotranspiration is driven by solar radiation, and its rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning to be more pronounced than in the afternoon (Sharmin et al., 2023).

### 3.3 Temperature heat index

We estimate the average THI at the university and terminal sides based on the measured air temperature and relative humidity in the study area. The average THI of the university side (Figure 9) at 08:00 ranges from 28.5-29.8 °C, with the lowest average THI found at T24 (segment III) and the highest at T6 (segment I). At 12:00, the average THI ranges from 30.2-31.6 °C; the lowest is T1 (segment I), and the highest is T20 (segment III). The average THI at 16:00 ranges from 30.6-31.4 °C; the lowest is T1 (segment I), and the highest is T17 (segment II). The average THI at 08:00, 12:00, and 16:00 is considered uncomfortable. The most uncomfortable time is at 12:00.

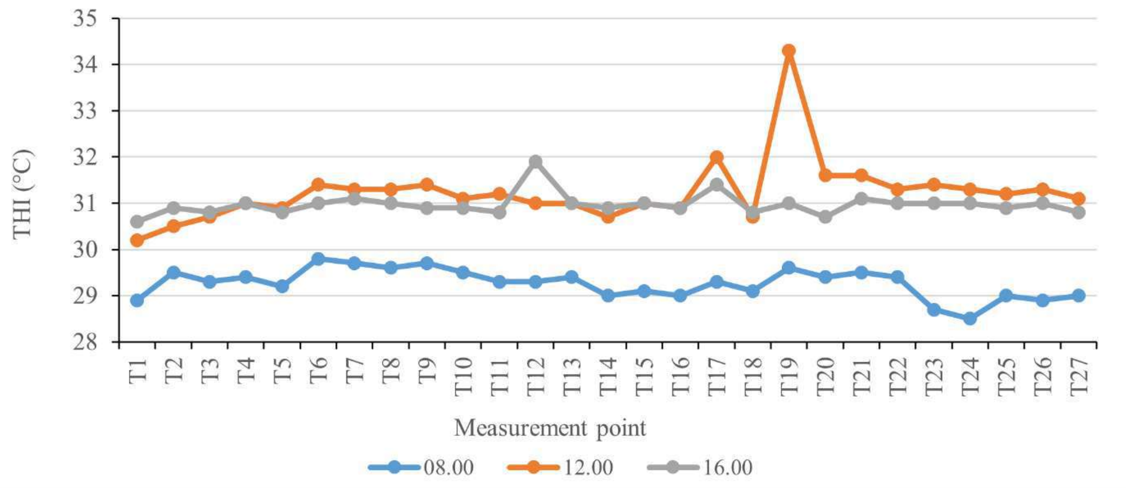


Figure. 9 The average THI on the university side

Figure 10 shows the average THI at the terminal side. The average THI at 08:00 ranges from 28.4-29.5 °C, with the lowest THI at T1 (segment I) and the highest at T9 (segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 16:00 ranges from 30.9-32.0 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 08:00, 12:00, and 16:00 is considered uncomfortable. Like the university side, the most uncomfortable time is at 12:00.

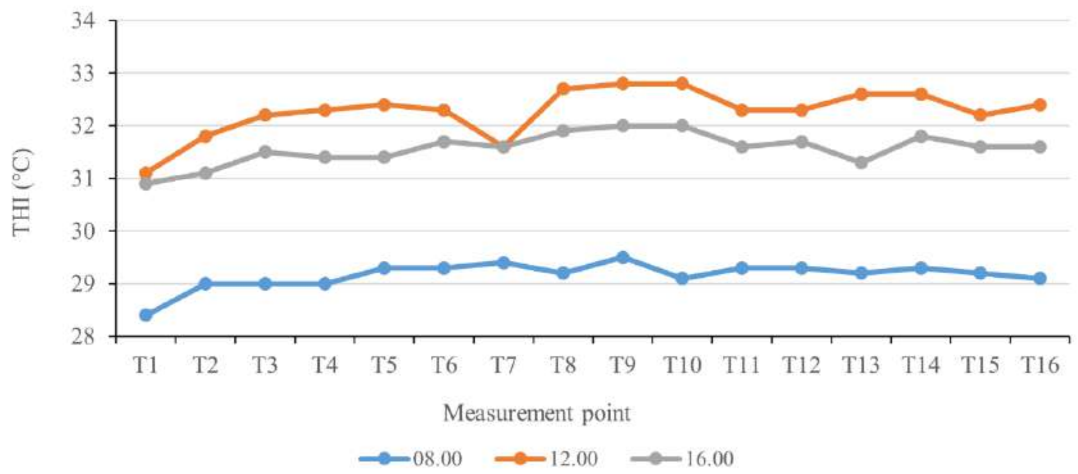


Figure. 10 The average THI at the terminal side

### 3.4 Factors that influence thermal comfort

According to the results, at the university side segments I, II, and II, there are 84 trees with varying canopy diameters from 1.5 – 9.0 m and varying heights from 3.2 – 11.2 m. Meanwhile, at the terminal side segments I, II, and II, there are 31 trees with varying canopy diameters from 2.0 – 5.0 m and varying heights from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameters. Trees with wide canopy diameters give more expansive shaded areas, improving thermal comfort (Boukhabla & Alkama, 2012). More expansive tree canopy and denser leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

Several factors possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters: foliage shape and dimensions, trunk height, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). The shape of a tree canopy is essential in distributing air temperature (Fabbri et al., 2017). The shade from the tree canopy influences the plants' evapotranspiration, increasing relative humidity and absorbing thermal energy that decreases air temperature (Perini et al., 2018) and decreases the ground temperature (Morakinyo et al., 2018). An existing study found that the most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is a one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also essential because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely more significant than canopy diameter and tree height.

Furthermore, tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Wang & Akbari, 2016). Concerning the results of this study, the trees' canopy diameter in the study area might not be wide enough to provide adequate improvement to the air temperature, considering the majority of the tree's canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to more accurately determine the cause of uncomfortable outdoor areas.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This condition is similar to what we found during field measurement at the university side, where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. An existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that T1 has the lowest average air temperature at the university side, and T17 has the highest temperature at 12:00 and 16:00. However, there is no tree at T1. There is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has the lowest temperature, and T6 has the highest temperature. T6 and T24 similarly have *Ficus virens* and *Mimusops elengi* nearby, but the number of trees is more significant at T24. The different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation, and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause trees' cooling benefits in the morning to be more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the difference in tendency between morning and afternoon observations. As for the afternoon phenomenon, where T1 (no tree) has the lowest average air temperature, and T17 (with tree) has the highest, possible canopy-associated warming occurred during observations. Sharmin et al. (2023) conducted a study to determine the cooling benefits of 10 urban tree species considering the tree traits and microclimatic conditions in suburban areas. The study found that there was canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases by 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with the highest LAI has the lowest sub-canopy warming effect. The heat from nearby buildings can also cause the sub-canopy warming effect. A study by Alonzo et al. (2021) conducted in Washington DC found that trees along streets have a less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under-tree canopy and surrounding surfaces. This condition further supports that the air temperature under trees might be higher than the ambient air temperature, mainly if buildings like the study area surround the area. This condition may also explain why such a phenomenon is not found on the terminal side, considering the terminal side has fewer structures and buildings than the university side. On a side note, it is worth noting that T1 is also located near a small water body, which may also help decrease the air temperature due to water body evaporation (Chen et al., 2023).

