Cooling effect to mitigate Urban Heat Island by *Pterocarpus indicus*, *Swietenia macrophylla* and *Samanea saman* In Bandung, West Java Indonesia

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Abstract. Urban Heat Island (UHI) has been detected in Bandung since 2001 and it can be mitigated by planting trees such as *Pterocarpus indicus* (angsana), *Swietenia macrophylla* (mahogany), and *Samanea saman* (trembesi). This research was conducted to measure temperature reduction by those road side trees at seven locations. Parameters were tree characteristics including shape and area of canopy, Plant Area Index (PAI), and leaf morphology (shape and arrangement), air temperature, relative air humidity, transmissivity, and surface temperature. Microclimate and edaphic data were measured in sunny day or partly cloudy. Data were analyzed using One-way ANOVA (Kruskal-Wallis test) to clarify significance differences among parameters in each tree species and measured reduction of discomfort index (dDI%). Air temperature in open area is 33.81±2.32°C, while surface temperature is 37.29±6.63°C. Result shows that trees have varies ability to decrease air and surface temperature. The highest reduction of air (A) and surface (S) temperature is shown by *S. saman* (A=3.80±1.21°C and S=10.49±2.84°C), then followed by *S. macrophylla* (A=3.10±1.94°C and S=5.64±5.51°C), and *P. indicus* (A=2.28±1.73°C and S=5.26±4.30°C). *S. saman* which has wide canopy with moderate leaf density can reduce air and surface temperature effectively, followed by *S. macrophylla* with narrow canopy and high leaf density; and *P. indicus* with narrow canopy with low leaf density. Thus, tree character with broad canopy and dense leaves such as *S. saman* can be recommended as shading tree to mitigate UHI in urban areas.

1. Introduction
The high rate of urbanization in Bandung city may cause ecological problems that form the phenomenon of the Urban Heat Island (UHI) which can have a negative impact on health, energy and food [1]. Since 2001, Bandung city has been reported for having UHI which is characterized by an increase in the average temperature of the Bandung area by 2°C from around 28°C in 1994 to 30°C in 2001. The main factor that drives UHI in Bandung City is land-use change from rural area (farm, forest) to urban area (neighbourhood, factory). In 2015, it was reported that average air temperature in areas surrounding Bandung City, such as Cimahi City in West Bandung Regency, Sumedang, and Bandung Regency increased from 1994 to 2001 about 1.2°C. However, in the areas that have no significant land use change such as Garut and Cianjur Regency tend to have constant average air temperature [2].

Several studies on UHI have been carried out, such as the distribution of UHI and the role of city parks in decreasing air temperature (cooling effect) in Bandung city [3] [4]. In addition, research on shade tree planting strategies in urban areas was carried out to see the role of vegetation in increasing...
community comfort, reducing air and noise pollution, providing habitat for a variety of biota, and increasing the aesthetic value of cities in addition to mitigating UHI [5] [6] [7] [8] [9].

In Bandung city there are three species of trees commonly planted as protective plants, namely arangsan (Pterocarpus indicus (L.) Willd), mahogany (Swietenia machrophylla King.) and trembesi (Samanea saman (Jacq.) Merr.). These species were established ca 80 years ago since the government of Bandung City proposed parks in some areas [10]. These tree species potentially provide cooling effect, but it has not been known the cooling effect of each tree in the vicinity of Bandung city. Therefore, a research is needed to study the effects on urban areas of these tree species and analyze their differences and their effectiveness [3]. The purpose of this study is to calculate the reduction in air temperature by arangsan (Pterocarpus indicus), mahogany (Swietenia machrophylla) and trembesi (Samanea saman) and compare the effectiveness of each three in lowering air temperature.

2. Methods

1.1. Research area description
This research was conducted on 2nd February 2019 to 16th June 2019. Citarum Avenue, Diponegoro Avenue, Cihapit Avenue, Belitung Avenue, Bali Avenue, Saparua Field, and Cihapit Park in Bandung City were selected as locations for sample sampling (Figure 1).

Legend:
- Pterocarpus indicus
- Samanea saman
- Swietenia machrophylla

Figure 1. Research area location

1.2. Tree sampling criteria
Sampled trees must have certain criteria: trees are not blocked by an object such as buildings, must be healthy, and at least ten years old. Each tree species is taken 10 individuals for sampling.
1.3. Tree canopy sampling
Tree characteristics observed were top and side view tree profiles (trunk diameter, tree height, canopy length and width, and canopy thickness), canopy shape, canopy area, tree architecture, leaf morphology (leaf type, leaf shape, phylataxis) and Plant Area Index (PAI). Tree height is measured using hagameter; canopy profiles including canopy area drawn using GeoGebra v6.0.541 and Autodesk Revit 2019 software.

