Measuring thermal comfort in a built environment: A case study in a Central Business District, Jakarta

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Abstract. It is obvious that an increase in the built environment in many major cities is not balanced with the availability of green open space causing environmental problems such as an increase in accumulative city temperature (e.g., urban heat island). Therefore, many initiatives have been implemented to integrate more green open spaces in an effort to deal with increasing air temperatures in cities, but baseline information on the positive impact on the built environment is still lacking. The objective of this study was to identify thermal comfort in green open spaces and built environments in a central business district. Basic microclimate variables and thermal humidity index (THI) were analyzed in three sites representing the district by also considering the distribution of green open spaces, buildings, and traffics. Results showed that in the morning, the average temperature at the three sampling points have a low temperature (T=27.77-28.50°C) with high humidity (RH=77.21-80.97%) and the THI value is quite comfortable (THI=26.72-27.22°C), while during the daytime, the temperature conditions at the three sites have high temperatures (T=31.37-33.04°C) with low humidity (RH=63.30-65.80%) and high THI values (THI=29.22-30.62°C). In the afternoon, the temperature conditions at the three sample points have a high enough temperature (T=29.70-30.61°C) and high humidity (RH=67.36-71.02%), while the THI value is only in point two, which is close to the quite comfortable category (THI=27.98°C), while other locations have a value THI=28.60°C and 28.62°C. The results of this study mark the presence of green open space with the trees in the district has a positive effect on decreasing air temperature and hence increasing environmental comfort. The addition and enrichment of trees can be done to increase thermal comfort in the built environment.

1. Introduction

The increase in air temperature is an environmental problem, especially in urban areas that impact human comfort. The increase of global air temperature in the big cities is mostly caused by rapid
infrastructure developments, the expansion of urban areas, and the density in urban activities, which lead to a decrease in green space [1]. The infrastructure of roads, settlements, and skyscrapers can lead to an increase in air temperature due to the reflection of the sun's heat radiation. High urban activities such as traffic, high energy consumption, and other industrial activities can increase accumulative city temperature and cause air pollution. Air pollution in the form of exhaust gases from various activities being emitted into the atmosphere will cause the greenhouse effect, thereby escalating the temperature of the environment, which leads to being an urban heat island. The main factor of urban heat islands is the change in the land surface which has vegetated areas into solid material and buildings so that it increases air temperature and decreases airflow, which can influence the local weather and climate [2].

Urban rapid development occurs in various cities in Indonesia, including Jakarta as the capital city. Jakarta covers 664.01 km² total area with 15,906 people/km² population density and has a population growth rate in the last ten years of 0.92 percent [3]. The dense population and high activities have led to the growth of buildings in the central business activities. In fact, the construction development of this city is not followed by the provision of green space. The regulation of government decree number 26 in 2007 mentions that green space needs to be a minimum of 30% of the city area. In Jakarta, the decrease of green space in 2007 has reached 33,467 ha and decreased in 2013 to 10,008 ha. Nowadays, it is almost 9% green space in the total area of Jakarta [4].

Central Business District (CBD) area is an economic center area in Jakarta that integrates building areas with green open space to maintain environmental condition's sustainability. The central business district has allocated around 13 ha or about 28.8% as green open space, including a road network to maximize the function of green open space as well as to provide environmental comfort. Environmental human comfort related to green open spaces is divided into four types, i.e. spatial comfort, visual comfort, audial comfort, and thermal comfort [5]. Green open space also takes part in the environment to advance the condition of groundwater, preventing floods, reducing air pollution, and manipulating microclimate to reduce air temperature [6]. Green open space in urban areas is needed to absorb carbon dioxide from air pollution, produce oxygen, absorb and store water so that it has a positive impact on the resilience of the city to climate change [7]. Green open space ability, effectiveness, and efficiency in micro-climate manipulation contribute to thermal comfort in urban areas still need to be studied. The objective of this study was to analyze thermal comfort in green open spaces and built environments in a central business district.

2. Method

2.1. Time and location of the research
This research was conducted from March – April 2021. The research location was in the Central Business District, South Jakarta.

