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# Heat Stress Analysis Using the Discomfort Index Method: Impact on Macro Environmental in Yogyakarta

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**ABSTRACT**

A growing urban development pattern can have both positive and negative impacts. One of them is the thermal discomfort in the form of heat stress. Heat stress is the maximum condition of the human body to receive the heat exposure to various activities. This study analyzed the thermal comfort in Yogyakarta City based on the Discomfort Index (DI) method. The DI method is commonly used in tropical climates using the parameters that include average air temperature and humidity. The data consists of secondary data obtained from Geophysics Station Gamping in 2004–2020 and Climatology Station Mlati in 2017–2020. The result of DI indicated that the highest value occurred in the wet moon climate type in April, with 25.63 °C. Therefore, the conditions showed that more than 50% of people in the city of Yogyakarta fall into an uncomfortable category with an average index of 24.97 °C, which can lead to heat stress. Environmental engineering can be employed to decrease the heat stress potential and improve the thermal comfort for Yogyakarta's urban community, which is public and private open space, plant road shade vegetation, implement a green façade (vertical garden), as well as improve people's living behavior and use appropriate clothing.

**Keywords:** discomfort index, environmental assessment, heat stress, impact heat stress, thermal comfort, Yogyakarta

## INTRODUCTION

With the development of the times, climate change has been widely discussed in all parts of the world. This issue does not necessarily occur without a causal factor. The factors that can affect *climate* and thermal conditions are often referred to as climate components and variability. Siami (2013) mentioned the climate components, which include temperature, humidity, rainfall, and wind speed.

The phenomenon of climate change has an impact on Indonesia. Indonesia is an archipelagic country that is dominated by small to large islands. One of the islands that are quite large and relatively densely populated is Java. An area on the island of Java that is quite famous is Yogyakarta, which is familiarly called the city of students. As a student city, Yogyakarta is certainly a densely populated area, both by local residents and immigrants. This has been conveyed by the Central Statistics Agency (2019) that the data shows the total population of Yogyakarta City is 431,939 people.

Yogyakarta is a medium-sized and densely populated city, so it has experienced significant changes in climatic and thermal conditions. Therefore, it is important to study the changes in climatic and thermal conditions due to the increasing air temperature in densely populated urban areas, such as Yogyakarta City. The conditions like this can create a lack of environmental comfort for the community (Fawzi, 2013). The discomfort is in urban heat stress, which can cause economic and environmental disturbances, fatigue, dehydration, as well as increased heart

rate and body temperature. On the basis of the problems that occur in urban areas, the analysis of climate change in urban areas or urban heat stress can be done with a simple approach that is often used to determine the outdoor thermal comfort, including the Temperature Humidity Index (THI), Discomfort Index (DI), and Comfort. Index (CI) (Siami, 2013).

The method used in this study is the Discomfort Index (DI). The DI method was chosen, because it is important to identify the category of climate comfort and conduct forecasts of thermal conditions (Xu, et al., 2017). In addition, the use of the DI method is relatively simple by forecasting the level of discomfort using a combination of temperature and relative humidity data (Epstein, 2006). In Indonesia, DI has been used as an index of human discomfort to heat in urban and densely populated areas such as Jakarta (Wati, 2018) and Banda Aceh (Siregar, 2020). Therefore, the city of Yogyakarta was chosen as the research location, because it is an area affected by urbanization and most densely populated, compared to other districts in the Special Region of Yogyakarta Province.

This research is important, because every human being has a different comfort zone depending on the physical, psychological, and pleasure factors, as well as activities of that person (Any, 2018). When the research results in the study area show a value that exceeds the standard, it is necessary to carry out environmental engineering to restore the comfortable climatic conditions of the area. However, if the results of research in the study area meet the standards of climate comfort, then environmental engineering does not need to be carried out; instead the urban structure has to be maintained so that the climatic conditions remain stable.

