THERMAL COMFORT OF GREEN OPEN SPACE AT PT SURABAYA INDUSTRIAL ESTATE RUNGKUT (SIER)

Vidya Nur Trissanti(1)(2), Rachmad Hermawan(1), Yudi Sertiawan(1)(2)

[1] Faculty of Forestry and Environment, IPB University, IPB Darmaga Campus, Bogor District, West Java, 16680, Indonesia
[2] Environmental Research Center, IPB University, IPB Darmaga Campus, Bogor District, West Java, 16680, Indonesia
Email: vidya_trissa@apps.ipb.ac.id; racher67@gmail.com; setiawan.yudi@gmail.com

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ABSTRACT: Industry is an important sector for the development of Surabaya. Industrial existence in Surabaya can absorb 108.803 work force. But that activity can reduce environmental quality. Green open spaces in industrial areas, must provide thermal comfort in industrial areas, but also must provide thermal comfort around the area. This study aims to study carefully about changes in temperature, relative humidity and increase in thermal comfort based on the increase in distance from the center of the green open space. The air temperature and humidity sample are taken at 7.00-8.00 AM, 1.00-2.00 PM and 5.00-6.00 PM inside, the border and outside the green open space. Supporting data are Leaf Area Index (LAI) and vegetation analysis. There are three plots that become the sample location. Changes in temperature and relative humidity have affected the distance from green open spaces. Tree density also affects temperature and relative humidity which creates thermal comfort.

1. INTRODUCTION

The city of Surabaya has main activities, namely services, trade and industry (Regional Regulation of the City of Surabaya 2016) which covers 816 large and medium industries by absorbing 108.803 workers (BPS 2016). Industry is an important sector in development because it expands job opportunities, produces goods and services needed by the community, generate foreign exchange through exports and save foreign exchange by substituting imported products (Napitupulu, 2013).

Regulation of the Minister of Industry of the Republic of Indonesia Number 35 / M-IND / PER / 3/2010 concerning Technical Guidelines for Industrial Estates states that the total area of green open space (GOS) is at least 10% of the total industrial area. Local Regulation of Surabaya City Number 12/2014 concerning Regional Spatial Planning (RSP)/Rencana Tata Ruang Wilayah (RTRW) for the City of Surabaya 2014-2034. Whereas RTH plays a role in environmental sustainability, namely as a regulator of the micro climate, water catchment areas and city aesthetics.

PT. SIER is an industry that has the second dominant area in the city of Surabaya after PT. Margomulyo. Based on the research of Hastuti and Sulistyarso (2012), The current GOS of PT. SIER is unable to absorb the resulting emissions, so it is necessary to increase the area by 7,32 ha. Green open space that is built in industrial areas, besides having to provide thermal comfort in the green open space, it must also provide a thermal comfort effect for the surrounding area.

Thermal comfort is a thermal condition that is felt by humans not by objects, animals, and architecture, but by the environment and objects around the architecture (Surjamanto, 2000). This comfort is influenced by climate (sun / radiation, temperature, air, humidity, and wind speed) and several individual / subjective factors such as clothing, acclimatization, age and sex, obesity level, health level, type of food and drink consumed, and skin color (Talarosha, 2005).

Therefore, to determine the extent of changes in the level of thermal comfort due to the effect of green space, this study was conducted. The purpose of this study was to examine changes in temperature, humidity, and the level of thermal comfort based on the additional distance from the center of green space.

2. METHODOLOGY

2.1 Study Location

This research was conducted in March - May 2018 in the RTH of the PT SIER Area, Rungkut District, Surabaya City, East Java Province (Figure 1).