1.4. Tree Plant Area Index (PAI) determination
PAI was calculated using the method developed by Tukiran et al. (2016) [4] using a canopy analysis system based on hemispherical image analysis. This parameter is measured at tree community level. The camera which is equipped with a fish eye lens (180°) is placed 1 meter above ground level and is directed right vertically towards the shade tree canopy. Pictures taken when the sun does not directly illuminate the camera: in the morning before 9:00 WIB, in the afternoon after 15:00 WIB or in cloudy weather. After the image is taken, the image is processed using CAN_EYE v6.495 software to get the PAI value.

1.5. Shaded area analysis
Shaded area is determined by the method of Tukiran et al. (2016) [4] with modifications. Shaded area is determined by computer simulation using the Autodesk AutoCAD 2019 and Autodesk Revit 2019 software. The main thing for determining the shaded area is to make a three-dimensional model of the tree. First, a digital photo of the measured tree (one tree per species) is taken using a digital camera. The picture was taken 10 meters from the tree eye level. Shooting is done in two cardinal directions: southeast, south, southwest or northwest, north, northeast. The image is transferred to a computer, then imported into Autodesk AutoCAD 2019 to make a tree model in the form of a three-dimensional tree frame. After that, the tree model is processed using Autodesk Revit 2019 to calculate the area of its shadow using a simulation. The simulation is set to take place at 10.00 WIB, 12:00 WIB, and 14.00 WIB on July 19, 2019.

1.6. Microclimate and edaphic sampling
Microclimate (air temperature, humidity, and light intensity) and edaphic (surface temperature) sampling were carried out under the canopy and outside the canopy for each individual tree observed by Tukiran et al. (2016) [4] method with some modifications. This measurement is carried out during the day when the weather is sunny or cloudy in three time periods: 9.30-10.30, 11.30-12.30, and 13.30-14.30 WIB [18] [4]. Microclimate measurements under the tree canopy were carried out at a height of 1.5 m above ground level in four quadrants separated by a virtual line of four magnetic compass directions. Microclimate measurements outside the tree canopy were carried out at a height of 1.5 m above the ground surface and in the shade-free space in the same area as the tree observed. The sampling position can be seen in Figure 2.

The sunlight intensity reduction percentage between below and outside the canopy, the percentage increase in air humidity between below and outside the canopy, and the percentage reduction in surface temperature between below and outside the canopy, were calculated. Surface temperature is measured using a surface thermometer below and in the shade-free space. Air temperature and light intensity are
measured using the HOBO® Pendant Temp / Light Data Logger UA-002-64, while under and outside the tree canopy. Air humidity was measured using HOBO® Pro v2 Temp / RH Data Logger U23-001 under and outside the tree canopy.

I.7. Discomfort index reduction percentage (dDI%) calculation
Data analysis was performed by calculating the discomfort index reduction percentage (dDI%) of each tree species to determine the level of cooling effect of each tree species [11] using the Thom's discomfort index (DI) equation as follows.

\[ dDI\% = \left( \frac{DI_{sun} - DI_{sh}}{DI_{sun}} \right) \times 100\% \] (1)

DI\(_{\text{sun}}\) is a discomfort index in areas that are not shaded by trees. DI\(_{\text{sh}}\) is a discomfort index in areas shaded by shade trees [11]. The equation of DI\(_{\text{sun}}\) and DI\(_{\text{sh}}\) are as follows.

\[ DI_{\text{sun}} = \frac{T_{\text{sun}}}{T_{\text{a}}} = -0.55(1 - 0.01R_{\text{h}}) (T_{\text{a}} - 14.5) \] (2)

\[ DI_{\text{sh}} = \frac{T_{\text{sh}}}{T_{\text{a}}} = -0.55(1 - 0.01R_{\text{h,sh}}) (T_{\text{a}} - 14.5) \] (3)

T\(_{\text{a}}\) is the temperature in an area that is not shaded by a tree, while T\(_{\text{sh}}\) is the temperature in an area that is shaded by a tree. R\(_{\text{h}}\) is the percentage of relative humidity in areas that are not shaded by shade trees, while R\(_{\text{h,sh}}\) is the percentage of relative humidity in areas that are shaded by shade trees [11]. The discomfort index (DI\(^{\circ}\)C) value and the scale of discomfort can be seen in Table 1.

