Study of Thermal Comfort under The Shade of Varied Tree Canopy Form and Distance from The Stem

M M Fadhlurrahman¹ and N Nasrullah²
¹ Student of Undergraduate Program, Department of Landscape Architecture
Faculty of Agriculture, IPB University
² Lecturer of Department of Landscape Architecture Faculty of Agriculture,
Bogor Agricultural University. Jl. Meranti, IPB University, Dramaga Campus, Bogor West
Java Indonesia 16680
E-mail: nizar_nasrullah@apps.ipb.ac.id

Abstract. Comfort environment is one of important goal in urban landscape development. Tree as main element of green open space has a function to reduce urban heat island problems by providing a shade. Trees with its various canopy form might have different effects based on how the canopy block and absorb the sunlight heat. This research aimed to find out the effects of shade from various canopy form in different distances form the trees. There were seven trees species chosen which representing different canopy form, namely Acacia mangium Willd., Paraserianthes falcatoria (L.) I.C. Nielsen, Ficus benjamina L., Buchida molineti (M.Gómez) Alwan & Stace, Palaquium amboinensis Burck, Agathis dammara (Lamb.) Rich., and Thuja orientalis L. The measurement of air temperature, relative humidity, and wind speed were done below the shade in the distance up to three times of the canopy radius at the east and west side of the tree with once in an hour duration from morning until evening (09.00 a.m. – 02.00 p.m.). Supportive data like tree position, height, stem diameter, and leaf density were observed to know the existing condition. Thermal comfort was indicated by using Temperature Humidity Index (THI). The results showed that there were correlation between tree canopy density represented by Leaf Area Index (LAI) and distance from tree with temperature and humidity. Trees with dense canopy has lower temperature and higher humidity by equation y = -2.037x + 37.19 for temperature and y = 8.1354x + 48.247 for humidity. Meanwhile, the further the distance from the tree, the higher the temperature and the lower the humidity. All trees was categorized uncomfortable by THI method, but Buchida molineti with opened-columnar canopy form has the lowest THI value.

Keywords: Canopy shape, Climatic elements, Shading effect, Thermal comfort

1. Introduction
Urban development is a phenomenon of urbanization that affects microclimate conditions. According to Marsh[1], the phenomenon of urbanization causes significant changes to the microclimate of the city. Cities can be several degree centigrade warmer than the surrounding rural landscape.[2] This makes conditions that can affect human activity and comfort thermally in this region. The American Society for Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in Lechner 2007 defines thermal comfort as a condition of thought that expresses satisfaction to the thermal state of its environment.[3] Four environmental conditions that need to be understood to create thermal comfort are a combination of air temperature, relative humidity (RH), air movement (wind), and mean radiant temperature (MRT).

Thermal comfort in open space can be obtained by the presence of vegetation in the form of trees that function for climate amelioration. Trees in urban areas will give a cool impression through the texture and green leaves[4], as well as right selection of tree type and planting.
position will give benefit by providing thermal comfort and reduced solar and ultra-violet exposure).[5] Morphologically, the degree of tree shade is determined by the diversity of tree canopy shapes. While the shape of the canopy is divide into globular (round), columnar (columnar), dome (dome), picturesque (exotic), weeping (dangling), conical (cone), and fastigiated (slim).[6] This form is also distinguished from the type of open and closed branching. The ability of trees to create shade is related to several factors including tree location, branch density, canopy structure and size [1]. Previous studies mainly focused on the effect of tree shade to material surface temperature such as surface of concrete, asphalt, porphyry and grass.[5,7] However study related to correlation between shade of varied tree canopy form and air temperature and relative humidity as the component that determine thermal comfort is still limited. In the other hand, when creating planting plant it is important to consider canopy form and their effect to environmental comfort. Moreover area of tree shade changed according to the angle of sun. In mid day shade area of tree canopy is the same as projection of canopy area, but in the afternoon, more longer shade formed in the eastern side of tree. So distance from the tree below the tree shade may influence distribution of air temperature and humidity.