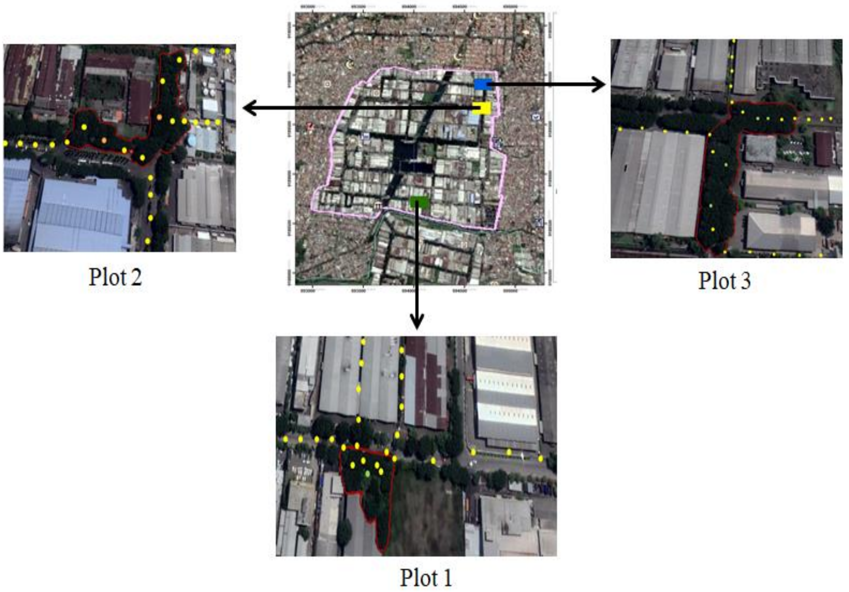

Figure 1 Location of data collection

2.2 Data Collection

The location of the plot is determined by purposive sampling method, namely the sampling technique uses criteria.

2.2.1 Measurement of Air Temperature and Air Humidity

Measurement of temperature and humidity is carried out on each plot, by having 4 transects whose directions have been determined and each transect has a maximum of 7 measurement points that the distance between the points is 25-50 m. Measurements are carried out 3 times (7.00-8.00 AM, 1.00-2.00 PM and 5.00-6.00 PM) in one day with 3 repetitions. Measurements were made using a wet and dry bulb thermometer which is placed 1,5 m from the ground and taken only during sunny weather. In this data collection, marking was also carried out using GPS to obtain the position of the measurement point and to support the need for making a zone map of thermal comfort.

2.2.2 Vegetation Analysis and LAI (Leaf Area Index)

Vegetation analysis use line transect plot method to obtain tree species and stand density data. In each plot a minimum of 5 plots were made which were determined purposively. LAI (Leaf Area Index) data collection was carried out on the three plots. LAI data were taken using the hemispherical photograph technique by placing 5 points on each plot of the observation sample and carried out in the morning or overcast conditions. The position of the DSLR camera and tripod (hemisperical view canopy) is right at a height of ± 1 m above the ground. A fisheye lens mounted on a DSLR camera is pointed north to take an image of the canopy cover by pointing the camera towards the sky (Rich, 1990).

2.2.3 Perceptions of Industrial Estate Managers and Communities

Information on GOS management was obtained through interviews with the Head of GOS Management at PT. SIER, while information related to public perceptions of the role of green open space in creating thermal comfort was explored using a questionnaire to the surrounding community. Determination of respondents in the study using purposive sampling technique, namely the technique of taking respondents by first determining the required criteria.

2.3 Data Analysis

2.3.1 Air Temperature and Humidity

Measurements in the field obtained data on wet bulb temperature and dry bulb temperature at three measurement times. The data is processed to obtain daily average temperature and daily average humidity using the formula according to Handoko *et al*., (1994) as follows:

$$\mathrm{Tr} = ((2\mathrm{T\ morning} + \mathrm{T\ afternoon} + \mathrm{T\ evening}))/4 \tag{1}$$

$$\mathrm{RHr} = ((2\mathrm{RHmorning} + \mathrm{RHafternoon} + \mathrm{RHevening}))/4 \tag{2}$$

Information:
Tr = average daily air temperature (°C)
T = dry bulb temperature (°C)
RHr = average daily air humidity (%)
RH = humidity (%)

Humidity data can be obtained through the formula (Abbott and Tabony, 1985):

$$U = \frac{100\left[\exp\left[1.8096 + \left(\frac{17.2694Tw}{237.3 + Tw}\right)\right] - 7.866 \times 10^{-4} P(T - Tw)\left(1 + \frac{Tw}{610}\right)\right]}{\exp\left[1.8096 + \left(\frac{17.2694T}{237.3 + T}\right)\right]} \tag{3}$$

Information:
U = humidity (%)
T = dry bulb temperature (°C)
Tw = Wet bulb temperature (°C)
P = Pressure (hPa), refers to Table 1.