In another case, T9 of the terminal side shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter, so we suggest it cannot provide the proper shade to cool down the air temperature. We mentioned that some spots with Casuarina equisetifolia at the university have better thermal comfort than *Mimusops elengi*. This condition indicates that vegetation species alone cannot determine thermal comfort. It is also related to the planting distance, design, and other elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the university side has better thermal comfort than the terminal side. The university side also has more trees and less pavement coverage than the terminal. Trees can improve thermal comfort, and to optimize tree function in pedestrian corridors, we should consider tree characteristics and arrangement. From the results of this study, we discussed that various factors and the trees determine the thermal comfort of pedestrian corridors' influence on microclimate, which can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during the morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically in measuring LAI and the distance between trees. Therefore, further research is required before proposing recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4. Conclusion

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01-31.54 °C and the relative humidity ranges from 56.19 – 57.74%. The average air temperature and relative humidity at Jalan Kyai Tapa are 31.2°C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52°C, which is categorized as uncomfortable. In areas with small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas with large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, they do not adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort, as we found a measurement point with no tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design in creating comfortable pedestrian corridors.

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**Author Contribution**
Conceptualization, N.I.S.; Methodology, N.I.S.; Analysis, N.I.S., D.D., R.F.; Investigation, N.I.S., R.F.; Writing – Original Draft Preparation, N.I.S.; Writing – Review & Editing, R.F., D.D., R.F.; and Funding Acquisition, N.I.S

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**(22 December 2023)**

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# MS #1201: New submission published to Journal of Environmental Science and Sustainable Development

1 message

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**Editors of Journal of Environmental Science and Sustainable Development** <editors-jessd-1201@dcuischolarhub.bepress.com> Fri, Dec 22, 2023 at 10:19 PM
To: NUR INTAN MANGUNSONG <nurintan@trisakti.ac.id>, Reza Fauzi <reza.fauzi@trisakti.ac.id>, Dibyanti Danniswari <dibyanti@trisakti.ac.id>, Rini Fitri <rini.fitri@trisakti.ac.id>
Cc: The Editors <editors-jessd-1201@dcuischolarhub.bepress.com>

Dear Nur Intan Simangunsong, Reza Fauzi, Dibyanti Danniswari, and Rini Fitri,

Your submission "ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD" (MS #1201) has been published to Journal of Environmental Science and Sustainable Development.

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

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# ROADSIDE GREENBELT EFFECTS ON THERMAL COMFORT OF PEDESTRIAN CORRIDORS AT A BUSY TRAFFIC ROAD

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## Abstract

The increasing number of motorized vehicles in Jakarta is causing environmental damage and can harm human health. In recent years, the Jakarta local government has the vision to focus on improving the human mobility network, including the pedestrian networks. As a heavily trafficked road, Jalan Kyai Tapa, West Jakarta, is used by many people. However, it may feel uncomfortable to walk there due to heat and sun exposure, which is compounded by extensive pavement coverage. The thermal condition of the pedestrian corridor is essential to create a comfortable walking experience. The objective of this study was to analyze the thermal comfort of the pedestrian corridors at Jalan Kyai Tapa concerning the landscape composition, including vegetation structure and pavement. This study was conducted quantitatively. This study identified the vegetation structure, including the tree species, canopy diameter, and height. Then, we measured the air temperature and relative humidity at predetermined measurement points to evaluate thermal comfort using the Temperature Humidity Index (THI). The results showed that the air temperature ranges from 31.01°C to 31.54°C, and the relative humidity ranges from 56.19% to 57.74%. The average THI value is 28.52 °C, which falls into the comfortable category. Despite having relatively wide canopies and providing shade, the trees in this pedestrian corridor do not seem to improve the thermal environment enough to achieve comfortable conditions for pedestrians. Interestingly, the result shows that, at certain observation times, points without trees had lower air temperatures compared to other spots with trees. Trees may not be the most influential factor in improving pedestrian thermal comfort. Furthermore, the spots near trees with more expansive canopies can be less comfortable than spots near trees with smaller canopies. Tree species and the planting spacing determine the efficiency of trees to improve thermal comfort.

**Keywords**: Koridor; Pedestrian way; Thermal comfort; Vegetation.

## 1. Introduction

The urban population has kept increasing in the past few decades. The population growth in Jakarta from 2010-2020 is about 0.92% (Badan Pusat Statistik (BPS), 2021). The population increase follows the increase in motor vehicles. In 2019, the motor vehicle increase in Jakarta was 0.7% compared to the previous year. Jakarta, infamous for its severe traffic congestion due to overloaded motor vehicles, would suffer more. Increasing the number of motor vehicles means more emissions of air pollutants and greenhouse gases that could eventually harm human health and the environment. If the environment is damaged, pedestrians are the most

impacted group of road users, as they are directly exposed to the environment. Adding and preserving roadside greenbelts in the city is a way to alleviate the negative impact of motor vehicles on users and the environment.

A roadside greenbelt is a linear green open space formed by landscape elements, such as trees and shrubs, providing users comfort, safety, and beauty (Departemen Pekerjaan Umum, 1996). Existing studies found that trees in urban areas play a role in microclimate amelioration, air quality improvement, carbon dioxide reduction, oxygen production, ecological function, and city's water supply protection (Nowak et al., 2006; Biao et al., 2010; Simangunsong et al., 2021; Simangunsong & Fitri, 2021). Greenbelt trees and other forms of urban greenery provide ecological function and ecosystem services (Childers et al., 2019).

In urban climate, vegetation at roadside greenbelts is an important design element to ameliorate microclimate and to improve outdoor thermal comfort (Picot, 2004; Spagenberg, 2004). Roadside greenbelts offer various benefits to improve urban environment quality (Samsoedin & Waryono, 2010), such as ameliorating microclimate, reducing pollutants, including particle and gas, controlling glare, producing oxygen (Simangunsong et al., 2021; Simangunsong & Fitri, 2021), reducing noise, controlling wastewater, controlling soil erosion, reducing stress, preserving biodiversity, providing wildlife habitat, prevention of seawater intrusion, improving urban aesthetic values, and supplier of groundwater. The vegetation type and species must be carefully selected by considering its natural habitat, bioclimatic factors, ecological functions, and architectural functions to optimize the role of roadside vegetation. Additionally, selecting the local species would make the adaptation more accessible for the vegetation (Oduor et al., 2016). Vegetation at roadside greenbelts can improve the thermal environment, not only on a micro scale but also at a city scale.

Roadside greenbelts offer many benefits to the environment that indirectly benefit humans as well. The direct benefits of roadside greenbelts to humans are providing shade, user safety, and improving users' comfort, especially pedestrians and cyclists. The position of the greenbelt influences the wind effect for pedestrians (Zeng et al., 2022). Wind could be dangerous for users if it is too strong, but mild wind could improve users' thermal comfort, especially in hot weather. Thermal comfort is the term used to describe satisfaction with the thermal environment. Outdoor thermal comfort is influenced by the building–environment interaction, which includes various factors such as height of buildings, relative humidity, air temperature, sky view factor, wind speed, and street width (Achour-Younsi & Kharrat, 2016). Air temperature and relative humidity directly influence THI, an index used to measure human body comfort. By paying attention to the thermal comfort of roadside greenbelts, we can improve the walkability of urban pedestrian corridors.