## DATA AND METHOD

### Study area and data collection

The research was carried out in the city of Yogyakarta using secondary data sourced from the Yogyakarta Gamping Geophysics Station and the Yogyakarta Mlati Climatology Station. The data period used is from January 2004 to December 2020. The data taken for the assessment of climate comfort are temperature and relative humidity. This refers to the specific data used for the calculation of the Discomfort Index (DI) method, namely air temperature and relative humidity (Din et al., 2014).

### Measurement of discomfort index parameters

The Discomfort Index (DI) method is a method used to identify the level of thermal comfort in an area (Epstein, 2006). The continuity between heat stress and DI can be obtained by the following equation:

$$DI = T - \{0.55 \cdot (1 - 0.01\,RH) \cdot (T - 14.50)\} \quad (1)$$

where: $DI$ – discomfort index (°C),
$T$ – average air temperature (°C),
$RH$ – relative humidity (%).

### Analysis of the relationship between variables

The methods used to analyze the relationship between variables include the linear regression method and the Spearman Rank method. According to Kurniawan (2016), regression is a test tool to measure the relationship between two or more variables expressed in the form of a relationship/ function. The following is a simple linear regression equation according to Yuliara (2016).

$$Y = a + bx \quad (2)$$

where: $Y$ – dependent variable or regression line (response variable),
$a$ – constant (intercept),
$b$ – the intersection with the vertical axis regression constant (slope),
$X$ – independent variable (predictor).

In addition to using the linear regression method, the determination of the relationship between variables in this study also uses

**Table 1.** Climate comfort category based on discomfort index value (Siami & Ramadhani, 2019)

| DI range (°C) | Thermal comfort level |
|---|---|
| DI < 21 | No discomfort |
| 21 ≤ DI < 24 | Less than 50% of the population feels discomfort |
| 24 ≤ DI < 27 | More than 50% of the population feels discomfort |
| 27 ≤ DI < 29 | Most of population suffers discomfort |
| 29 ≤ DI < 32 | Everyone feels severe stress |
| DI ≥ 32 | State of medical emergency |

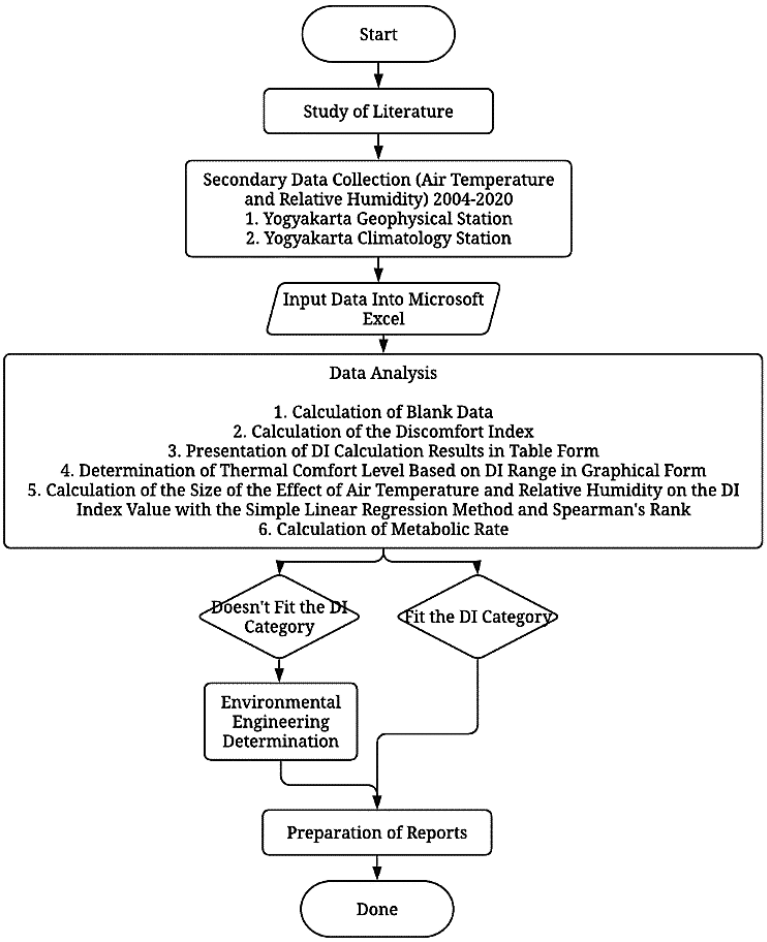


**Figure 1.** Flowchart of heat stress analysis research methods in Yogyakarta City using the Discomfort Index method

Spearman Rank correlation analysis. Spearman's rank is a statistical test tool used to test the allegations about the existence of a relationship between variables if the data is on an ordinal scale (rank) with the following formula.