Tabel 1 Standard pressure

Height (m)	0 – 250	251 - 500	501 - 750	1001 - 1250	1251 - 1500
Pressure (hPa)	998,3	969,0	940,4	912,5	885,2

2.3.2 Thermal Comfort

The comfort index uses the formula according to Nieuwolt and Mc Gregor (1998). Quantitative comfort can be explained through the Temperature Humidity Index (THI), which is an index to determine the effect of heat conditions on human comfort (Effendy *et al.*, 2006).

$$\mathrm{THI} = 0{,}8\,\mathrm{T} + ((\mathrm{RH}\ \mathrm{x}\ \mathrm{T}))/500 \qquad (4)$$

Keterangan:
THI = Temperatue Humidity Index (^{o}C)
T = Air Temperature (^{o}C)
RH = Humidity (%)
The comfort index can be determined by referring to the comfort level criteria associated with the assessment of human respondents (Table 2).

Table 2 Criteria for comfort level

No	Criteria	THI (^{o}C)
1	Comfortable	21-24
2	quite comfortable	25-27
3	Uncomfortable	>27

Emmanuel (2005)

2.3.3 Vegetation Structure and Composition

The data from the results of vegetation analysis were used to determine the stand density and density of species in the green open space. The stand and species density is obtained from calculations using the Kusmana formula (1997), namely:

$$\text{Vegetation Density (ind/ha)} = (\text{Number of a three/pole})/(\text{Total area sampled}) \qquad (5)$$

$$\text{Species Density (species/ha)} = (\text{Number of a species})/(\text{Total area sampled}) \qquad (6)$$

2.3.4 Determination of LAI

LAI data analysis using hemiview 2.1 software. LAI data were processed using a threshold method that was determined manually on the canopy cover image using a standard procedure to maximize the contrast between the leaves and the sky.

2.3.5 Simple Linear Regression Equations

Simple linear regression analysis aims to predict the Y value for a given X value, this model is the simplest regression model which has only one independent variable X (Hijriani *et al.*, 2016). The results were obtained through processing using Microsoft Excel 2010 software which aims to determine the effect of temperature and humidity on a predetermined distance. Linear regression analysis used in the study refers to Mattjik (2013).

$$\tilde{Y}i = \alpha + \beta Xi \quad (7)$$

Information:

$\tilde{Y}i$ = Dependent variable
Xi = Independent variable
α = Intercept / intersection with vertical axes
β = Slope / gradient

2.3.6 Thermal Comfort Zone

The thermal comfort zone is obtained through map making using ArcGIS 10.3. The method used is interpolation with the IDW (Inverse Distance Weighted) technique. The data used are the research location Shapefile, temperature measurement coordinate points, and temperature data.

3. RESULT AND DISCUSSION

3.1 Green Open Space Management

The management of green open space in the SIER area is entrusted to the Parks and Roads Division, the Strategic Business Unit (SBU) Office. The form of management that is carried out is maintenance and monitoring. Its maintenance is in the form of downsizing (pruning branches and crowns), litter cleaning, routine watering every morning and evening which is only done during the dry season. In addition, routine chemical injections are also carried out on trees every year, namely in the spring. The chemicals used are Siputox 5 g and Thiodan. This poison is a pesticide with the active ingredient endosulfan, namely gastric and contact poison insecticides. In this case, the injection method applied by the manager is quite appropriate, because exposure to humans can be through the respiratory route if endosulfan is used by spraying it.

3.2 The Role of Vegetation as Forming Thermal Comfort

The vegetation in the PT SIER area is dominated by the species Angsana (Pterocarpus indicus) which is commonly known as the Sono Tree by the industrial community. According to Sanger *et al*. (2016), vegetation has a very close relationship to the microclimate. Ecologically trees can help improve air quality by absorbing water and air pollutants. Table 3 shows the density based on the structure found at the data collection location.