Other than thermal comfort, the comfortability of pedestrian corridors is influenced by circulation, accessibility, safety, cleanliness, and aesthetics. Vegetation in roadside landscape serves as a view controller, physical barrier (Cabral et al., 2023), microclimate regulator (Cai et al., 2022), air pollution mitigator (Baldauf, 2020), wildlife habitat (Fischer et al., 2022), and aesthetic function (Qin et al., 2023). To create a sustainable roadside landscape, we must carefully select the vegetation species, the amount, and the planting design and manage the landscape. A pedestrian corridor is formed by softscape (vegetation) and hardscape (pavement, shelter, etcetera). The interaction between softscape and hardscape determines thermal comfort.

Jakarta's local government initiated the concept of a Smart City in 2014 by improving the city based on six elements: Smart Economy, Smart Governance, Smart People, Smart Mobility, Smart Environment, and Smart Living (Syalianda & Kusumastuti, 2021). This concept aims to address urban problems and solve them. The local government has been improving its public transportation service to reduce traffic congestion, air pollution, citizen mobility, etcetera. Dinas Bina Marga DKI Jakarta (a local government organization in charge of roads and public infra-structure) revitalizes public facilities such as pedestrian corridors to support public

transportation. Dinas Bina Marga cooperates with the Institute for Transportation Development Policy (ITDP) Indonesia to plan a human mobility network in Jakarta and realize their vision to focus on pedestrian networks by improving public facilities for pedestrians and cyclists (ITDP, 2019).

Jalan Kyai Tapa, Jakarta, is a major road with two pedestrian corridors and green belts on the side. The traffic at Jalan Kyai Tapa is generally quite busy because this road is passed by several Transjakarta bus routes and is connected to other major roads. Quite a lot of people use pedestrian corridors at Jalan Kyai Tapa. However, in the afternoon, it may feel uncomfortable to walk there due to heat and sunlight exposure, and significant coverages of pavements worsen that. The thermal condition of a pedestrian corridor is essential to create a comfortable walking experience. Considering the local government's goal to improve the pedestrian corridors, we need to understand the current conditions of pedestrian corridors in Jakarta in terms of their thermal comfort. Pedestrian comfort has been widely studied overseas but is still relatively limited in Indonesia. Existing studies have analyzed pedestrian corridors' comfort in Indonesia cities concerning its users' preferences (Illiyin & Alprianti, 2017), perception (Budiarto et al., 2019), and facilities quality (Krisnaputri et al., 2023). Only a few studies specifically focus on the thermal comfort of pedestrian corridors and analyze it quantitatively (Febriarto, 2016). Even fewer studies exist on the thermal comfort of pedestrian corridors in Jakarta. Studies on pedestrian corridors in Jakarta primarily relate to transit-oriented development concepts (Mulyadi, 2020; Wulanningrum, 2021). More quantitative research on the thermal comfort of pedestrian corridors in Jakarta is needed. This study analyzes the thermal comfort of pedestrian corridors at Jalan Kyai Tapa concerning its landscape composition, including vegetation structure and pavement. By analyzing the existing thermal condition of pedestrian corridors at Jalan Kyai Tapa, this study can briefly illustrate other pedestrian corridors with a similar condition in Jakarta. Hopefully, this study can help improve the pedestrian corridors in Jakarta.

## 2. Methods

### 2.1 Study area

The study area is two pedestrian corridors at Jalan Kyai Tapa, Grogol, West Jakarta. Jalan Kyai Tapa is a significant road passed by several Transjakarta routes and is connected to other major roads, such as Jalan Letjen S. Parman and Jalan Daan Mogot (Figure 1). There are two sides of pedestrian corridors at Jalan Kyai Tapa: (1) the terminal side (north side) and (2) the university side (south side).

The terminal side has a bus terminal, police station, and traffic gardens. Meanwhile, university buildings, hotels, restaurants, and other commercial buildings are on the university side. The tree information in the study area is collected for further analysis. When inventorying vegetation, existing studies created plots of 100 meters by 100 meters in broad areas, such as national parks (Haryadi et al., 2019; Maulidiyan et al., 2019), and created belt transects of 100 m in linear areas, such as roadsides (Danniswari & Nasrullah, 2017). Therefore, we divided the 300-meter-long pedestrian corridors into three segments, 100 m-long each. The study area and the segmentation are shown in Figure 2. The field data was collected from November 2021 until February 2022.

### 2.2 Data collection

The study is conducted quantitatively. We collect data on field air temperature, relative humidity, wind speed, tree species, tree height, and canopy diameter. Air temperature, relative humidity, and wind speed measurement points are distributed along the corridors. The measurement is done three times daily at 08:00, 12:00, and 16:00 for seven days during sunny weather using a digital thermohygrometer. The pedestrian corridors have two sides, the university side and the terminal side, with a length of 300 m. We observed both corridors and

divided each corridor into three segments 100 m long. Table 1 shows the location and measurement point at each corridor side. The number of measurement points at the terminal side is fewer due to the smaller vegetation coverage on this side.

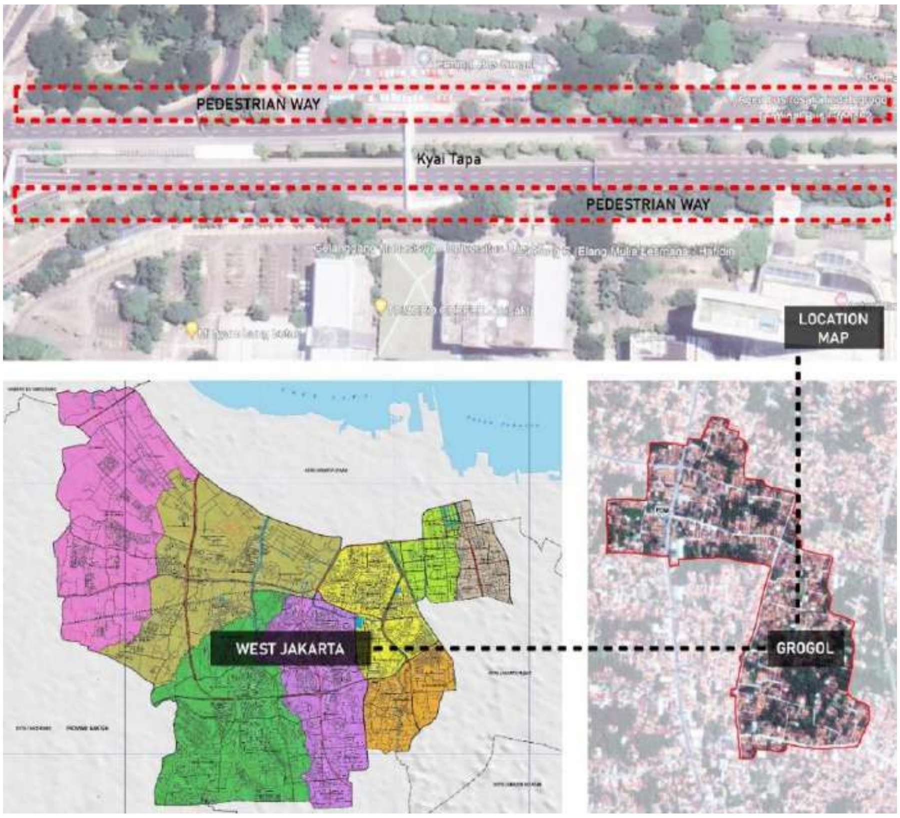

Figure. 1 Study location map

Figure. 2 Study area, the pedestrian corridors at Kyai Tapa, and the segmentation

### 2.3 Data analysis

The data are analyzed to calculate the Temperature Humidity Index. The THI is estimated to determine the equivalent temperature perceived by humans by considering the air temperature and relative humidity. This index has been widely used to measure the human body's comfort (Isnoor et al., 2021; Putri et al., 2021; Rusdayanti et al., 2021).