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_1^2}{n(n^2-1)} \quad (3)$$

**Table 2.** Coefficient range based on rank spearman method (Sudarno, 2018)

| R interval | Meaning of R |
|---|---|
| -1 | Perfect negative |
| -1 < r < -0.9 | Strong negative |
| -0.9 < r < -0.5 | Moderate negative |
| -0.5 < r < 0 | Weak negative |
| 0 | Uncorrelated |
| 0 < r < 0.5 | Weak positive |
| 0.5 < r < 0.9 | Moderate positive |
| 0.9 < r < 1 | Strong positive |
| 1 | Perfect positive |

where: $r_s$ – rank Spearman,
$n$ – number of cases or samples,
$d$ – difference in ranking between variables $X$ and $Y$ for each subject,
6 – constant number.

## Risk categorization based on DI index value and calculation of metabolic rate

Metabolic rate was calculated using standardized, average body weight data grouped by the age category. The average weight of the Indonesian people can be seen in Table 3.

After obtaining the weight data, the data is then used to calculate a person's metabolic rate by referring to the formula contained in Minister of Health Regulation No. 70 of 2016:

$$Metabolic\ Rate_{(correction)} = \frac{Worker\ weight\ (kg)}{70\ (kg)} \times \times\ metabolic\ rate_{(observation)} \quad (4)$$

**Table 3.** Average weight of men and women by age category (Sri Muljati et al., 2016)

| Group | Age | Weight | |
|---|---|---|---|
| | | Men | Women |
| 1 | 15–24 | 52.4 | 48.5 |
| 2 | 25–30 | 60.9 | 56.2 |
| 3 | 31–34 | 62.9 | 58.6 |
| 4 | 35–44 | 62.9 | 58.6 |
| 5 | 45–54 | 61.9 | 57.7 |
| 6 | 55–59 | 60.9 | 56.8 |
| 7 | 60–64 | 60.9 | 56.8 |
| 8 | 65+ | 54.4 | 46.6 |

According to the results obtained, further categorization is carried out from the results of the calculation of the metabolic rate according to the formula above. On the basis of the results of the categorization, it can be seen that the age group with the highest potential for heat stress is known.

## RESULT AND DISCUSSION

### Data analysis based on the discomfort index method

On the basis of the data obtained from 2 (two) stations, the climatic conditions in Yogyakarta City during 2004–2020 (17 years) had a minimum air temperature of 22.61 °C, a maximum air temperature of 31.60 °C, an average air temperature of 26.12 °C, and average humidity is 82.14%. In addition to these parameters, rainfall is also a factor in determining thermal comfort. However, the rainfall data is only used to determine the wet months, humid months, and dry months.

The highest air temperature in the city of Yogyakarta occurs in October, and the lowest air temperature occurs in August. The increase in the DI value occurred in March–April and August–November. The air temperature value is directly proportional to the DI value. If the air temperature increases, the DI value will increase as well. In addition to the air temperature data, the relative humidity data is also needed to determine the value of the DI index. After calculating and processing data, the highest humidity results in Yogyakarta City occurred in February, and the lowest humidity was found in September.

On the basis of the previous graph, the value of the Discomfort Index in Yogyakarta City forms a Bimodal – Shoulder Peaks pattern (Hasanah et al., 2020). In the graph above, the peak DI value in Yogyakarta City occurred in April and November, with the highest DI value in April of 25.66 °C. On the basis of Figure 2, peak season, the average air temperature value is in October and November, with the highest average air temperature value in October of 26.89 °C. Then, based on Figure 3, the peak season of relative humidity values is in February and March, with the highest relative humidity value in February of 85.26%.

