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Analysis of Heat Stress in Semarang City Utilizing the Temperature Humidity Index (THI) Method

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Abstract

Background: The urbanization of Semarang City leads in a decrease in green open spaces (GOS), causing disruptions in the urban microclimate that may decrease thermal comfort.
Aims: This study aims determine climate comfort and the risk of heat stress through the Temperature Humidity Index (THI), which integrates air temperature and relative humidity.
Methods: The analysis was conducted using 13 years (2010–2022) of secondary data obtained from the Semarang Climatological Station, Ahmad Yani Meteorological Station, and Tanjung Emas Maritime Meteorological Station. The novelty of this study lies in the assessment of climatic comfort based on the THI method using long-term data from three types of meteorological stations representing inland, airport, and maritime climatic characteristics in Semarang City.
Result: The results indicate that the "partly comfortable" category dominates at 66.67%, occurring for approximately eight months per year, while the "uncomfortable" category accounts for 33.33% or about four months per year.
Conclusion: These findings suggest that residents of Semarang City are potentially exposed to heat stress for most of the year, highlighting the need for environmental engineering measures and community adaptation to improve urban thermal comfort.

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1. Introduction

Global climate change has emerged as a significant environmental concern, exerting extensive effects on natural systems and human existence, characterized by elevated severe temperatures and a heightened occurrence of heat waves. In urban environments, the effects of climate change are intensified by the urban heat island (UHI) phenomenon, which arises from elevated building density, diminished green open space (GOS), and extensive human activity. This situation results in elevated thermal temperatures and diminished climate comfort, ultimately causing heat stress for urban populations, especially in tropical cities.

Climate comfort is a vital factor in assessing the quality of the urban environment, as it directly influences human health, productivity, and well-being. Temperature discomfort may indicate heat stress, a condition in which the body weakly maintains thermal balance. Heat exposure may result in dilation, decreased blood pressure, and symptoms such as dizziness, feeling sick, impaired equilibrium, and the risk of faint. It can diminish concentration and work performance psychologically (Karyono, 2010). Consequently, climatic comfort analysis is an essential element of climate change adaptation research in urban environments.

Several prior investigations have identified quantitative approaches to assess climate comfort, one of which is the Temperature Humidity Index (THI) method, which combines air temperature and relative humidity to assess heat stress on individuals. The THI approach is extensively utilized owing to its straightforwardness, ease of application, and pertinence to tropical areas. Nevertheless, the majority of prior research is typically spatially constrained, utilize relatively brief data intervals, or represent solely a singular environmental attribute, so failing to comprehensively illustrate changes in urban climate comfort both temporally and across regional characteristics.

Semarang City is a prominent metropolitan center in Indonesia experiencing significant urbanization challenges. Semarang City, covering an area of 373.78 km² and housing a population of 1,659,975 in 2022, attained a population density of 4,441 individuals per km², ranking it as the fifth most populous city in Central Java Province (Semarang City in Figures, 2023). The expansion of urban areas in Semarang City has risen markedly from 8,107.41 hectares in 1999 to 19,510.87 hectares, constituting 50.26% of the total area, in 2019 (Zahra *et al.,* 2021). This state signifies significant strain on green open spaces, perhaps leading to microclimate alterations and reduced thermal comfort.

Nevertheless, research on climate comfort and potential heat stress in Semarang City, utilizing long-term climatological data and a multi-faceted depiction of the area (including land, airport, and coastal/maritime aspects), remains scarce. This signifies a study deficiency in fully and chronologically comprehending the dynamics of urban climatic comfort, especially in highly urbanized tropical coastal towns like Semarang. This study intends to: (1) assess the degree of climate comfort and the risk of heat stress in Semarang City utilizing the Temperature Humidity Index (THI) method; (2) examine the alignment of climate comfort conditions with established comfort threshold classifications; and (3) develop recommendations for environmental engineering and community lifestyle adaptations in response to the existing climate comfort conditions. This research is innovative due to the utilization of 13 years of extensive climatological data from three categories of meteorological stations, thereby providing a more thorough representation of climate fluctuations in terrestrial, airport, and maritime regions. *The novelty of this study lies in its use of 13 years of climatological data from three distinct meteorological station types (inland, airport, and maritime) to comprehensively assess urban climate comfort and heat stress dynamics in Semarang City using the Temperature Humidity Index (THI) method.* This project aims to establish a scientific foundation for climate change adaptation planning, management of green open spaces, and the development of policies to enhance thermal comfort in coastal metropolitan regions.