Table 1. Location and measurement points

| Pedestrian corridor side | Location | Total Length (m) | Segment length (m) | Total measurement points | Measurement points per segment |
|---|---|---|---|---|---|
| University side | May 12th Monument to Aston Hotel | 300 | 100 | 27 | 8-11 |
| Terminal side | Flyover garden to Terminal garden | 300 | 100 | 16 | 5-6 |

Measured field air temperature and humidity are calculated following the THI formula by McGregor & and Nieuwolt (1998), shown in Equation 1. Where: *THI* = Temperature Humidity Index (°C), *T* = Air Temperature (°C), *RH* = Relative Humidity (%).

$$THI = 0.8\,T + (RH \times T)/500 \quad (1)$$

Table 2 shows the categories for THI values. The categories of THI used in this study follow the categories made by McGregor & Nieuwolt (1998) and Emmanuel (2005), which are modified by Effendy (2007) for tropical climate use. Ideal environments perceived as comfortable by humans fall in the range of 27-28 °C for temperature and 40-75% for relative humidity (Laurie, 1975).

Table 2. THI value categories

| THI value (°C) | Category |
|---|---|
| $21 \geq THI \leq 24$ | Comfortable |
| $25 \geq THI \leq 27$ | Less comfortable |
| $THI > 27$ | Not comfortable |

## 3. Results and discussions

### 3.1 The structure of vegetation

There are two sides of pedestrian corridors at Jalan Kyai Tapa: university and terminal. Each side is divided into three segments. At segment I of Jalan Kyai Tapa, university side, 30 trees comprise six species. The canopy diameter varies from 1.5 – 6.4 m, and the height varies from 3.75 – 9.6 m. The most common species are *Mimusops elengi* and *Ficus virens*, each of 11 trees. There are five trees of *Casuarina equisetifolia*, 2 of Artocarpus heterophyllus, and 1 of *Cerbera manghas*. The vegetation structure of segment I, the university side, is shown in Table 3.

In segment II, there are a total of 17 trees that consist of 5 different species, which are seven trees of *Ficus virens*, six trees of *Mimusops elengi*, two trees of *Cerbera mangas*, one tree of *Samanea saman*, and one tree of *Muntingia calabura*. The canopy diameter at segment II ranges from 3 – 9 m, and the tree height from 3.2 – 11.2 m. The vegetation structure of segment II is summarized in Table 4. Segment III has the highest number of trees compared to Segment I and II. There are 37 trees of 7 species with the canopy diameter varying from 3.2 – 7 m and the tree height ranging from 6 – 9 m. This segment is dominated by *Ficus virens* of 20 trees, *Mimusops elengi* of 5 trees, *Casuarina equsetifolia* of 9 trees, *Cerbera manghas* of 2 trees, and *Samanea saman* of 1 tree. The vegetation structure of segment III is shown in Table 5.The number of trees at the terminal side is fewer than at the university side because the pedestrian corridor is disconnected at several points due to the entrance/exit way for vehicles to or from the terminal.

Table 3. Vegetation structure at segment I, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Scientific Name | Canopy Diameter | Height | |
| I | T1 | - | - | - | - | - |
| | T2 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | T3 | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 5.0 | 1 |
| | T4 | Ficus | *Ficus virens* | 6.4 | 3.8 | 1 |
| | T5 | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.8 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | T6 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T7 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T8 | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | T9 | Ficus | *Ficus virens* | 6.4 | 9.6 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 1 |
| | | Nangka | *Artocarpus heterophyllus* | 4.8 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 1 |
| | T10 | Cemara angin | *Casuarina equisetifolia* | 2.4 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.6 | 1 |
| | T11 | Ficus | *Ficus virens* | 6.4 | 9.6 | 3 |
| | | Tanjung | *Mimusops elengi* | 1.5 | 4.5 | 2 |

Table 4. Vegetation structure at segment II, university side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| II | T12 | Ficus | *Ficus virens* | 4.8 | 5.8 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 2 |
| | | Ficus | *Ficus virens* | 3.5 | 4.5 | 1 |
| | T13 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T14 | Bintaro | *Cerbera manghas* | 3.6 | 7.0 | 1 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | T15 | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | | Trembesi | *Samanea saman* | 9.0 | 11.2 | 1 |
| | T16 | - | - | - | - | - |
| | T17 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Kersen | *Muntingia celabura* | 3.2 | 3.2 | 1 |
| | T18 | Tanjung | *Mimusops elengi* | 3.2 | 4.8 | 1 |
| | | Ficus | *Ficus virens* | 3.2 | 4.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T19 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.2 | 6.4 | 1 |
| | T20 | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |

At segment I of the Terminal side, there are 21 trees of 5 species whose canopy diameter varies from 3 – 5 m and the height varies from 6 – 10.8 m. This segment has 14 trees of

*Handroanthus chrysotrichus*, three trees of *Swietenia mahagoni*, one tree of *Samanea saman*, one tree of *Casuarina equisetifolia*, and one tree of *Pterocarpus indicus*.

Table 5. Vegetation structure at segment III, university side

| **Segment** | **Point** | **Tree Name** | | **Tree Size (m)** | | **Number** |
|---|---|---|---|---|---|---|
| | | **Local Name** | **Latin Name** | **Canopy Diameter** | **Height** | |
| **III** | T21 | Trembesi | *Samanea saman* | 7.5 | 7.5 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.2 | 6.9 | 1 |
| | T22 | Ficus | *Ficus virens* | 5.6 | 9.0 | 1 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T23 | Ficus | *Ficus virens* | 3.8 | 6.0 | 2 |
| | T24 | Ficus | *Ficus virens* | 3.8 | 6.0 | 3 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 1 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 1 |
| | T25 | Ficus | *Ficus virens* | 3.8 | 6.0 | 7 |
| | | Tanjung | *Mimusops elengi* | 3.0 | 7.5 | 2 |
| | | Cemara angin | *Casuarina equisetifolia* | 4.5 | 8.3 | 1 |
| | T26 | Ficus | *Ficus virens* | 3.8 | 6.0 | 6 |
| | | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |
| | | Bintaro | *Cerbera manghas* | 3.0 | 7.0 | 1 |
| | T27 | Cemara angin | *Casuarina equisetifolia* | 3.0 | 8.3 | 2 |
| | | Ficus | *Ficus virens* | 6.4 | 9.0 | 1 |
| | | Tanjung | *Mimusops elengi* | 4.5 | 7.5 | 1 |

In segment II, there are only three trees: 2 of Casuarina equisetifolia and 1 of *Pterocarpus indicus*. In segment III, seven trees consist of 7 of *Pterocarpus indicus*, 2 of Casuarina equisetifolia, and 1 of *Ficus benjamina*. The canopy diameter varies from 2 – 4 m, and the height varies from 10 – 11 m. The vegetation structure of the Terminal side is shown in Table 6.