2.2. Materials and equipment
Materials and equipment used in this research are thermometer dry and wet and tripod.

2.3. Data collection and processing
The thermal comfort data were collected from green open spaces and the built environment. Air temperature and humidity were measured and analyzed in 3 (three) sites representing the area with a specific condition. Site 1 was a built environment directly in border to the outside of the CBD area with a total of about 1.92 ha. Site 2 was a green open space in the area and surrounded by a building with a total area of about 1.77 ha. While site 3 was a built environment located in the area of CBD with a total 1.73 ha.

The measurement point at site 1 was carried on a sidewalk that was located 1 – 5 meters from the highway and entrance point to the CBD area. There are palm vegetation and decorative plants without tree vegetation on this site. On-site 2, the measurement point was located at the CBD sidewalk right under tree vegetation. Environmental on site 2 surrounded by parking lots and buildings with different
heights. Site 2 is the location with the greatest number of trees in a large area without any tall buildings. Measurement point on site 3 takes place on a sidewalk in the CBD area that is surrounded by tall building and road intersection. Site 3 vegetation is fulfilled by decorative plants and some trees along the side of roads.

Data was collected at three periodic times due to the different ranges of solar radiation, in the morning at 07.00 – 08.00 WIB, in the daytime at 12.00 – 13.00 WIB, and in the afternoon at 16.00 – 17.00 WIB [8] in three weeks (21 days). Measurement of ambient air temperature and relative humidity using a dry and wet bulb thermometer which is placed at 1.5 meters above the ground. At this altitude, the climatological data obtained allows it to cover a wider area [9].

2.3.1. The temperature analysis. The temperature data was analysed based on the maximum and minimum temperature for each periodic time, referring to Handoko et al. [10] using equations (1). The daily average temperature and humidity conditions comprising morning, daytime and afternoon time were observed following the equations (2) and (3).

\[
T_{\text{time}} = \frac{(T_{\text{max}} + T_{\text{min}})}{2} \quad (1)
\]

\[
T_{\text{daily}} = \frac{(2 \times T_{\text{morning}} + T_{\text{daytime}} + T_{\text{afternoon}})}{4} \quad (2)
\]

\[
\text{RH}_{\text{daily}} = \frac{(2 \times \text{RH}_{\text{morning}} + \text{RH}_{\text{daytime}} + \text{RH}_{\text{afternoon}})}{4} \quad (3)
\]

where:

- \(T_{\text{time}}\): air temperature at periodic time, morning or daytime or afternoon (°C),
- \(T_{\text{max}}\): maximum air temperature at periodic time (°C),
- \(T_{\text{min}}\): minimum air temperature at periodic time (°C),
- \(T_{\text{daily}}\): daily air temperature (°C),
- \(\text{RH}_{\text{daily}}\): daily relative humidity (%).

2.3.2. Thermal humidity index. Thermal Humidity Index was a parameter that explained the level of comfort condition based on temperature and relative humidity at periodic time in green open spaces and built environments which was calculated following the equations (4) as stipulated by Nieuwolt [11].

\[
\text{THI} = 0.8 \ T + \{(\text{RH} \times T)/500\} \quad (4)
\]

where:

- \(\text{THI}\): thermal humidity index for each periodic time (°C),
- \(T_{\text{time}}\): air temperature at periodic time, morning or daytime or afternoon (°C),
- \(\text{RH}\): average relative humidity at periodic time (%).

2.3.3. Statistical analysis. Statistical analysis using a two-factor completely randomized design was used in this study based on equations (5) referring to Harrar et al. [12], in which the factor \(A\) was site factor and factor \(B\) was time measurement.

\[
Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (5)
\]

where:

- \(Y_{ijk}\): response for factor A level \(i\), factor B level \(j\) and group level \(k\),
- \(\mu\): overall mean,
- \(\alpha\): effect of level \(i\) of factor A,
- \(\beta\): effect of level \(j\) of factor B,
- \((\alpha\beta)_{ij}\): interaction effect of factor A level \(i\) and factor B level \(j\),
- \(\varepsilon_{ijk}\): experimental error.
3. Result and discussion

3.1. General conditions of the study area
Central Business District Jakarta is one of the business areas in South Jakarta which consists of condominiums, office buildings, hotels, shopping and entertainment centres. The Central Business District area of Jakarta is located between building areas and the main road in the city. Condition around the Central Business District area of Jakarta also has urban forest and a city sports centre. The area has a total area of 45 ha and allocates around 13 ha which is designated as green space and road network.