2. Methods

This study depends on a quantitative descriptive methodology to delineate and assess the climate comfort conditions and potential heat stress in Semarang City, utilizing measured climatological data. The quantitative methodology was selected due to the study including numerical variables, specifically air temperature and relative humidity, which were subsequently converted into a thermal comfort index value via the Temperature Humidity Index (THI) method. The descriptive methodology was employed as this study seeks to uncover patterns, trends, and levels of climate comfort objectively, rather than to test a causal hypothesis, utilizing observational data. This study involved the analysis of secondary data pertaining to average air temperature (°C) and relative humidity (%) in Semarang City over a 13-year span (2010-2022). This study employs a time-series methodology, where climate data is examined chronologically over an extended duration. This method facilitates the detection of temporal fluctuations, seasonal trends, and medium-term patterns in climate comfort and possible heat stress in Semarang City. This study is not cross-sectional, as it not only compares circumstances at a single moment but also examines climatic dynamics across time using monthly and annual data. Alongside average air temperature and relative humidity, rainfall (mm) data will be utilized for climate type classification study. Additionally, data on minimum (°C), average (°C), and maximum (°C) air temperatures will be utilized for the annual analysis of climate change. Data were sourced from the Semarang City Climatology Station, the Ahmad Yani Meteorology Station, and the Tanjung Emas Maritime Meteorology Station, retrieved via the Database Center website of the Meteorology, Climatology, and Geophysics Agency (BMKG). This duration was selected based on the subsequent considerations:

1) Accessibility and reliability of daily and monthly climatological data from the Meteorology, Climatology, and Geophysics Agency (BMKG);
2) Adequate data duration to depict annual and interannual climate variability; and (3) This timeframe includes multiple global climate phenomena, such as El Niño and La Niña, which may influence thermal comfort in tropical areas.
3) Consequently, utilizing 13 years of data is deemed adequate to illustrate representative climate conditions and mitigate short-term anomalous bias.

The three stations were deliberately chosen to represent the changes in Semarang's primary climatological features: terrestrial, airport, and maritime zones. Semarang possesses a multifaceted geographic profile as a coastal city characterized by significant urban and transportation activity, so the utilization of a singular station may lead to spatial bias. Consequently, a triad of stations was employed to achieve a more spatially representative depiction of climatic conditions. Moreover, the three stations provide mutual support when daily or monthly data is inaccessible at alternative stations. Figure 1 illustrates the map of the research site and the climatic monitoring stations utilized.

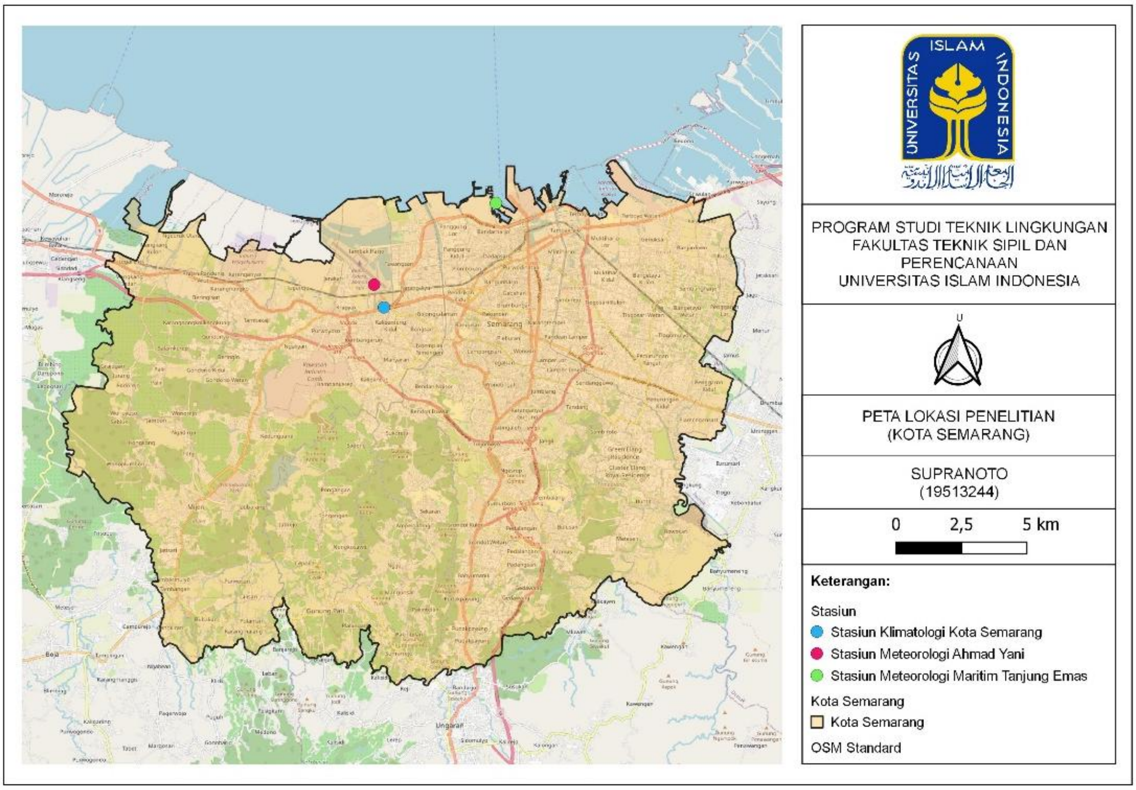

Figure 1. Map of Research Location (Semarang City)

The obtained data was processed using Microsoft excel and google spreadsheets. The research flowchart can be seen in Figure 2.