On the basis of the results of the linear regression calculation, the weight of the air temperature in the city of Yogyakarta is 0.9215, while the relative humidity is only 0.3298. Then, based on Spearman's formula, it was found that air temperature has a correlation value of 0.92 (strongly positive) while humidity has a correlation value of 0.38 (weakly positive). Therefore, the air temperature has a greater influence in determining the DI index, while humidity has a smaller effect on the DI value.

### Hazard category analysis based on the discomfort index method

Determination of the level of climate comfort for humans using the DI method produces

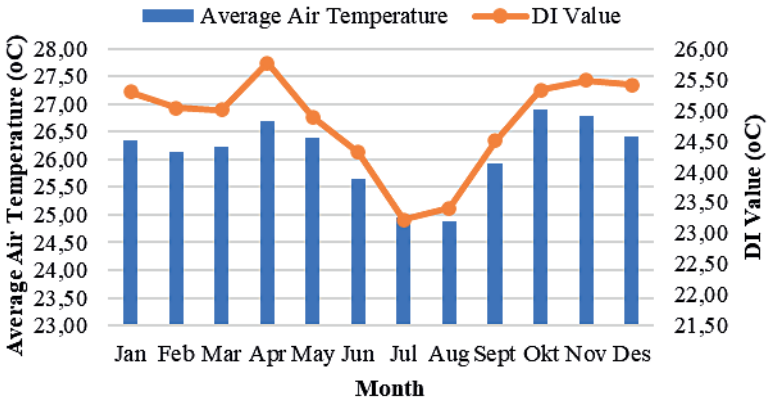


**Figure 2.** Relationship between average air temperature and DI index value in Yogyakarta City

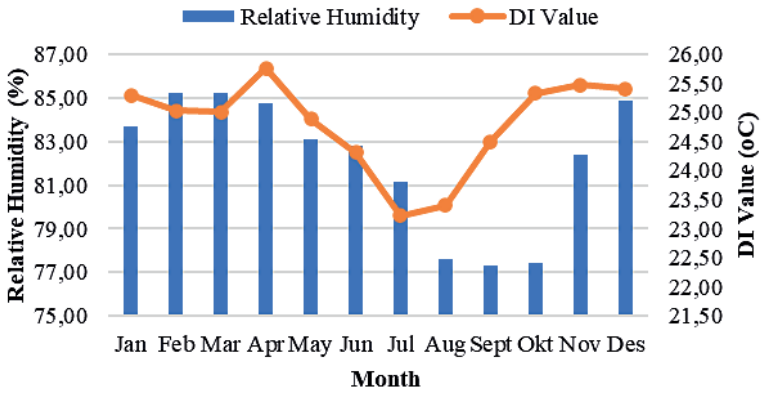


**Figure 3.** Relationship between relative humidity and DI index value in Yogyakarta City

varying values. The DI value was obtained from daily data of air temperature (°C) and relative humidity (%). The daily values of each parameter are averaged into monthly values.

On the basis of SNI: 03-6572-2001, the ideal air temperature conditions for tropical areas, especially for Indonesians are divided into three categories, namely cool comfortable (20.8–22.8 °C), optimal comfort (22.8–25.8 °C), and warm comfortable (25.8–27.1 °C). According to the DI value in Figure 6, the comfortable category occurs in July and August, while the uncomfortable category occurs in September – June. The average DI value in Yogyakarta is 24.97 °C, which is included in the optimal comfort category. However, overall from the results of monthly calculations, it can be concluded that most (more than 50%) of the people of Yogyakarta City feel uncomfortable with the existing thermal conditions. The index values that do not meet or exceed the threshold can cause discomfort and trigger heat stress in the community when outdoors.

Climatic conditions can influence heat stress in an area. When correlated with thermal comfort, the climatic conditions in Yogyakarta City show varying results. According to the classification of climate types from Oldeman (2014), climatic conditions in the city of Yogyakarta fall into the category of optimal comfort in all months, both wet months, humid months, and dry months. On the basis of the existing climate type, the thermal comfort in Yogyakarta City, which shows optimal conditions, is included in the dry month climate type category, more precisely in July with a DI value of 23.87 °C and in August with a DI value of 23.61 °C.