| Scale | Feeling of discomfort                                      | DI\(^{\circ}\)C |
|-------|-----------------------------------------------------------|-----------------|
| 1     | No discomfort                                             | < 21            |
| 2     | Discomfort expressed by < 50% of the population            | 21-24           |
| 3     | Discomfort expressed by > 50% of the population            | 24-27           |
| 4     | Discomfort expressed by the majority of the population     | 27-29           |
| 5     | Discomfort expressed by all                               | 29-32           |
| 6     | Stages of medical alarm                                   | >32             |

I.8. Statistical analysis of inference
Statistical inference analysis was carried out to determine the significance of the difference in test parameters between tree species. The tested parameters are decrease in air temperature, decrease in surface temperature, the percentage increase in relative air humidity, the percentage of transmissivity, canopy area, shaded area, and PAI. Statistical analysis of inference was also performed on the results of the analysis of dDI% of each tree species. Statistical analysis of inference used is the analysis of the One-way ANOVA test or the Kruskal-Wallis test (depending on the results of the normality test using Shapiro-Wilk for population data counted below 50 samples and Kolmogorov-Smirnov for population data counted above 50 samples). Tukey's post-hoc analysis was carried out for the results of the significantly different One-way ANOVA analysis and Dunn's post-hoc for the significantly different Kruskal-Wallis analysis results.

3. Results and discussion

I.9. Tree canopy characteristics comparison
Morphological observations showed that P. indicus has an umbrella canopy shape, a Troll (sympodial) tree architecture model, pinnate compound leaf types with disticus leaflets, disticus leaf arrangement, and 7-11 cm leaf size. S. macrophylla has a rounded canopy shape, a Rauh tree architecture model, paripinatus compound leaf type, spiral leaf arrangement, and 5-12 cm leaf size. S. saman has the shape
of umbrella canopy, Leeuwenberg tree architecture model, bipinnate compound leaf types, spiral leaf arrangement, and 15-40 cm leaf size. The characteristic picture of the tree canopy can be seen in Table 2.

| Tree architecture model | Leaf morphology | Canopy shape | Tree species |
|-------------------------|----------------|--------------|--------------|
| Troll model (symphodial) | Pinnate compound leaf with distichous leaflets | Umbrella | *Pannocarpus indicus* |
| Raun model | Pinnate compound leaf | Rounded | *Swietenia macrophylla* |
| Leeuwenberg model | Bipinnate compound leaf | Umbrella | *Samanea saman* |

Table 2: Tree canopy characteristics
The highest average canopy area was owned by *S. saman* (513.44 ± 223.45 m²), followed by *P. indicus* (223.55 ± 123.87 m²) and *S. macrophylla* (108.45 ± 27.12 m²). The area of *S. saman* canopy is significantly different from *S. macrophylla* and *P. indicus*. Graph of average canopy area can be seen in Figure 3. The range of canopies of the three trees can be seen in Table 3.

The area of the canopy of each tree is supported by the architecture of the tree. Trees with plagiotrophic branching will tend to be broader than orthotropic trees [12]. This is because the branching direction of the plagiotrop tree is more lateral than the orthotropic tree. This branching direction is related to the tree architecture model of the three tree species studied. Troll (sympodial) model of *P. indicus* mixed branching (orthotropic on main stem; plagiotropic on branch) [13], Rauh model of *S. macrophylla* directed orthotropic branching [14], and Leeuwenberg model of *S. saman* trending plagiotropic branching [15]. This is consistent with the results of field observations which show that the *S. saman* canopy is wider than *P. indicus* and *S. macrophylla*.

Tree with spreading canopy shape will also have a wider canopy than the rounded canopy shape [4]. The relationship between the shape of the canopy and the tree architecture model has not been described in depth in any research. However, there have been several studies that show a pattern that the shape of the canopy is influenced by the branching direction which clearly can determine the tree architecture model [15].

**Figure 3.** The average canopy area of *P. indicus*, *S. macrophylla* and *S. saman*

| Tree species     | Range of canopy area (m²) | Smallest | Largest |
|------------------|----------------------------|----------|---------|
| Angsana (*P. indicus*) | 89.82                     | 424.35   |
| Mahogany (*S. macrophylla*) | 46.64                     | 137.97   |
| Trembesi (*S. saman*)    | 126.15                    | 893.92   |