Therefore, quantitative information and calculations are needed in order to be able to compare the different effects of the form of the canopy at varied point from the tree. This study aims to observe the effect of differences in the form of the single tree canopy and its distance from the tree to the thermal comfort forming elements of air temperature and humidity in open spaces.

2. Method
2.1 Research Location and Time
The study was conducted in the area of Puspiptek (Center for Research, Sciences and Technology), South Tangerang City, Banten (Figure 1), which has varied mature single trees in their open space. Data collection was conducted on November 19, 2016 from morning to afternoon (9 am – 2 pm) when the weather was sunny.

Figure 1. Research site and position of observed Trees (Map Source: Google Earth)
2.2. Research methods

2.2.1 Research Design
This research used seven species of single trees which canopy shape consisting of four basic shapes (round, dome, columnar, and cone) with closed and open canopy types. The observed tree was a single tree (solitary) which forms a complete shade on the west side and east side of the tree. Observation of the physical characteristics of the trees including tree location, canopy diameter, tree height, lowest branch height, and canopy density. The positions of the trees were scattered at several points in the Puspiptek area. Temperature and humidity measurements were carried out below the shade at the measuring points 1.5 m above the ground namely at the point P0 right on the trunk of the tree, then the east side of the tree in the point P1 (1 x canopy radius), P2 (2 x canopy radius), P3 (3 x the radius of the canopy), and the west side are P4 (1 x the radius of the canopy), P5 (2 x the radius of the canopy), and P6 (3 x the radius of the canopy) (Figure 2). Measurement of wind speed below the shade of the tree was also done at the same point.

![Observation point based on multiplication of canopy radius](image)

2.2.2 Method of Data Collection
a. Survey and Inventory
Observation was carried out to determine the availability of trees that are possible to be observed by selecting tree species with the appropriate shape of the canopy. Inventory of tree dimensions consisted of tree height, canopy radius, and lowest branch height. Next the tree is marked with a measuring point at a distance based on multiplication of the radius of the canopy. Canopy density was observed to describe canopy form characteristics by measuring Leaf Area Index (LAI) using a camera with a fisheye lens and analyzed using Hemiview 2.1 Canopy Analysis Software.[8]

b. Observation Climate Elements Influencing Thermal Comfort
Air temperature and humidity were measured using a Thermo hygrometer which is calibrated with a Mini Weather Station PCE-FWS20. Wind speed measurements were carried out using an anemometer together with temperature and humidity measurements.

2.2.3 Data Analysis
Correlation analysis is used to determine the strength and direction of the relationship between the Leaf Area Index (LAI) and the distance from the tree to the temperature (°C) and humidity (%). Linear regression explains the shape of the causal relationship between variables and estimates its value using the following equation model [9]:

\[ Y = a + bX \]

Description:
- \( Y \) = Dependent variable (temperature and humidity) 
- \( a \) = Constanta 
- \( X \) = Independent variable (LAI and distance) 
- \( b \) = Trend coefficient (slope) of the regression line

2.2.4 Thermal Comfort Rating
Temperature Humidity Index (THI) is used to determine the level of thermal comfort at a location in the presence of air temperature and humidity data. THI calculations are formulated as follows [10]:

\[ THI = 0.8T + \frac{RH \times T}{500} \]

Description:
- THI = Temperature Humidity Index
- T = air temperature (°C)
- RH = Relative humidity of air (%)

3. Results and Discussion

3.1 General condition

The Puspiptek area has an area of 460 hectares which is administratively located in Setu Sub district, South Tangerang City and a small portion is included in Bogor Regency. Puspiptek area has a lot of land planted with trees. According to BMKG (Meteorological, Climatological, and Geophysical Agency) Region II data, on the day of observation, South Tangerang had a minimum temperature of 24.4 °C and a maximum temperature of 35.0 °C with a daily average of 28.2 °C. The average humidity of this area was 78% with rainfall of 4.7 mm. The maximum wind speed was 2.1 m/s with an average of 1.0 m/s from the north. The condition of the sky when the data collected was not completely bright because cloud instability starts around 11:00 am. This was a natural disruption that can affect the measurement results due to cloud cover. The condition of the earth’s surface when covered by clouds receives lesser global radiation [11]. Therefore, observations were only be made until 2:00 pm due to increasingly cloudy conditions and rain begin.