This area is developed in an integrated modern way by integrating the built environment with green open space to maintain the sustainability of the environment and increasing the ecological grade of the city. Green open space in this location is mostly designed as green paths or corridors along the sidewalk and also green zones or green areas. There are 50 species of trees consisting of hardwood and palm trees found in the CBD area with 1 101 in the total number of trees. The five dominant tree species are *Samanea saman*, *Tabebuia argentea*, *Delonix regia*, *Polyathia longifolia* and *Swietenia mahagoni*. Meanwhile, the dominant palm trees are *Veitchia merillii*, *Licuala grandis* and *Roystonea regia*.

3.2. Temperature and relative humidity
The phenomenon of urban heat islands (UHI) as a consequence of temperature increasing correlates with population density growth. The high population density in an urban area will increase the air temperature cumulatively in that area [13]. Jakarta had a 1.09% population growth rate from 2010 – 2015 with the population density reaching 15 328 people/km² in 2015. This has made Jakarta increase in temperature from 28.1 °C to 28.4 °C since 2012 to 2015 [14].

The previous study shows a correlation between population growth and air temperature, which depends on their population activities. A higher correlation was found when activities of people increase mainly in activities resulting in pollution [15]. Rising population numbers also change the land cover to become non-water absorbing areas, like the area that is made from concrete or other materials that absorb heat, increasing temperature in urban areas [16]. Kaplan [17] mentioned that the increase in temperature in urban areas as a consequence of UHI was strongly influenced by human activities, building density, and green open spaces.

The Central Business District in the South Jakarta area has 3 182 004 people in 2019 and an average air temperature of 28.5 – 28.9 °C with an average humidity of 74% [18]. The study reported that in several days the weather in the area faced rain in the very early morning and very late afternoon until midnight. It caused the air temperature as well relative humidity to fluctuate. The average daily temperature at the study site was 29.8 °C with an average daily humidity of 72.49% (table 1).

| Site     | Air temperature (°C) | Relative humidity (%) |
|----------|----------------------|-----------------------|
| Site 1<sup>a</sup> | 30.17 (±2.33)         | 71.30 (±8.26)         |
| Site 2<sup>b</sup> | 29.15 (±1.96)         | 74.69 (±8.54)         |
| Site 3<sup>c</sup> | 30.06 (±2.49)         | 71.49 (±8.62)         |
| Average              | 29.80                 | 72.49                 |

<sup>a</sup> A built environment that is directly adjacent to the outside of area
<sup>b</sup> Green open space in CBD
<sup>c</sup> A built environment in CBD
Value in parentheses points out standard deviation
The result showed the temperature difference between green open space and building environment was around 1.02 °C for site 1 to site 2 and about 0.91 °C for site 2 to site 3. Meanwhile, the difference in temperature between building environments was around 0.11 °C for site 1 to 3. Studies by Wong and Yu [19] reported that the contrast in temperature between green open space and the building environment could reach around 1.6 to 4.01 °C, while the study by Jáuregui [20] and Estoque et al. [16] found the difference of about 2 to 3 °C. Data from BMKG (Meteorological, Climatological, and Geophysical Agency) [21] reported the daily temperature of Jakarta in 2018 (28.73 °C), 2019 (28.92 °C), and 2020 (29.0 °C). In terms of daily humidity, the green open space was higher than the site around the building environment (3.2 – 3.39%), with an average humidity of about 72.49%.

Our study pointed out the increase in air temperature compared BMKG’s data in the past three years. Even though our study in a smaller area it could be considered that in the wider area the air temperature could increase too. Jakarta's temperature has been increasing every year by 0.17 °C from 1980 to 2007 and central Jakarta had a higher temperature than any other suburbs area (Halim and Cengkareng) with the temperature difference was about 0.7 – 0.9 °C [15]. In the Urban heat island phenomenon, General differences between urban temperature and suburban’s temperature are not more than 3 – 4 °C [22].