According to ISO 8996:2004, outdoor activities or activities can involve employment training, sports activities, special jobs, and so on. Outdoor activities are closely related to a person's metabolic condition. Metabolic rate has an important role in determining the comfort level of heat exposure in the community environment. The climate conditions that tend to be hot and high

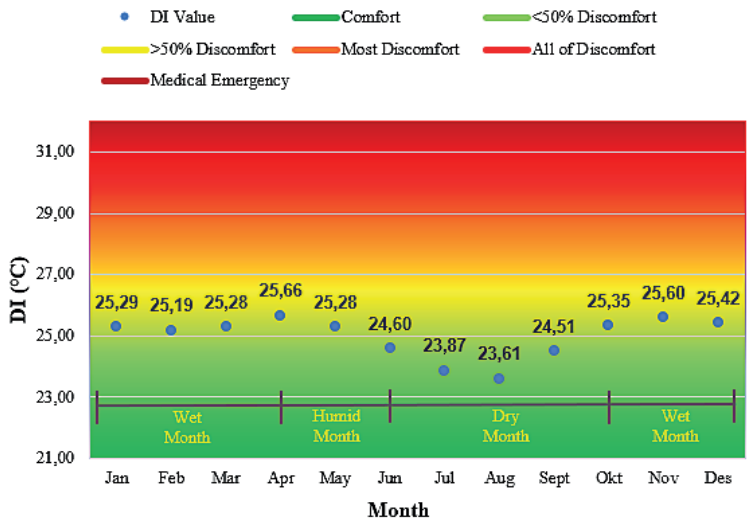


**Figure 4.** Value of climate comfort level in Yogyakarta City in 2004 – 2020 Based on the DI Method

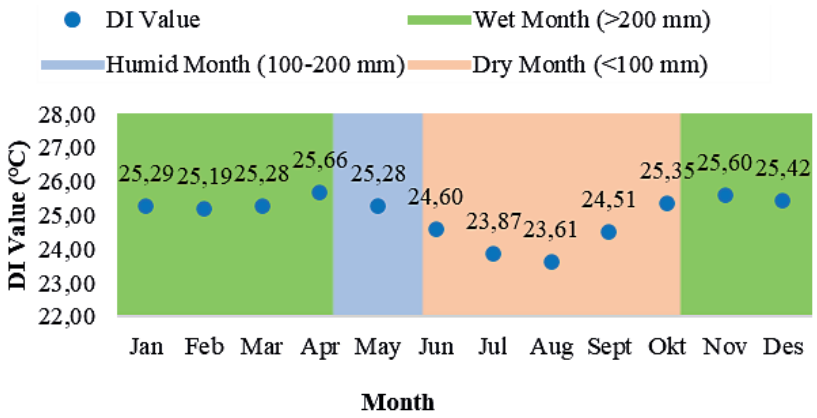


**Figure 5.** Climate type relationship with DI index value in Yogyakarta City

**Table 4.** Metabolic rate based on ISO 8996:2004

| No | Age (year) | Metabolic rate | |
|---|---|---|---|
| | | Men | Women |
| 1 | 15–24 | Mild and heavy | Mild, medium, and heavy |
| 2 | 25–30 | Mild, medium, and heavy | Break, mild, medium, and heavy |
| 3 | 31–34 | Break, mild, medium, and heavy | Break, mild, medium, and heavy |
| 4 | 35–44 | Break, mild, medium, and heavy | Break, mild, medium, and heavy |
| 5 | 45–54 | Mild, medium, and heavy | Break, mild, medium, and heavy |
| 6 | 55–59 | Mild, medium, and heavy | Break, mild, medium, and heavy |
| 7 | 60–64 | Mild, medium, and heavy | Break, mild, medium, and heavy |
| 8 | > 65 | Mild, medium, and heavy | Mild, medium, and heavy |

muscle work activities can potentially cause heat stress. According to Minister of Health Regulation No. 70 of 2016, the metabolic rate is divided into five categories, as shown in Table 4, the results of processing the average weight data based on ISO 8996:2004.