3.2 Physical Condition of Trees Samples

3.2.1 Surface Coverage

Surface coverage can affect the temperature and humidity above it so that it becomes a consideration in investigating the effect of tree shade on these variables. Surface temperatures can differ depending on the type of surface and sunlight exposure [12]. The surface under the Acacia mangium and Paraserianthes falcataria trees was fully covered with grass, while the other five trees were partially covered with grass and pavement (Table 1).

| No. | Trees Name               | Surface Coverage       | Grass | Pavement |
|-----|--------------------------|------------------------|-------|----------|
| 1.  | Acacia mangium           | Po, P1, P2, P3, P4, P5, P6 | -     |          |
| 2.  | Paraserianthes falcataria| Po, P1, P2, P3, P4, P5, P6 | -     |          |
| 3.  | Ficus benjamina          | Po, P1, P2, P3, P4, P5 |       | P6       |
| 4.  | Bucida molineti          | Po, P1, P2, P3         | P4, P5, P6 |          |
| 5.  | Palaquium amboinensis    | Po, P1, P2, P3         | P4, P5, P6 |          |
| 6.  | Agathis dammara          | Po, P4, P5, P6         | P1, P2, P3 |          |
| 7.  | Thuja orientalis         | Po, P1, P4, P5, P6     | P2, P3 |          |

3.2.2 Leaf Area Index Value (LAI)

Leaf Area Index (LAI) measurements were carried out on three different sides of canopy as replicates for each tree. LAI value indicates the amount of canopy density of a tree. LAI was observed due the shape and density of the canopy can affect the shade of a tree [13]. Acacia
mangium trees has closed round canopy and Palaquium amboinensis has closed columnar canopy. Which have a high LAI with averages of 1.56 and 1.59, respectively. The Agathis dammara tree has a high LAI (1.57) despite being open columned canopy. This is due to the horizontal branches in this tree being denser. The tree with the lowest LAI was Paraserianthes falcatoria with open round canopy (Table 2).

### 3.2.3 The Physical Character of Trees and Wind Speed

Physically the tree observed has a different character in terms of its size which includes the height of the tree, the lowest branch height, and the radius of the canopy (Table 2). In general, the tree with the largest dimension was the Ficus benjamina tree with a closed dome-shaped canopy, while the smallest tree was Thuja orientalis. Meanwhile, the wind speed when observing each the tree ranges from 0.4 to 0.9 m/s.

#### Table 2 Measurement of Physical Character and Tree Dimensions

| Canopy Form | Tree Name                  | Tree dimension | LAI  | Wind speed (m/s) |
|-------------|----------------------------|----------------|------|------------------|
|             |                           | Tree height (m)| Lowest branch height (m) | Canopy Diameter (m) | Canopy radius (m) |                  |
| Round       | Closed Acacia mangium     | 11             | 2    | 12               | 6                | 1.56             | 0.6              |
|             | Open Palaquium amboinensis | 18             | 5    | 20               | 10               | 1.11             | 0.5              |
| Dome        | Closed Ficus benjamina    | 24             | 6    | 34               | 17               | 1.36             | 0.6              |
|             | Open Bucida molineti      | 8              | 2    | 7                | 3.5              | 1.31             | 0.5              |
| Columnar    | Closed Palaquium amboinensis | 15        | 3    | 10               | 5                | 1.59             | 0.9              |
|             | Open Agathis dammara      | 18             | 2    | 8                | 4                | 1.57             | 0.8              |
| Conical     | Closed Thuja orientalis   | 7              | 1.6  | 6                | 3                | 1.38             | 0.4              |

#### 3.3 Analysis of Influence of Observation Side, Tree Species and Distance of Measuring Points

##### 3.3.1 Effect of Observation Side on Temperature and Humidity

Measurement results show the lowest temperature in all tree found in the centre of tree canopy shade (P0) than the temperature increased with the increasing distance from the stem both in east and west side of tree. Position of canopy shade change following the sun angle. In the morning canopy shade fall in the west side of tree, and in afternoon it fall in the east side of tree. It indicated that the degree tree shade effect in the morning (9-11 am) and in the mid day (1-2 pm) decrease with the increasing distance from the stem (Figure 3).