Table 3 Density of plan species

Plot	Species name	Species density	
		tree	pole
1	*Ficus elastic*	25	0
	Pterocarpus indicus	92	8
	Ficus benjamina	50	0
2	*Acacia auriculiformis*	4	0
	Pterocarpus indicus	139	0
3	*Pterocarpus indicus*	104	0

Based on the plant species found, 2 families were identified, namely Fabaceae and Moraceae. According to Lewis *et al*. (2005) explained that the legume family is a major component of the world's vegetation and is often found in marginal lands because of its ability to fix nitrogen from the atmosphere through root nodules. Therefore, *Pterocarpus indicus* and *Acacia auriculiformis* are grown in industrial areas with marginal land.

Table 4 Vegetation density

Plot	Density (ind/ha)	
	Tree	Pole
1	167	8
2	143	0
3	71	0

The tree density in plot 1 is 167 ind / ha (Table 4) is denser than plots 2 and 3. This indicates that plot 1 has a higher power than other plots in absorbing pollution and creating better micro-climatic conditions, so that thermal comfort can be felt.

Table 5 LAI analysis result

Plot	LAI average	LAI range
1	2,3	1,60-4,26
2	2,1	1,23-2,59
3	2,1	1,02-2,88

The LAI values in the three plots are in the range 1,02-4,26 with different mean LAI for each plot (Table 5). The lowest and highest average LAI, respectively, are found in plots 2 & 3 and plot 1. The condition of the canopy cover in the plot is illustrated by the high and low average values of the LAI.

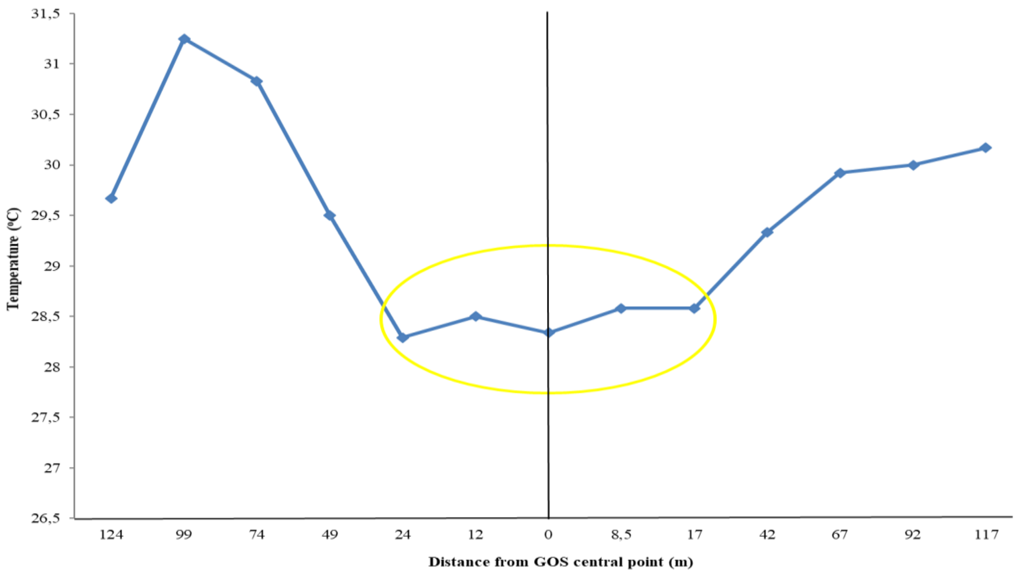

Figure 2 Average temperature of plot 1 (T2-T3); (Note: T = Transect)

In Figure 2, the highest average temperature reaches 33,5 ^{o}C, this is in accordance with Wijaya (2007) in Santoso (2012) that the maximum air temperature in Surabaya can reach 36,4 ^{o}C. Figure 2 shows that the farther the measurement point is from the plot (yellow polygon), the higher the temperature.

3.3 Effect of Distance on Temperature and Humidity of green open space

The simple linear regression results between distance and temperature obtained indicate that the variables have an influence on each other. However, this is not the case with plot 2, the P-value number at the distance has a real level of more than 0,05 (Table 6), so it can be stated that the distance does not affect the temperature in plot 2. This happens the opposite in plots 1 and 3 which means that the distance the temperature measurement point or standing position is from plots 1 and 3, the more influential the temperature is.