On the basis of the table above, with the condition of the metabolic rate, people can experience thermal discomfort and heat stress. This discomfort is caused by the increase in air temperature in the city of Yogyakarta in certain months if it is associated with the relatively high air temperature in Yogyakarta, the possibility of heat stress in the community when outdoors is also higher.

Heat stress experienced continuously can cause several impacts on the body, such as a lack of comfort for the community (Fawzi, 2013), as well as urban heat stress, which can cause physiological disorders such as fatigue, dehydration, increased heart rate, and body temperature, economic and social disturbances (Fawzi, 2013; Taslim et al., 2015). Environment an increase in skin temperature and core body temperature (Anjani et al., 2013). In addition, it can also cause heat exhaustion that occurs due to hot temperatures in a relatively long period, causing a large amount of fluid loss in the body (Sahna, 2019).

## Environmental engineering in the Yogyakarta City

The environmental problems faced by the city of Yogyakarta are the increase in air temperature and humidity and the problem of air pollution. The level of air pollution in the city of Yogyakarta is indicated by high levels of $CO_2$, which is 559.54 ppm, and this value has exceeded the threshold set by the World Bank, which is 381 ppm (Astuti et al., 2013). Therefore, it is necessary to carry out environmental engineering to solve these problems. The environmental engineering recommendations include intensifying Green Open Space (RTH), planting road shade trees (tree vegetation), implementing green facades (vertical gardens) (Haryanto et al., 2019), implementing roof garden (Kinasih, 2013), and improving people's behavior.

The creation of Green Open Space (RTH) has been regulated in Law No. 26 of 2007 concerning Spatial Planning, of which there are two types of green open space, namely public green open space and private green open space. The minimum area of green open space is 30% of the area, which is divided into 20% public green open space and 10% private green open space. According to the Head of the RTHP (Public Green Open Space) Division of the Yogyakarta City Environment Service, the public green open space is only 8% and private green open space is 15% of the total area, so the current total green open space (in 2020) is still 23%.

According to Zayadi (2017), trees play a very important role in preventing air pollution and maintaining the global climate balance. The shade from the trees also serves to reduce evaporation (Julismin, 2013). Aside from providing shade, tree planting is also carried out to benefit the community, the including aesthetic and comfort aspects. The types of plants with round and open crowns can effectively reduce the temperature by 2 °C and relative humidity by 5% (Femy et al., 2014). The selection of plant species should be conducted paying attention to the plant's function and the requirements for plant placement (Al-Hakim, 2019). The characteristics of the trees used as shade can be seen in Table 5.

On the basis of the previously mentioned characteristics of the shade trees, the recommendations for possible vegetation to be used to fulfill green open space include, *Angsana* (Pterocarpus indicus), *Mahoni* (Swietenia macrophylla), *Pucuk Merah* (Oleina syzygium), and *Trambesi* (Albizia saman) (Siwi, 2020; Zayadi, 2017).

As for the existing public green open space and private green open space, intensification or maintenance of the current public and private green open space can also be carried out. According to the Directorate General of Highways, the maintenance of public green open space and road shade vegetation can be in the form of regular watering of plants, screening or weeding, pruning, fertilizing, eradicating pests and diseases, and replacing plants or replanting. Meanwhile, the maintenance of private green open space can be carried out by the community independently, according to the characteristics of the plant.

**Table 5.** The characteristics of the trees used as shade (Directorate General of Clan Development, 2010; Sari, 2019)

| No. | Characteristic of the tree |
|---|---|
| 1 | Total height ranges from 3–15 m |
| 2 | Big and wide canopy |
| 3 | Spreading, dome, globular, and irregular header shapes |
| 4 | The diameter of the crown is greater than 0.5 m |
| 5 | Plant height 2–3 m from the root surface boundary |
| 6 | Minimum planting distance 4 m |
| 7 | Already has 3–5 branches |