The results of humidity measurements were inversely related to the temperature at each tree and distances. Figure 4 show the highest value of relative humidity found in the center of tree canopy shade (P0) than gradually decreased with the increasing distances from the stem of tree. It is due to rising air temperatures cause humidity to be lower during the day temperature.[14].

Even the is more higher than in the center of tree shade, the area in the point P1, P2, P3 in the afternoon and P4, P5, P6 in the morning which received the shade of canopy, that points obtained advantage due to tree shade protect that area from UV exposure and experiencing more lower relative humidity.
Figure 3. Average temperature measured in each tree/canopy form in different measurement point Po-P3 in the east side (left) and Po-P6 in the west side (right) of tree.

Based on Figure 5, the average temperature and humidity on the east and west sides of the tree were relatively not much different. However temperature on the west side was generally more higher than that in east side. Small differences on both sides can be caused by the condition of surface coverage and surround environment on both side. Besides, in the mid day and afternoon when temperature was more higher, the area in west side (P4, P5, P6) did not receive any shade of tree canopy.
3.3.2 Effect of Trees on Temperature and Humidity

The average temperature of each tree ranged from 33.7 °C to 35.7°C. *Thuja orientalis* with closed canopy has the highest average temperature which was 35.7°C due to conical canopy trees provide less shade because of their smaller canopy on upper layer [15]. The tree with the lowest average temperature (33.7 °C) was *Palaquium amboinensis* which has closed columnar canopy (Figure 6). It may be caused this tree has the highest LAI (1.59), so it is better to reduce temperature.

The average humidity of all trees ranges from 52% to 64%. The highest average humidity (64%) was found in the *Ficus benjamina* tree. The lowest average humidity was found in *Bucida molineti* (52%). Part of the surface coverage on this tree was pavement, which causes the surrounding air conditions to be drier. Condition of dryness bring to the higher capacity of air to collect water vapor. Increased vapor pressure deficits cause lower humidity [16].

Figure 5 Graph of average temperature (left) and humidity (right) on the west and east sides of the tree

Figure 6 Graph of average temperature and humidity of trees / canopy form
3.3.3 Effect of Distance on Temperature and Humidity
The average temperature at the measuring distance from the tree at the midpoint (Po), the east side (P1, P2, P3) and the west side (P4, P5, P6) shows the average temperature increased with the increasing distance from the tree (Figure 7). This is due to the further away from the tree, the more no shade can block the sun's rays. The lowest temperature average was Po point as the midpoint under the shade of the tree at 33.1˚C, while the highest temperature average was at the points P3 and P6, respectively 34.9˚C and 35.1˚C.

![Figure 7 Graph of average temperature and humidity at the distance of the measuring point](image)

The highest average humidity at the measuring distance from the tree is at the Po point of 63%. This average humidity tends to decrease with increasing distance from the tree. On the east side, point P1 has an average humidity of 61%, followed by point P2 at 60% then point P3 at 58%. While on the west side, point P4 has the same average humidity as point P2 which is 60%. Furthermore point P5 has an average humidity of 59% and point P6 of 57%. Point P6 is the point with the lowest average humidity among other points.

3.4 Correlation Analysis Between Variables
The correlation of LAI to temperature is significant (<5%) with an inverse relationship (negative) of -0.250, while the correlation of LAI with humidity of 0.221 is directly proportional (positive) (Table 3). Meanwhile, the correlation of LAI with THI is also significant with the inverse relationship of -0.219. This shows that the closer branch canopy of trees, the temperature and THI tend to be lower, while humidity is higher. The relationship between distance and temperature is significantly proportional to 0.452, while the distance to humidity is -0.309 (inversely proportional). Meanwhile, the distance relationship with THI is directly proportional to -0.431. This shows the farther the distance from the tree, the higher the temperature and THI, while the lower the humidity.