Table 6 ANOVA of temperature effect on distance

Plot	*P-value*	Equation
1	0,03421	Y = 28,47 + 0,014 X
2	0,360921	Y = 30,68 + 0,004 X
3	0,004069	Y = 29,29 + 0,016 X

This is inversely proportional to the effect of distance and humidity. The simple linear regression results on plot 2 show that the P-value number has a real level of less than 0.05 (Table 7), while plots 1 and 3 show the opposite results.

Table 7 ANOVA of humidity effect on distance

Plot	*P-value*	Equation
1	0,384037	Y = 65,26 + 0,022 X
2	0,098631	Y = 77,82 + 0,016 X
3	0,139617	Y = 76,63 + 0,019 X

The difference in results between plot 2 and plot 1 and 3 is influenced by factors around the temperature measurement point. On plot 2 transects 3 and 4 outside the plot there are trees that are used as traffic barriers. Meanwhile, on transects 1 and 2 outside the plot, only 3 temperature measurement points were obtained, with a distance of less than 20 m.

3.4 Thermal Comfort Zone

The temperature comfort index (THI) in Figure 3 shows that only plot 1 has a location for measuring green open space which is included in the criteria as quite comfortable, while locations on the border and outside of green open space are included in the uncomfortable criteria. The elevated air temperature and drier air conditions over the open area causes the highest THI value, as well as showing the most uncomfortable open areas (Saputro *et al*., 2010).

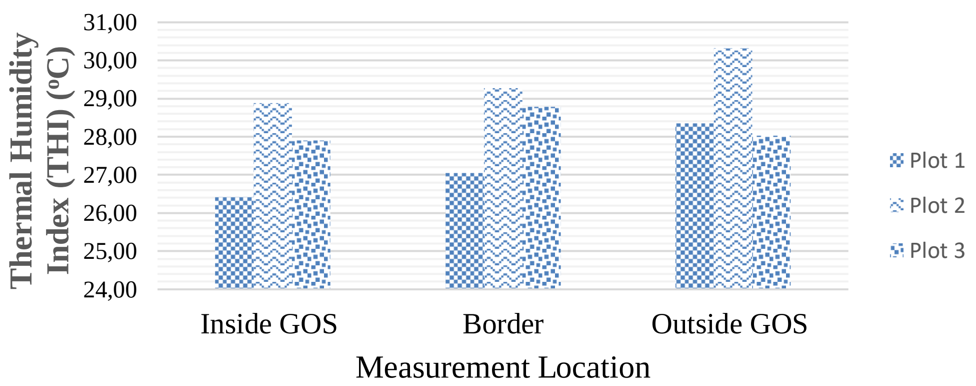

Figure 3 Temperature comfort index

The results showed that the temperature trend was lower inside the GOS than outside the GOS (Figure 4). The air temperature in vegetated areas is more comfortable than in non-vegetated areas, because the leaves on trees can intercept, reflect, absorb and transmit sunlight (Sanger *et al*., 2016).