Temperature and humidity conditions measured at sites and times showed different results (table 2). Statistical analysis for temperature and relative humidity found no significant difference in the interaction between site and periodic time (α = 0.05). It was presumably related to the coverage area of CBD which is not in a wide area. However, looking at a single factor it seemed that temperature and relative humidity for each site and periodic time were significant differences (α = 0.05).

| Source             | Sum of Squares | df  | Mean Square | F     | Sig. (α= 0.05) |
|--------------------|----------------|-----|-------------|-------|----------------|
| Temperature (°C)   | 47.701         | 2,180 | 23.851     | 11.084 | .000**         |
| Time               | 569.017        | 2,180 | 284.508    | 132.218 | .000**         |
| Site vs Time       | 7.543          | 4    | 1.886       | .876   | .479 ns        |
| Relative humidity (%) | 430.296     | 2,180 | 215.148    | 5.964  | .000**         |
| Time               | 6854.932       | 2,180 | 3427.466   | 95.004 | .000**         |
| Site vs Time       | 12.888         | 4    | 3.222       | .089   | .986 ns        |

* **Significant difference
  ns No-significant difference

The temperature and humidity of the air have inversely proportional values. When the temperature is high, the humidity will be lower and vice versa. The highest air temperature at the research site reached 33.04 °C, while the lowest temperature was 27.77 °C (figure 1).

Figure 1 explained the measurements of air temperature and humidity at three different sites for each periodic time. The vegetation in site 2 as part of open green space (figure 1a) has proven the decreasing temperature at each periodic time compared to other sites of a built environment of site 1 and site 3. While the relative humidity at those three sites had the same trend values, daytime had the lowest relative humidity (figure 1b). The difference in temperature and humidity in green open spaces and a built environment could reach a temperature difference of 0.5 – 1.6 °C and air humidity of 2.4 – 3.8%. The interaction was detected between air temperature and land use on various lands such as
industrial areas, settlements, airports, central businesses, forests, or green open spaces where the difference in each land use can reach 1.6 – 4.01°C [19].

Specific for the built environment observed in two sites of site 1 and site 3, a difference was found in temperature of 0.2 °C and humidity of 0.1 – 0.4%. There could be several factors that caused differences in temperature and relative humidity in the built environment, such as land use, human activities, proximity to buildings, and vegetation. At site 1, the edge of the highway where human activity in the form of vehicle density will be higher than site 3 is a road within the area. The increase in temperature and humidity drop in an area was influenced by gas emissions from vehicles that trigger global warming, and also the proximity of buildings that produce radiation reflections also affects the increase in temperature in a built area [15, 23, 24]. It shows that green open space and built environment on various land use types are factors that affect the temperature and humidity conditions in the environment.

![Graph](image1.png)

**Figure 1.** The temperature (a) and relative humidity (b) conditions at the three sites.
Site 1: A built environment that is directly adjacent to the outside of the CBD area
Site 2: Green open space in CBD
Site 3: A built environment in CBD
3.3. Thermal humidity index

The thermal Humidity Index (THI) value in this research was obtained by analysing air condition, such as air temperature and relative humidity so that the reference value for thermal comfort was acquired. Thermal comfort can be different in every country, region, weather and climate condition. In general, THI values categories by Nieuwolt [11] have three categories, such as comfortable category at 21 – 24 °C, quite comfortable at 24 – 26 °C and uncomfortable at >26 °C. While the studies by Emmanuel [25] mentioned that THI values were no longer relevant to the current state of global warming because the result showed THI value rose to 1.7 °C from the upper limit of discomfort.