Based on Table 5, the relationship between time and temperature and THI has a negative correlation of -0.262 and -0.316. The correlation of time to humidity has a significance greater than 5%, so it has not a significance correlation.
### Table 3 Correlations between observed variables

|        | LAI Correlation | Distance Correlation | Time Correlation | Temperature Correlation | Humidity Correlation | THI Correlation |
|--------|-----------------|----------------------|------------------|-------------------------|----------------------|----------------|
| LAI    | 1               | 0.000                | 0.000            | -0.250                  | 0.221                | -0.219         |
| Distance | 1.000           | 1.000                | -0.452           | 0.002*                  | 0.007*               | 0.008*         |
| Time   | -0.262          | 0.008                | -0.316           | 0.001*                  | 0.960                | 0.000*         |
| Humidity | 0.452           | -0.309               | 0.431            | 0.000*                  | 0.000*               | 0.000*         |
| THI    | -0.678          | 0.951                | -0.416           | 0.000*                  | 0.000*               | 0.000*         |

Note: *Significance at level 5%.

### 3.5 Linear Regression Between Variables

#### 3.5.1 Relationship of Trees (LAI) with Temperature, Humidity, and THI

The results of the LAI linear regression analysis with temperature, humidity and THI variables show a significant relationship (Table 4). Multiple R of temperature and humidity is > 0.2 so it has a weak but evident relationship [7]. Likewise, THI which is a combination of the two (temperature and humidity). This shows that temperature, humidity, and THI are not only influenced by LAI, but also be influenced by other factors. Temperature and humidity have a strong effect on thermal comfort, but it is usually difficult to change because the atmospheric efficiency mixes both so that the differences disappear quickly [17].

### Table 4 Results of regression analysis between LAI and the dependent variable

| Variables related to LAI | Multiple R | R square | F | Significant | Equation                     |
|--------------------------|------------|----------|---|-------------|-----------------------------|
| Temperature              | 0.25007    | 0.06253  | 0.00225* | y = -2.0337x + 37.19         |
| Relative humidity        | 0.22085    | 0.04878  | 0.00719* | y = 8.1354x + 48.247         |
| THI                      | 0.21873    | 0.04784  | 0.00778* | y = -1.32x + 33.405          |

Note: *Significance at level 5%.

#### 3.5.2 Relationship between Distance in Each Tree with Temperature, Humidity, and THI

Based on Table 5, some of the trees observed had significant relationship between the distance to each tree to the temperature, humidity and THI variables. The spacing of Acacia mangium, Bucida molineti, and Palaquium amboinensis trees significantly (significance <5%) affected all of the dependent variables. The distance in Acacia mangium has a significant relationship (0.4 <multiple r <0.7) to temperature, humidity, and THI with the magnitude of influence/contribution (r square) of 33%, 41%, and 28%, respectively. Distance on Bucida molineti has a strong relationship (multiple r > 0.7) to temperature and THI with contributions of 51% and 58%. The distance in Palaquium amboinensis is also strongly related (multiple r > 0.7) to temperature and humidity with contributions of 52% and 67%. Meanwhile the relationship of distance to other trees shows the significance of one of the dependent variables with multiple R and R square.
Table 5 Results of regression analysis between the distances in each tree to the dependent variables