Table 6. Vegetation structure at segment I, II, III, terminal side

| Segment | Point | Tree Name | | Tree Size (m) | | Number |
|---|---|---|---|---|---|---|
| | | Local Name | Latin Name | Canopy Diameter | Height | |
| I | T1 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 1 |
| | | Trembesi | *Samanea saman* | 5.0 | 10.0 | 1 |
| | T2 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 10 |
| | T3 | Tabebuya | *Handroanthus chrysotrichus* | 3.0 | 6.0 | 3 |
| | T4 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | | Mahoni | *Swietenia mahagoni* | 3.0 | 10.0 | 3 |
| | T5 | Angsana | *Pterocarpus indicus* | 3.0 | 10.8 | 2 |
| II | T6 | - | - | - | - | - |
| | T7 | - | - | - | - | - |
| | T8 | Cemara angin | *Casuarina equisetifolia* | 4.0 | 11.0 | 1 |
| | T9 | Cemara angin | *Casuarina equisetifolia* | 2.0 | 11.0 | 1 |
| | T10 | - | - | - | - | - |
| | T11 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| III | T12 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 1 |
| | T13 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T14 | Angsana | *Pterocarpus indicus* | 4.0 | 10.8 | 2 |
| | T15 | Angsana | *Pterocarpus indicus* | 2.0 | 11.0 | 1 |
| | T16 | Beringin | *Ficus benjamina* | 2.0 | 10.0 | 1 |

In previous studies, a more expansive tree canopy and thicker leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). Trees with wider crown diameters provided a larger shaded area, improving thermal comfort (Boukhabla & Alkama, 2012). The most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). Tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). The diameter of the tree canopy in the study area is mostly less than 5 meters. This length may not be extensive enough to improve air temperature adequately.

### 3.2 The thermal environment

The air temperature and relative humidity of Jalan Kyai Tapa are measured at 27 points on the university side and 16 points on the terminal side. At the university side (Figure 3), the average air temperature at 08:00 ranges from 30.16-31.29°C.

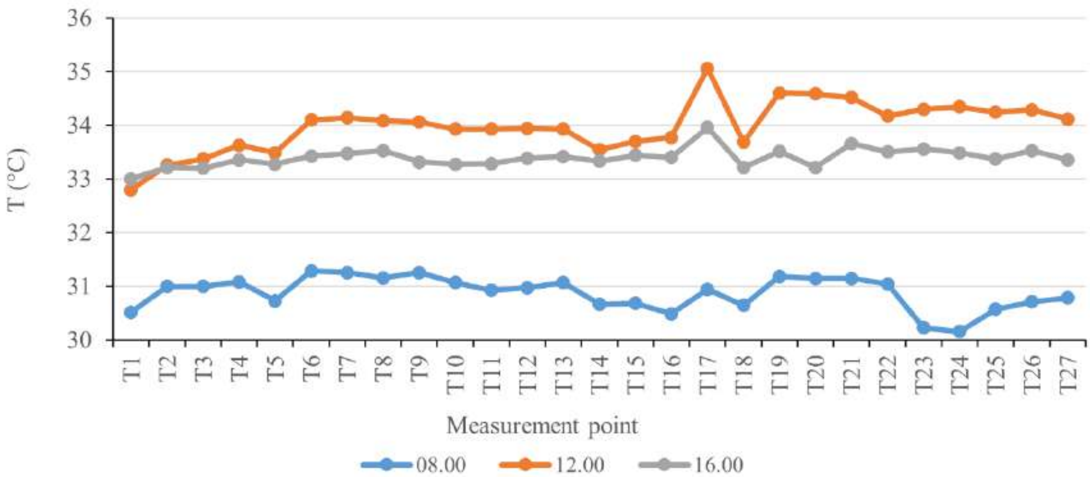


Figure. 3 The average temperature of Jalan Kyai Tapa, university side

At 08:00, the lowest air temperature is found at T24 (segment II), and the highest is found at T6 (segment I). The average air temperature at 12:00 ranges from 32.8-35.1°C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperature at 16:00 ranges from 33-34 °C. The lowest air temperature is T1 (segment I), and the highest is T17 (segment II). The average air temperatures measured at 08:00, 12:00, and 16:00 are considered less comfortable for human activities.

At the terminal side (Figure 4), the average air temperature at 08:00 ranges from 30.07-31.33°C. The lowest air temperature is found at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 12:00 ranges from 33.71-36.03 °C; the lowest is at T1 (segment I), and the highest is at T9 (segment II). The average air temperature at 16:00 ranges from 33.37-34.67 °C, the lowest at T1 (segment I) and the highest at T9 (segment II). Although the air temperature ranges differ in three observed times, all three segments' lowest air temperature is found at T1 and the highest at T9. Based on these values, the air temperature of the terminal side at 08:00, 12:00, and 16:00 is considered less comfortable for humans.

Figure 5 shows the average relative humidity measured at the university side. The average relative humidity at 08:00 ranges from 71.99 – 75.94%, the lowest at T26 (segment II) and the highest at T18 (segment II). This temperature is categorized as less comfortable for humans.

At 12:00, the average relative humidity ranges from 56.21 – 61.46%, the lowest at T26 (segment II) and the highest at T9 (segment I). At 16:00, the average relative humidity ranges from 62.7 – 65%; the lowest is at T17 (segment II), and the highest is at T4 (segment I). The average relative humidity at 12:00 and 16:00 is considered comfortable for humans.