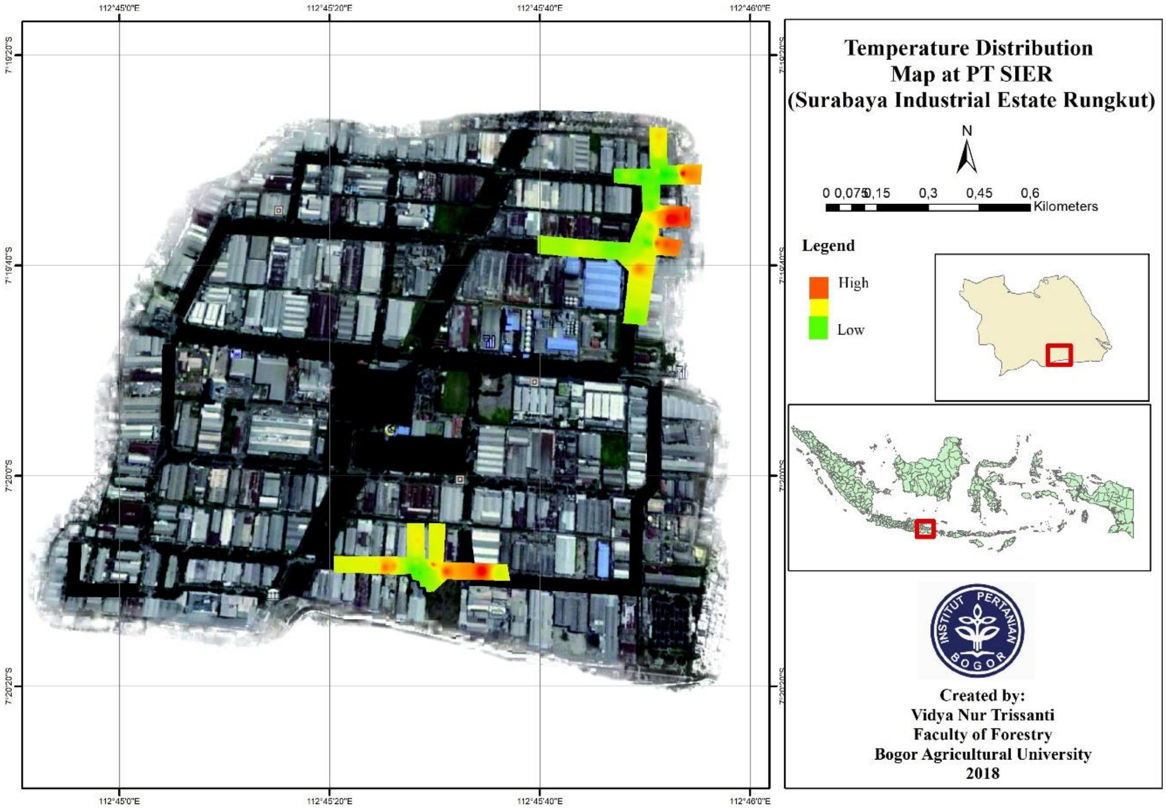

Figure 4 Thermal comfort zone

3.5 Public Perception

The perception of the industrial community states that 58% feel comfortable (Figure 5) when they are in the PT SIER area. Comfortable in this case means that the community feels that the condition of the area does not interfere with their activities, but it does not rule out that there are comfortable conditions expected. This hope can be seen from percentage figure which stated very comfortable and uncomfortable.

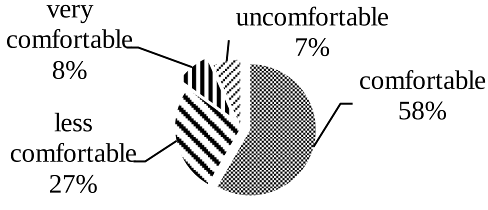

Figure 5 Percentage of comfort in the PT SIER area

3.6 Implications of Research Results in GOS Development

SIER provides direct benefits, namely as a support for the economy of the surrounding community, while indirect benefits are as a micro climate. The benefits of green open space that are expected by industrial area communities are as many as 24 hopes for reducing air pollution, 15 hopes for beauty and 13 hopes for creating a comfortable area. Apart from that, based on direct observations, green open space which was dominated by Pterocarpus indicus, the condition of the individual trees was quite bad. This affects the absorption of these trees to CO_2.

Therefore, the streamlining carried out by the manager is appropriate, but it would be even better if the tree health condition checks could be implemented. The absorption capacity of trees to CO_2 is also influenced by their species, so it is necessary to select tree species for the PT SIER area.

4. CONCLUSIONS AND SUGGESTIONS

4.1 Conclusions

Temperature and humidity are affected by distance from green open space. This is explained in the results of the simple linear regression between temperature and distance which show that plots 1 and 3 have a real level value of less than 0.05. The presence of vegetation also plays a role in changes in temperature and humidity, the higher the dense, the lower the temperature and the ability of green open space to absorb pollution better, thus increasing thermal comfort at PT SIER.

4.2 Suggestions

The tree species found in the PT SIER area are dominated by Pterocarpus indicus, while many other benefits are expected. Therefore, species diversity is highly recommended, especially in species with high CO2 absorption. Suggestions for a minimum width of green open space equal to or greater than 40 m, with a minimum density of equal to or more than 167 individuals per hectare and a thicket supported by a tall tree canopy.

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