1.10. Shaded area comparison

The highest average shaded area is provided by *S. saman* (348.60 ± 50.58 m²), followed by *P. indicus* (128.23 ± 24.25 m²), and *S. macrophylla* (100.15 ± 7.19 m²). The shadow area of *S. saman* is significantly different from *S. macrophylla* and *P. indicus*. Graph of average shadow area can be seen in Figure 4. The shadow of the simulation tree can be seen in Figure 5.
1.11. Plant Area Index (PAI) comparison
PAI from *P. indicus* is 0.84 m$^2$/m$^2$, then for *S. macrophylla* is 1.66 m$^2$/m$^2$, and for *S. saman* is 1.13 m$^2$/m$^2$. The PAI graph of the three trees can be seen in Figure 6. A larger leaf (or leaflets) and denser leaves will have a larger PAI [4]. The arrangement of leaves is influenced by the shape of the canopy. The shape of the rounded canopy tends to be more dense than the shape of the wide canopy. Therefore, *S. macrophylla* has a higher PAI than *P. indicus* and *S. saman*. In addition, larger tree branches will also have larger branch leaf areas so that they have a larger PAI [16]. Therefore *S. saman* has a higher PAI than *P. indicus*. Hemisphere photographic images from the canopy of the three trees can be seen in Figure 7.

![PAI comparison graph](image)

**Figure 6.** PAI of *P. indicus*, *S. macrophylla* and *S. saman*

### 1.12. Microclimate and edaphic condition comparison
The microclimate and edaphic conditions under the tree canopy are quite different. Statistical analysis of inference shows that decreasing air temperature, increasing relative air humidity, and decreasing surface temperature between tree species are significantly different. Meanwhile, transmissivity between tree species did not differ significantly. Analysis of microclimate and edaphic factor inference at the individual level will not reach a significantly different status, but can still provide a description of the
differences in microclimate and edaphic states [4]. New significant results will appear at the level of species observations [17]. Because this research was conducted at the individual level, it can be concluded that the difference in decrease in air temperature, increase in relative air humidity, and decrease in air temperature between species is quite high.

The temperature of the area without tree cover is 33.81 ± 2.32 °C. The air temperature under the canopy of *P. indicus* was 31.53 ± 1.80 °C; under the canopy of *S. macrophylla* is 30.07 ± 2.31 °C; and under the *S. saman* canopy is 30.01 ± 1.84 °C. The highest decrease in air temperature was under the canopy of *S. saman* (3.80 ± 1.21 °C), followed by *S. macrophylla* (3.10 ± 1.94 °C), and *P. indicus* (2.28 ± 1.73 °C). The decrease in air temperature between the three species is significantly different. The graph of air temperature reduction of the three species can be seen in Figure 8.

Relative air humidity in areas without shade trees was 54.69 ± 7.11%. The relative air humidity under the *P. indicus* canopy was 64.06 ± 6.00%; under the canopy of *S. macrophylla* was 56.70 ± 5.43%; and under the *S. saman* canopy is 55.01 ± 5.51%. The highest increase in relative humidity was under the canopy of *S. saman* (13.61 ± 13.34 %), followed by *S. macrophylla* (4.51 ± 6.97 %), and *P. indicus* (3.16 ± 5.70 %). The increase in relative humidity between *S. saman* and the other two species is significantly different. The graph of relative humidity increase in the three species can be seen in Figure 9.

The lowest transmittivity was under the canopy of *S. saman* (17.62 ± 11.91 %), followed by *S. macrophylla* (20.33 ± 17.04 %), and *P. indicus* (22.53 ± 14.63 %). Transmissivity between the three species was not significantly different. The transmissivity graph of the three species can be seen in Figure 10.

The surface temperature in areas without shade trees was 37.29 ± 6.63 °C. The surface temperature under the canopy of *P. indicus* was 34.96 ± 8.74 °C; under the canopy of *S. macrophylla* is 31.65 ± 4.96 °C; and under the *S. saman* canopy is 26.81 ± 1.87 °C. The highest decrease in surface temperature was under the canopy of *S. saman* (10.49 ± 2.84 °C), followed by *S. macrophylla* (5.64 ± 5.11 °C), and *P. indicus* (5.26 ± 4.30 °C). The graph of surface temperature reduction of the three species can be seen in Figure 11.