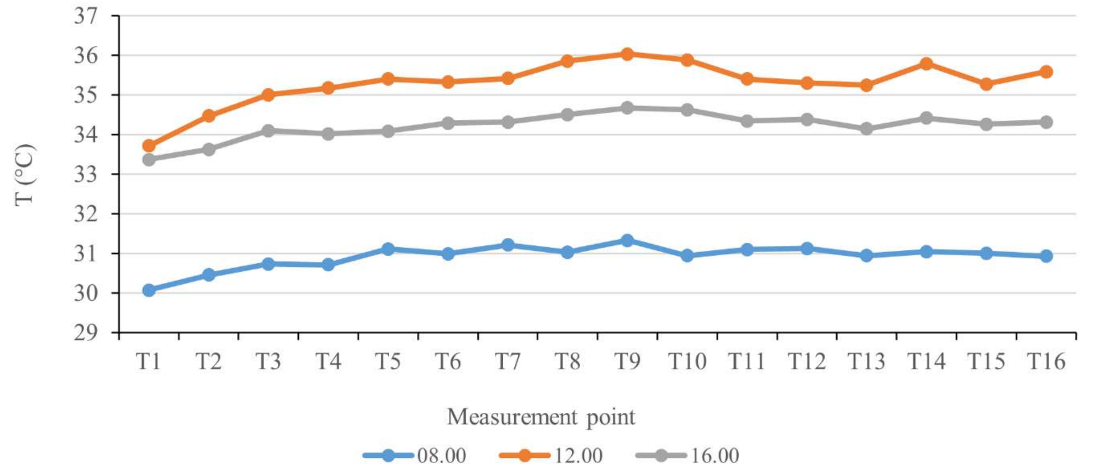


Figure. 4 The average temperature of Jalan Kyai Tapa, terminal side

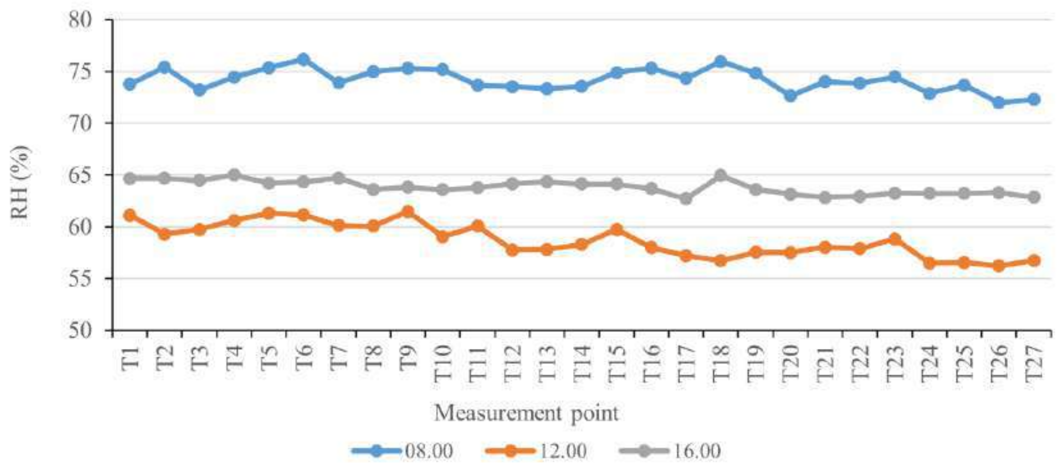


Figure. 5 Average relative humidity of Jalan Kyai Tapa, university side

The average relative humidity measured at the terminal side is shown in Figure 6. The average relative humidity at 08:00 ranges from 71.19 – 73.10%, the lowest at T10 (segment I) and the highest at T4 (segment I). This temperature is categorized as less comfortable for humans. At 12:00, the average relative humidity ranges from 56.0 – 61.4%, the lowest at T14 (segment III) and the highest at T1 (segment I). At 16:00, the average relative humidity ranges from 60.74 – 64.3%, the lowest at T7 (segment II) and the highest at T1 (segment I). The average relative humidity at 12:00 and 16:00 is considered comfortable for humans.

Additionally, we measured the wind speed at the university side (Figure 7) and terminal side (Figure 8) of Jalan Kyai Tapa. Generally, the average wind speed at the terminal side is slightly higher than the university side, possibly due to fewer trees at the terminal side. At the terminal side, the average is 33.41 km/hour; at the university, the average is 32.86 km/hour.

According to the Beaufort Scale (Stewart, 2008), a 29-38 km/hour wind speed is considered a fresh breeze. Both sides show a similar tendency where the highest wind speed is found at 12:00, and the lowest is at 08:00. Although wind speed does not influence the THI, the existence of wind can improve perceived human thermal comfort.

In previous studies, canopy shape is essential in distributing air temperature (Fabbri et al., 2017). Shade from the tree canopy affects plant evapotranspiration, which increases relative humidity and absorbs heat energy, leading to decreased air temperature (Perini et al., 2018) and decreased soil temperature (Morakinyo et al., 2018). At T1 on the university side, although there were no trees, the average air temperature was lowest, and at T17, it was highest at 12:00 and

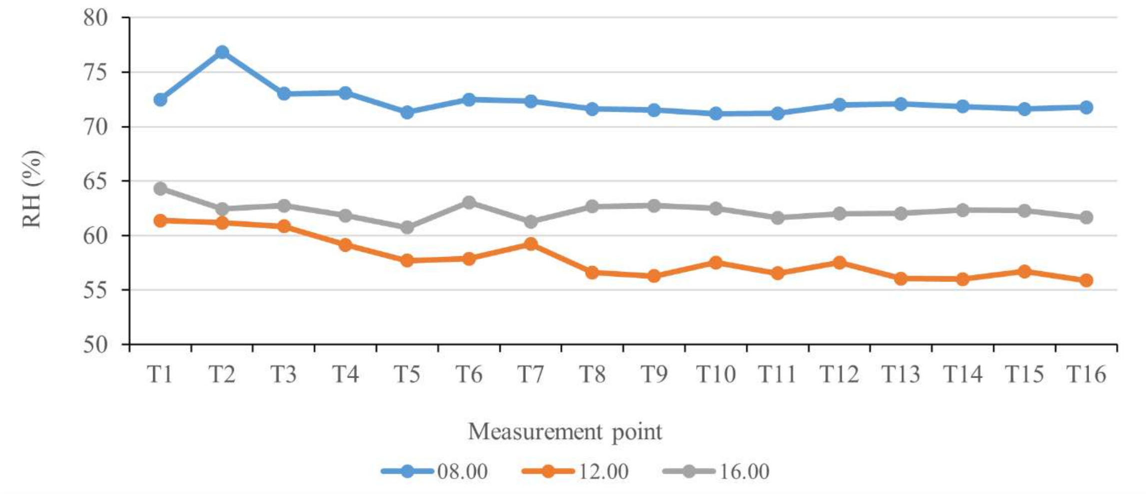


Figure. 6 Average relative humidity of Jalan Kyai Tapa, terminal side

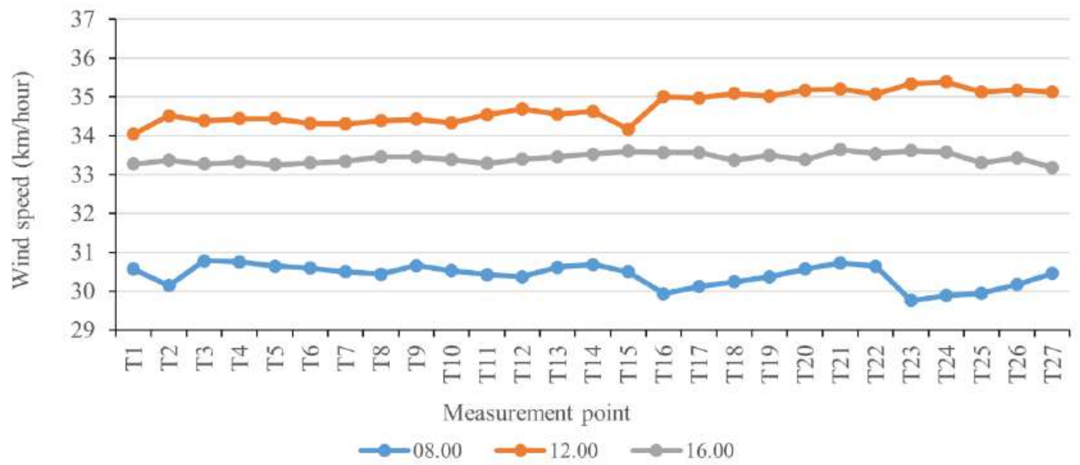


Figure. 7 Average wind speed of Jalan Kyai Tapa, university side

16:00, despite the presence of *Mimusops elengi* trees. However, at 08:00, T24 had the lowest temperature, and T6 had the highest. T6 and T24 had *Ficus virens* and *Mimusops elengi* trees nearby, but there were more trees in T24.

The different trends between the morning (08:00) and afternoon (12:00 and 16:00) observations are likely related to the evapotranspiration activity of the trees throughout the day. Evapotranspiration is driven by solar radiation, and its rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause the cooling benefits of trees in the morning to be more pronounced than in the afternoon (Sharmin et al., 2023).