Other than planting of road shade trees, the environmental engineering to reduce the potential for heat stress in the city of Yogyakarta can be done by implementing a vertical garden. A vertical garden is a form of green building that is suitable for application in densely populated cities such as Yogyakarta City. A vertical garden can provide benefits in decreasing the wall surface temperature up to 7.03 °C (Wong et al., 2010), 10 °C for 60 °C, and 5 °C for 30 °C (Widiastuti et al., 2014). In addition, the presence of shading by the green facade can reduce the cooling energy by up to 23% (Bass & Baskaran, 2013). Vertical gardens can be applied in buildings or in the area of a private house. The plants that can be used for vertical gardens include *Markisa* (Passiflora edulis), Morning Glory (Ipomea), *Air Mata Pengantin* (Antigonon), Flame of Irian (Mucuna Benetti), and *Sirih Belanda* (Scindapsus aureus) (Laloan et al., 2015).

Other form of environmental engineering that can be applied in the city of Yogyakarta to reduce the potential for heat stress is a roof garden (green roof) which is a garden or greenery on the roof of a building that has open space (Kinasih, 2013). Roof gardens can also be an alternative for the areas that have limited land, such as the city of Yogyakarta. The benefits of roof garden are that it can reduce the effect of urban heat island and air pollution. The study conducted by Arisanti et al. (2010) stated that a good recommendation for plants to be used for making a roof garden is a tree with leaves that have trichomes (hair) and a waxy coating, such as *Pohon Kupu-Kupu* (*Bauhinia purpurea), Pohon Dadap Merah* (Erythrina christagalli), and *Pohon Palem Ekor Tupai* (Wodyetia bifurcata).

Another alternative to minimize the impact that occurs due to heat stress in the city of Yogyakarta is to improve people's behavior. This can involve wearing clothes that fit the conditions and meet the needs of fluids that enter the body. The lack of fluids in the body can cause several disorders, such as dehydration, easy sleepiness,

fatigue, and difficulty concentrating (Lufyana, 2020; Mujib & Pramono, 2020). The fluid needs of each person are different, depending on physical conditions, age, weight, diet, and climatic conditions (temperature) (Briawan et al., 2011). For the people who work in hot environments, it is recommended to consume 2.8 liters of water / day, while for workers with non-hot (stable) environmental temperatures, it is recommended to consume at least 1.9 liters of water/day (Tarwiyanti et al., 2020). Therefore, there is a need for public awareness to meet the needs of fluids by bringing personal drinking water using a drinking bottle and the Yogyakarta City government also needs to provide drinking water in public areas.

Improvement of community behavior can also be done by using appropriate clothing. Clothing has a function as a barrier to evaporation and an inhibitor of body heat loss by reducing the air circulation near the skin (Pascoe et al., 2009). The higher the water vapor permeability of clothing, the higher its ability to absorb sweat. According to Jannah (2019), cotton-based clothing is characterized greater water absorption than synthetic-based clothing. Therefore, the highwater absorption capacity of cotton clothing is expected to reduce body temperature when performing outdoor activities such as employment training, sports activities, special jobs, and so on. The ability of sweat absorption in clothing can reduce core and skin temperature, which can minimize the occurrence of heat strain (Muflichatun, 2006).

## CONCLUSIONS

On the basis of on the research results and discussion of heat stress in the city of Yogyakarta, several conclusions can be formulated:

1. The highest DI index value occurs in the wet month climate type is on April with an index value of 25.63 °C. This condition can cause heat stress in Yogyakarta City.
2. The condition of thermal comfort in Yogyakarta City based on the calculations performed using the Discomfort Index method shows that more than 50% of the people of Yogyakarta City included in the uncomfortable category, with an average index value of 24.97 °C.
3. Environmental engineering recommended in Yogyakarta City is Green Open Space (public and private). The existing public green open space and private green open space will be regularly maintained. One example of a tree that can be used for public and private green open space is the *Pohon Angsana* (Pterocarpus indicus). In addition, the form of environmental engineering that can be implemented is planting of trees as road shade, application of green façade (vertical garden), application of roof garden, and improvement of people's living behavior.

### Acknowledgements

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