Comfort conditions measured at different times or sites generate different comfort categories and THI values. Statistical analysis found that the interaction between two factors of site and time was not significant (α = 0.05). However, the single of each factor was a significant difference in THI values.

| Source       | Sum of Squares | df  | Mean Square | F     | Sig. (α = 0.05) |
|--------------|----------------|-----|-------------|-------|----------------|
| Site         | 27.260         | 2,180 | 13.630    | 10.445 | .000**         |
| Time         | 307.073        | 2,180 | 153.537   | 117.664 | .000**         |
| Site vs time | 7.024          | 4    | 1.756      | 1.346  | .255 ns        |

**Significant difference

ns No-significant difference

The THI index value in Jakarta since 1985 – 2012 increased significantly by 50% toward uncomfortable conditions, and it will be more uncomfortable when it gets closer to the city center [26]. The THI value in the Indonesian urban area around Jakarta, called JABODETABEK, in simulation for 2015 – 2025 showed a comfortable category with a value at 21 – 24 °C, quite comfortable at 25 – 27°C and uncomfortable at >27 °C [27]. The THI analysis at three sites with different land cover and land used resulted in only the morning time approaching the quiet comfortable category at 26.72 – 27.22 °C (figure 2).

![Figure 2](image_url)

**Figure 2.** Thermal humidity index value (°C) in three sites.
Site 1: A built environment that is directly adjacent to the outside of area
Site 2: Green open space in CBD
Site 3: A built environment in CBD

Figure 2 indicated the THI value at the three sites was the smallest in the morning. In the morning, the THI value at site 2, a green open space, was categorised as quite comfortable. In contrast, the other sites were a built environment categorised as uncomfortable, yet it was just 0.06 – 0.22 °C beyond the
uncomfortable category limit at 27 °C. Jakarta's comfortable air temperature between 25.1 – 27.9 °C was optimal for maintaining body temperature in the range of 37 °C [28]. Indonesian people have adapted to air conditions Indonesia's average maximum air temperature reaches 27 – 32 °C with an average minimum value of 20 – 23 °C and average humidity of 75 – 80% [29]. This showed that THI values in the morning at the three sites and in the afternoon at site 2 were still classified as normal conditions in general and comfortable for the Central Business area located in urban Jakarta.

The lowest THI value at the three observation times was at site 2 because it was a green open space with the most trees. According to the results, green open spaces could reduce the THI value at 0.34 – 0.5 °C in the morning, 1.34 – 1.40 °C during the day and in the afternoon by 0.62 – 0.64 °C compared to the built environment's temperature. Compared to the built environment, green open space has ecological effects in regulating air temperature and providing a cooling effect. Every increase in green open space amount can reduce the temperature at 0.2 – 0.5 °C, while the reduction can increase the temperature at 0.4 – 1.8 °C in a certain percentage of the area [30]. The role of green open space in lowering air temperature can reduce heat in the surrounding environment up to a radius of 30 meters [31].

The THI value in the built environment (site 1 and site 3) showed site 3 has the lower THI value in the morning and daytime, while site 1 had the lower THI in the afternoon. The difference in THI values at site 1 and site 3 was slightly significant, at 0.02 – 0.16 °C. Those two locations had different environmental conditions. Site 1 was crowded traffic at all times, while site 3 just had it in the afternoon. Afterwards, the building area in site 3 was located close to the measurement point while site 1 was further. Then there were hardwood trees, palm trees and shrubs vegetation at both sites. Thermal comfort is affected by environmental factors that include temperature, wind movement, humidity, and radiation; personal factors include metabolic activity and clothing and other factors such as age, gender, body shape, and health conditions [32]. Thermal comfort is also affected by the individual ability to adapt to environmental conditions. People who live in tropical climates are more resistant to hot temperatures than people who live in subtropical climates and vice versa.

4. Conclusion

The difference in air temperature, humidity and THI values at the three different sites and periodic time was caused by vegetation conditions, land cover, and urban activities. The research pointed out that the presence of green open space in the Central Business Jakarta area has a positive effect on decreasing air temperature in increasing environmental comfort compared to conditions in the built environment. Efforts to increase the level of thermal comfort in an area can be conducted by adding or optimizing green open spaces that contribute to reducing air temperature. The application of different comfort standards can result in different categories of comfort levels because each standard has different conditions.

5. References

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