| Trees                  | Multiple R | R square | F Significant | Equation        |
|------------------------|------------|----------|---------------|-----------------|
| **Dependent Variable: Temperature** |            |          |               |                 |
| Acacia mangium         | 0.58090    | 0.33744  | 0.00576*      | $y = 0.1124x + 32.791$ |
| Paraserianthes falcataria | 0.64813    | 0.42007  | 0.00149*      | $y = 0.0723x + 33.487$ |
| Ficus benjamina        | 0.44077    | 0.19428  | 0.04551*      | $y = 0.0225x + 33.332$ |
| Bucida molineti        | 0.76836    | 0.59038  | 4.74E-05*     | $y = 0.2193x + 32.994$ |
| Palaquium amboinensis  | 0.72152    | 0.52059  | 0.00022*      | $y = 0.1314x + 32.531$ |
| Agathis dammara        | 0.22244    | 0.04948  | 0.33247       | $y = 0.0741x + 33.418$ |
| Thuja orientalis       | 0.39911    | 0.15929  | 0.04551*      | $y = 0.0741x + 33.418$ |
| **Dependent Variable: Humidity** |            |          |               |                 |
| Acacia mangium         | 0.64404    | 0.41479  | 0.00163*      | $y = -0.2922x + 65.577$ |
| Paraserianthes falcataria | 0.33314    | 0.11098  | 0.14002       | $y = -0.1048x + 63.654$ |
| Ficus benjamina        | 0.42928    | 0.18428  | 0.05214       | $y = -0.0871x + 66.205$ |
| Bucida molineti        | 0.59613    | 0.35537  | 0.00343*      | $y = -0.7152x + 56.244$ |
| Palaquium amboinensis  | 0.82004    | 0.67246  | 5.35E-06*     | $y = -0.4094x + 67.013$ |
| Agathis dammara        | 0.20307    | 0.04124  | 0.37732       | $y = -0.2228x + 63.885$ |
| Thuja orientalis       | 0.55852    | 0.31194  | 0.00850*      | $y = -0.8141x + 57.115$ |
| **Dependent Variable: THI** |            |          |               |                 |
| Acacia mangium         | 0.53825    | 0.28972  | 0.01183*      | $y = 0.0839x + 30.535$ |
| Paraserianthes falcataria | 0.63647    | 0.40510  | 0.00192*      | $y = 0.0594x + 31.065$ |
| Ficus benjamina        | 0.41937    | 0.17587  | 0.05843       | $y = 0.015x + 31.075$ |
| Bucida molineti        | 0.76333    | 0.58267  | 5.69E-05*     | $y = 0.1499x + 30.105$ |
| Palaquium amboinensis  | 0.64022    | 0.40688  | 0.00177*      | $y = 0.0901x + 30.388$ |
| Agathis dammara        | 0.22029    | 0.04853  | 0.33728       | $y = 0.0542x + 30.987$ |
| Thuja orientalis       | 0.32180    | 0.10355  | 0.15487       | $y = 0.11x + 31.722$ |

Note: *Significance at level 5%.

3.6. Thermal Comfort

According to comfort category range[10], the comfort is at the range of THI 21-24 and discomfort occurs at THI>26. The thermal comfort is obtained by a combination of low temperature and low humidity. The results of thermal comfort calculations showed that all trees fall into the uncomfortable category. However, it can be seen in Figure 8 that Bucida molineti in the form of an open columnar canopy has the lowest THI value of 31.0. Meanwhile the tree with the highest THI value is Thuja orientalis with a THI of 32.3.

![Figure 8 Graphic comparison of THI values between trees](image)

Note: Am = Acacia mangium ; Pf = Paraserianthes falcataria; Fb = Ficus benjamina ; Bm = Bucida molineti ; Pa = Palaquium amboinensis ; Ad = Agathis dammara ; To = Thuja orientalis

4. Recommendation

Based on the results obtained, seven of the trees observed were classified as thermally uncomfortable. This shows that a single tree (solitary) is not very effective in creating thermal comfort with THI calculations. The function of trees in creating thermal comfort can be felt
when trees are planted in groups/groups.[18] When compared between trees, Bucida molinetti has more potential in creating thermal comfort. Likewise with the distance at points P0 to P1 or P4. This can be made as a recommendation for placing a trees on landscapes that be prioritized the function for climate amelioration in the micro scale landscape

5. Conclusions and Suggestions

5.1 Conclusions

The results showed a difference in the value of climate elements forming thermal comfort (temperature and humidity) following the different shape of the canopy and the distance from the tree. The difference in temperature and humidity between tree canopies is affected by canopy density (LAI) in each tree. Dense trees canopy such as Acacia mangium, Ficus benjamina, Palaquium amboinensis, and Agathis dammara tend to have lower average temperatures and higher humidity. The distance relationship shows the point Po (midpoint below the canopy) has the lowest temperature and highest humidity. The farther the distance from the tree, the higher the temperature tends to be while the humidity is lower. The combination of temperature and humidity for thermal comfort in the form of THI in each tree is included in the uncomfortable category. This shows that solitary planted trees are less effective in creating thermal comfort.