The observations regarding air temperature with transmissivity are in accordance with the literature which states that if transmissivity decreases, the air temperature will increase [4]. However, the observation of transmissivity does not indicate what should be in the correlation with PAI (the higher the PAI, the lower the transmissivity) [4]. *S. saman* trees have lower transmissivity than *S. Saman* even though *S. Saman*’s PAI is lower than *S. macrophylla*’s PAI. This is probably due to the size of the *S. macrophylla* canopy which is narrower than the *S. saman* canopy so that *S. macrophylla* cannot disperse sunlight from various directions [4]. For *P. indicus* which has the lowest PAI and narrow canopy area, this species has the highest transmissivity and lowest air temperature reduction.
The decrease in surface temperature also has the same case with air temperature. The higher the PAI, the lower the surface temperature. However, the surface temperature in *S. saman* is higher than *S. macrophylla* even though *S. Saman*’s PAI is lower than *S. macrophylla*’s PAI. This is also likely due to the size of *S. saman*’s shadow being wider than *S. macrophylla* has [4].

1.13. DI and dDI% comparison

DI on *P. indicus* is 27.42 (scale 4); on *S. macrophylla* is 26.84 (scale 3); and on *S. saman* is 26.71 (scale 3). The table with the DI scale of each tree type can be seen in Table 4. The value of dDI% on *P. indicus* is $5.35 \pm 4.09^a$ %; on *S. macrophylla* is $7.36 \pm 4.69^b$ %; and *S. saman* on is $7.82 \pm 3.12^b$ %. One-way ANOVA test showed that there was a significant difference in dDI% between tree species ($P = 0.000$). The results of post-hoc analysis between *P. indicus* (0,000) with *S. macrophylla* and *P. indicus* (0,000) with *S. saman* were significantly different. Meanwhile, the results of *S. saman* analysis with *S. macrophylla* did not differ significantly ($P = 0.917$). The dDI% graph can be seen in Figure 12.

![Figure 10. Transmissivity of the three species](image)

![Figure 11. Surface temperature decrease of the three species](image)

![Figure 12. dDI% of the three species](image)

### Table 4. DI of the three species

| Tree species       | DI°C  | Scale | Feeling of discomfort                        |
|--------------------|-------|-------|---------------------------------------------|
| Angsana (*P. indicus*) | 27.42 | 4     | Discomfort expressed by the majority of the population |
| Mahogany (*S. macrophylla*) | 26.84 | 3     | Discomfort expressed by $>50\%$ of the population |
| Trembesi (*S. saman*) | 26.71 | 3     | Discomfort expressed by $>50\%$ of the population |

The discomfort index is positively correlated to air humidity and negatively correlated to air temperature [17]. The *P. indicus* tree has the lowest dDI% because it has the lowest value of air temperature decrease and relative humidity increase. Therefore, the results are in accordance with the literature. *S. macrophylla* trees have a lower dDI% value than *S. saman* despite having a higher PAI. This is probably due to the *S. saman* tree having a much wider canopy so that the light transmissivity in *S. saman* is much lower than *S. macrophylla*. The insignificant One-way ANOVA test result might be caused by the part of the quadrant that was exposed to shadows on *S. macrophylla* [17].
1.14. Cooling effect

Based on the observations above, the effectiveness of cooling is greatly influenced by the canopy characteristics of the trees studied. Trees with denser leaf cover (higher PAI, larger leaves/leaflets, and denser branches) will reduce air and surface temperatures more [4]. Likewise with a broader canopy, the area of shadows formed on trees with wider canopies will be wider as well and eventually will lower the air temperature as well.

The *P. indicus* tree has a drier leaf cover and a narrower canopy area. Therefore the cooling effectiveness of *P. indicus* was the lowest of the three trees studied. *S. saman* trees with moderate leaf lush and wider canopy had the highest effectiveness of the three trees studied. *S. macrophylla* trees with denser leaf and wider canopy have lower cooling effectiveness than *S. saman* and higher than *P. indicus*. Although *S. macrophylla* has a higher PAI than *S. saman*, its effectiveness is lower than *S. saman*. This is probably due to the wide canopy tree species potentially having a wider shaded area when the position of the sun is directly overhead compared to narrow canopy trees thus expanding the cooling area [4].

4. Conclusion

The conclusions obtained from this study were a decrease in air temperature in *P. indicus* by 2.28 °C, in *S. macrophylla* by 3.10 °C, and in *S. saman* by 3.80 °C. The decrease in surface temperature on *P. indicus* was 5.26 °C, on *S. macrophylla* was 5.64 °C, and on *S. saman* was 10.49 °C. Shade trees with the most effective cooling effect are *S. saman* with moderate leaf density and highest canopy area, then *S. macrophylla* with high leaf density arrangement and narrow canopy area, then *P. indicus* with low leaf density with narrow canopy area. Suggestions that can be given for further related research are computer simulation studies to test the cooling effect of trees in different types of roads and site situations, as well as further research for other tree species or trees with different canopy characteristics.

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