### 3.3 Temperature heat index

We estimate the average THI at the university and terminal sides based on the measured air temperature and relative humidity in the study area. The average THI of the university side (Figure 9) at 08:00 ranges from 28.5-29.8 °C, with the lowest average THI found at T24 (segment III) and the highest at T6 (segment I). At 12:00, the average THI ranges from 30.2-31.6 °C; the lowest is T1 (segment I), and the highest is T20 (segment III). The average THI at 16:00 ranges from 30.6-31.4 °C; the lowest is T1 (segment I), and the highest is T17 (segment II). The average THI at 08:00, 12:00, and 16:00 is considered uncomfortable. The most uncomfortable time is at 12:00.

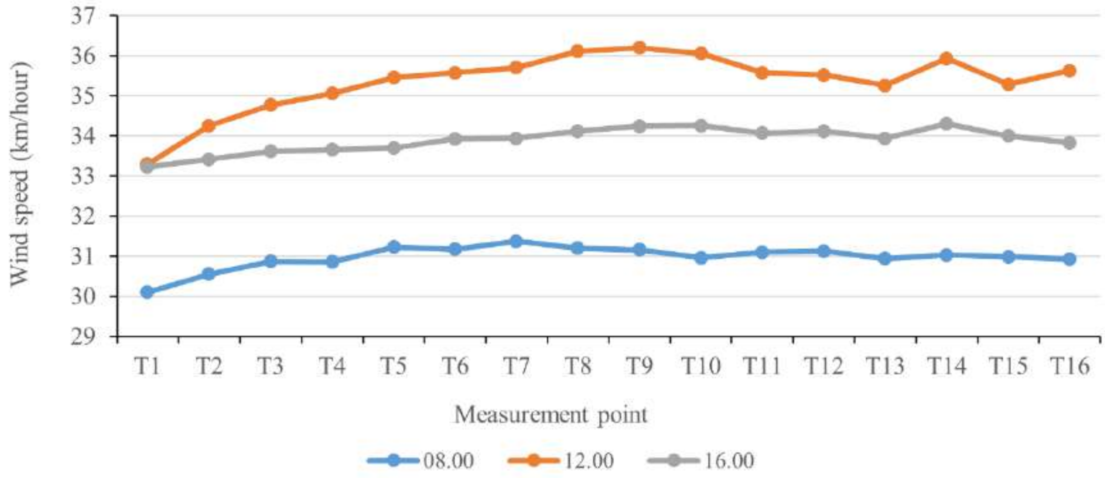


Figure. 8 Average wind speed of Jalan Kyai Tapa, terminal side

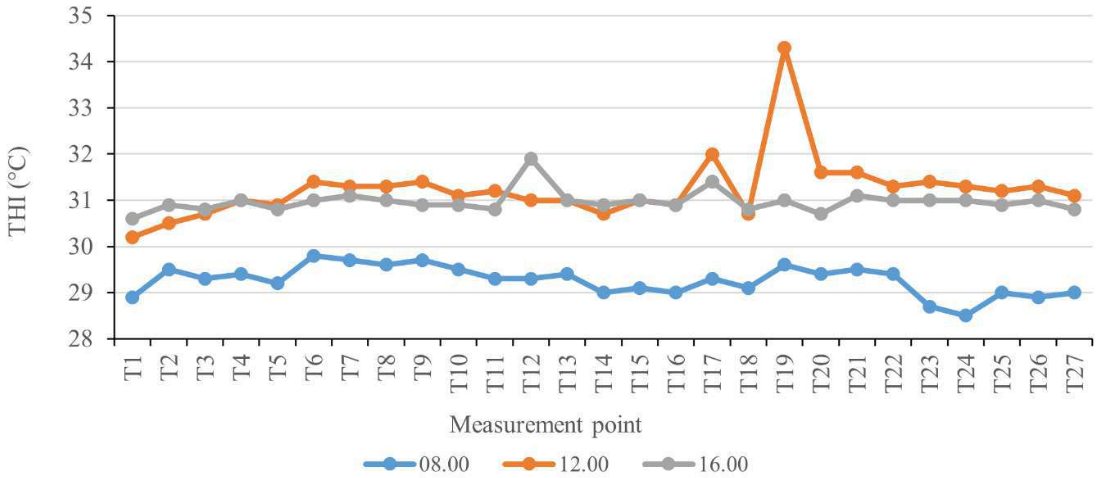


Figure. 9 The average THI on the university side

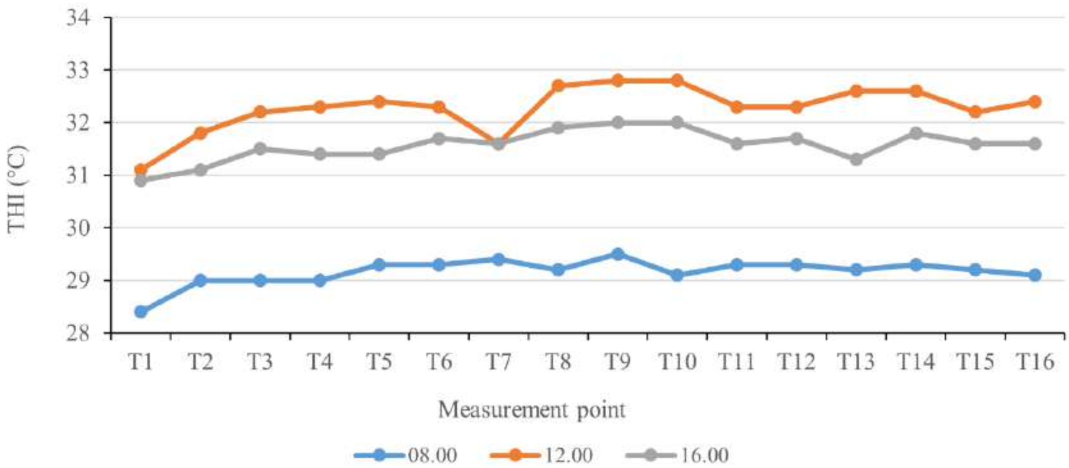


Figure. 10 The average THI at the terminal side

Figure 10 shows the average THI at the terminal side. The average THI at 08:00 ranges from 28.4-29.5 °C, with the lowest THI at T1 (segment I) and the highest at T9 (segment II). At 12:00, the average THI ranges from 31.1 – 32.8 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 16:00 ranges from 30.9-32.0 °C; the lowest is at T1 (segment I), and the highest is at T9 and T10 (segment II). The average THI at 08:00,

12:00, and 16:00 is considered uncomfortable. Like the university side, the most uncomfortable time is at 12:00.

### 3.4 Factors that influence thermal comfort

According to the results, at the university side segments I, II, and II, there are 84 trees with varying canopy diameters from 1.5 – 9.0 m and varying heights from 3.2 – 11.2 m. Meanwhile, at the terminal side segments I, II, and II, there are 31 trees with varying canopy diameters from 2.0 – 5.0 m and varying heights from 6.0 – 11.0 m. Trees at Jalan Kyai Tapa have relatively wide canopy diameters. Trees with wide canopy diameters provide more expansive shaded areas, improving thermal comfort (Boukhabla & Alkama, 2012). More expansive tree canopy and denser leaves can help reduce air temperature and improve microclimate (Hanifah & Yulita, 2018). However, based on the THI results, the trees at Jalan Kyai Tapa's pedestrian corridors do not seem to adequately improve the air temperature and relative humidity to reach a comfortable state for pedestrians.