5.2 Suggestion

Ideally, thermal comfort is not only influenced by Climatological factors (temperature, humidity, and other climatic elements), but is also influenced by factors that related to humans who feel it. This can be estimated by knowing the balance of energy budget for each factor involved.[4] Therefore, further research is needed with calculations that can involve all factors in full.

References

[1] Marsh WM. 1983. Landscape Planning, Environmental Application. New York (US): John Wiley and Sons.
[2] Armson D, P. Stringer, A.R. Ennos. 2012. The effect of tree shade and grass on surface and globe temperatures in an urban area. Urban forestry and Urban Greening. 11(3):245-255.
[3] Lecher N. 2007. Heating, Cooling, Lighting: Method Desain untuk Arsitektur. Edisi kedua. Sandriana Siti, penerjemah. Jakarta (ID): PT Raja Grafindo Persada. Terjemahan dari: Heating, Cooling, Lighting: Design Methods for Architects.
[4] Carpenter PL, Walker TD, FO Lanphere. 1975. Plants in the Landscape. New York (US): W. H. Freeman and Company.
[5] Lengenheim N, M White, N Tapper, SJ Livesley, DR Lovering, 2020. Right tree, right place, right time: A visual-functional design approach to select and place trees for optimal shade benefit to commuting pedestrians. Sustainable Cities and Society. 52: (Januari) 2030, 101816. https://doi.org/10.1016/j.scs.2019.101816
[6] Booth NK. 1983. Basic Elements of Landscape Architectural Design. Waveland Press, Inc. Illinois.315 p.
[7] Speak A, M Leonardo, C Welstein and S Serbe. 2020. The influence of tree traits on urban ground surface shade cooling. Landscape and Urban Planning. 197 (Januari 2020) 103748.
[8] Webb, N (Editor). 1999. User Manual for HemiView Version 2.1. Delta T Devices Ltd. Cambridge UK.
[9] Hasan MI. 2012. Pokok-Pokok Materi Statistik 2 (Statistik Inferensif) Edisi Kedua. Jakarta (ID): PT Bumi Aksara.
[10] McGregor GR, Niewolt S. 1998. Tropical Climatology. Edisi ke-2. London (UK): John Wiley and Sons ltd.
[11] Tjasyono B. 2004. Klimalogi. Bandung (ID): Penerbit ITB.
[12] Laurie M. 1986. Pengantar Kepada Arsitektur Pertamanan. Aris K Onggodiputro, penerjemah. Bandung (ID): Intermedia. Terjemahan dari: Introduction to Landscape Architecture.
[13] Abreu-Harbich LV,Labaki LC, Matzarakis A. 2015. Effect of Tree Planting Design and Tree Species on Human Thermal Comfort in the Tropics. Landscape and Urban Planning. Elsevier 138(2015): 99-109. [3] Booth NK. 1983. Basic Elements of Landscape Architectural Design. Waveland Press, Inc. Illinois.315 p.
[14] Handoko. 1993. Klimatologi Dasar: Landasan pemahaman fisika atmosfer dan unsur-unsur iklim. Bogor (ID): Pustaka Jaya.
[15] Grey GW, FJ Deneke. 1978. Urban Forestry. New York (US): John Willey and Sons Inc.
[16] Saputro TH, Fatimah IS, Sulistyantara B. 2010. Studi Pengaruh Area Perkераan terhadap Perubahan Suhu Udara (Studik Kasus Area Parkir Plaza Senayan, Sarinah Thamrin, dan StasiunGambir). J LanskIndones. 2(2):76-82.
[17] Brown RD, TJ Gillespie. 1995. *Microclimatic Landscape Design: Creating Thermal Comfort and Energy Efficiency*, New York (US): John Wiley and Sons.

[18] Irwan ZD. 2008. *Tantangan Lingkungan dan Lansekap Hutan Kota*. Jakarta (ID): PT Bumi Aksara.