Several factors possibly caused the uncomfortable THI results of this study. Generally, the effectiveness of vegetation affecting outdoor microclimate is determined by five main parameters: foliage shape and dimensions, trunk height, leaf area density, seasonal cycle, and daily transpiration (Perini et al., 2018). The shape of a tree canopy is essential in distributing air temperature (Fabbri et al., 2017). The shade from the tree canopy influences the plants' evapotranspiration, increasing relative humidity and absorbing thermal energy that decreases air temperature (Perini et al., 2018) and decreases the ground temperature (Morakinyo et al., 2018). An existing study found that the most influential parameter affecting outdoor thermal comfort is leaf area index (LAI), followed by trunk height, tree height, and crown diameter (Morakinyo et al., 2018). LAI is a one-sided green leaf area per unit ground area (Wu et al., 2020). Another study suggests that tree arrangement (height-to-distance ratio of trees) is also essential because the arrangement influences wind speed and sunlight blockade (Zhang et al., 2018). The same study mentioned that large LAI is likely more significant than canopy diameter and tree height.

Furthermore, tall trees with an extensive leaf area index and canopy diameter (> 6 meters) should be prioritized when selecting trees to improve outdoor comfort (Zhang et al., 2018). Vegetation in its best condition can decrease air temperature up to 3.5 °C (Wang & Akbari, 2016). Concerning the results of this study, the trees' canopy diameter in the study area might not be wide enough to provide adequate improvement to the air temperature, considering the majority of the tree's canopy diameter is less than 5 meters. However, this study does not investigate the LAI of each tree, which was found to be the most influential parameter in existing studies. Further studies on LAI and tree arrangements are required to more accurately determine the cause of uncomfortable outdoor areas.

Many studies analyzed how urban trees can benefit human thermal comfort. Trees can alleviate urban air temperature, but not all are equally effective (Richards et al., 2020). Some studies suggest that taller trees have a better performance at improving street thermal comfort (Manickathan et al., 2018; Yang et al., 2018). It may be related to how taller trees can pass through incoming airflow horizontally and remarkably improve pedestrian wind comfort (Kang et al., 2020). This condition is similar to what we found during field measurement at the university side, where some spots under *Casuarina equisetifolia* trees that can pass wind have lower THI (better thermal comfort) than some spots under *Mimusops elengi* trees that tend to have dense canopy. An existing study suggests that trees with a large canopy, short trunk, and dense canopy can reduce mean radiant temperature effectively (Kong et al., 2017).

Interestingly, we found that T1 has the lowest average air temperature at the university side, and T17 has the highest temperature at 12:00 and 16:00. However, there is no tree at T1. There is a *Mimusops elengi* tree at T17. However, the tendency is different at 08:00. At 08:00, T24 has *virens* and *Mimusops elengi* nearby, but the number of trees is more significant at T24. The

different tendency between morning observation (08:00) and afternoon observations (12:00 and 16:00) is possibly related to the evapotranspiration activity of the trees across the day. Evapotranspiration is driven by solar radiation, and the rate increases rapidly in the morning, especially from 07:00 to 10:00, which may cause trees' cooling benefits in the morning to be more apparent than in the afternoon (Sharmin et al., 2023). The difference between evapotranspiration rates in the morning and afternoon likely causes the difference in tendency between morning and afternoon observations. As for the afternoon phenomenon, where T1 (no tree) has the lowest average air temperature, and T17 (with tree) has the highest, possible canopy-associated warming occurred during observations. Sharmin et al. (2023) conducted a study to determine the cooling benefits of 10 urban tree species considering the tree traits and microclimatic conditions in suburban areas. The study found that there was canopy-associated warming in the afternoon, and it continued overnight. In the afternoon, the average temperature under the tree canopy increases by 1.19 °C compared to ambient air temperature. Meanwhile, at night, the average temperature increases 1.53 °C. Among the observed species in that study, the species with the highest LAI has the lowest sub-canopy warming effect. The heat from nearby buildings can also cause the sub-canopy warming effect. A study by Alonzo et al. (2021) conducted in Washington DC found that trees along streets have a less cooling effect than trees surrounded by grass or other vegetation due to re-radiated heat from under-tree canopy and surrounding surfaces. This condition further supports that the air temperature under trees might be higher than the ambient air temperature, mainly if buildings like the study area surround the area. This condition may also explain why such a phenomenon is not found on the terminal side, considering the terminal side has fewer structures and buildings than the university side. On a side note, it is worth noting that T1 is also located near a small water body, which may also help decrease the air temperature due to water body evaporation (Chen et al., 2023).

In another case, T9 of the terminal side shaded by *Casuarina equisetifolia* consistently has the highest air temperature at 08:00, 12:00, and 16:00, and also the highest THI (worst thermal comfort). The tree is not a shade tree and only has a canopy diameter of 2 meters. Furthermore, the planting distance between trees in that area is larger than the canopy diameter, so we suggest it cannot provide the proper shade to cool down the air temperature. We mentioned that some spots with Casuarina equisetifolia at the university have better thermal comfort than *Mimusops elengi*. This condition indicates that vegetation species alone cannot determine thermal comfort. It is also related to the planting distance, design, and other elements close to it. The planting design and the vegetation type must be considered according to the intended usage of the space (Meili et al., 2021).

Generally, the university side has better thermal comfort than the terminal side. The university side also has more trees and less pavement coverage than the terminal. Trees can improve thermal comfort, and to optimize tree function in pedestrian corridors, we should consider tree characteristics and arrangement. From the results of this study, we discussed that various factors and the trees determine the thermal comfort of pedestrian corridors' influence on microclimate, which can be different depending on the time of the day. Our findings offer the thermal comfort overview of pedestrian corridors in Jakarta during the morning and afternoon, which was not sufficiently explored in existing studies. This research still has limitations, specifically in measuring LAI and the distance between trees. Therefore, further research is required before proposing recommended planting designs and plant selection that can improve people's thermal comfort, such as reducing air temperature, adjusting relative humidity, and creating a wind corridor.

## 4. Conclusion

The findings of this study show that the air temperature of Jalan Kyai Tapa ranges from 31.01-31.54°C and the relative humidity ranges from 56.19 – 57.74%. The average air temperature

and relative humidity at Jalan Kyai Tapa are 31.2°C and 57%, respectively. The average THI at Jalan Kyai Tapa is 28.52°C, which is categorized as uncomfortable. In areas with small tree spacing, the air temperature tends to be low, and the relative humidity tends to be high. On the contrary, in areas with large tree spacing, the air temperature tends to be high, and the relative humidity tends to be low. Although many trees at Jalan Kyai Tapa have relatively large canopies, they do not adequately improve the air temperature and relative humidity to make the corridor thermally comfortable for pedestrians. Trees might not be the most influential factor in improving pedestrian thermal comfort, as we found a measurement point with no tree with the lowest temperature in the afternoon. Further research about the impact of tree arrangement, tree selection, and hardscape structure on thermal comfort is necessary to optimize the roadside greenbelt design for creating comfortable pedestrian corridors.

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**Author Contribution**
Conceptualization, N.I.S.; Methodology, N.I.S.; Analysis, N.I.S., D.D., R.F.; Investigation, N.I.S., R.F.; Writing – Original Draft Preparation, N.I.S.; Writing – Review & Editing, R.F., D.D., R.F.; and Funding Acquisition, N.I.S.

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