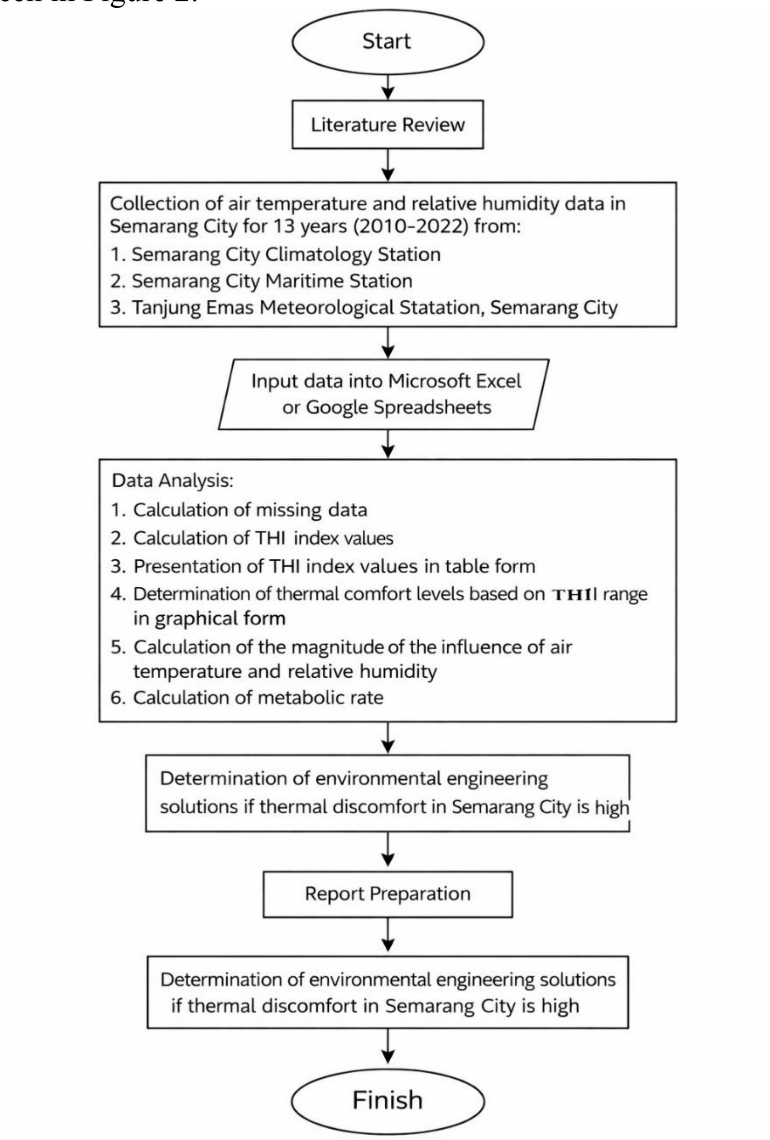

Figure 2. Research Flowchart

The climate classification study of Semarang City was performed with Oldeman's methodology. Climate classification was utilized to analyze the impact of climate type on the THI index value. The classification depends on the count of consecutive humid and dry months over a minimum duration of 10 years. Oldeman's climate classification comprises three categories: the wet month climate type, characterized by average rainfall exceeding 200 mm; the humid month climate type, with average rainfall between 100 mm and 200 mm; and the dry month climate type, defined by average rainfall below 100 mm (Sasminto *et al.,* 2014). The outcomes of the climate type categorization analysis are presented graphically, illustrating the association between the climate type of Semarang City and its THI index value.

The Temperature Humidity Index (THI) is a quantitative instrument utilized for measuring the thermal comfort of an urban environment. The THI calculation combines air temperature (°C) and relative humidity (%) to yield an index value in degrees Celsius (°C) (Wati & Fatkhuroyan, 2017). The formula for calculating the THI comfort index, as established by Nieuwolt (Hasanah *et al.,* 2020), is as follows:

$$\boldsymbol{THI} = (\mathbf{0{,}8}\ \boldsymbol{x}\ \boldsymbol{T}) + \{\boldsymbol{RH}\ \boldsymbol{x}\ \boldsymbol{T}/\mathbf{500}\}$$

Description:
THI = Temperature Humidity Index (℃)
T = Average air temperature (℃)
RH = Relative air humidity (%)

According to Nieuwolt in Wati & Fatkhuroyan (2017), thermal comfort classification is divided into three categories: a THI range of 21-24℃ is "comfortable," 25-27℃ is "partially comfortable," and >27℃ is "uncomfortable." Parameter analysis was conducted quantitatively by presenting data in tables and graphs. The table contains the THI index value in Semarang City and the graph is a comparison between the average air temperature and relative humidity to the THI index value in Semarang City. Next, the results of the THI index analysis will be classified according to the comfort level category and analyzed the impact of heat stress that will occur on the community in Semarang City using a literature review. The Nieuwolt formula was chosen because it has been widely used and validated for humid tropical climates, including Indonesia. Compared with other THI variations developed for subtropical climates or industrial work environments, the Nieuwolt formula is more suitable for assessing outdoor thermal comfort in tropical areas with high humidity such as Semarang City. In addition, the thermal comfort classification based on Nieuwolt has been widely used in research in Indonesian cities, thus allowing for consistent comparison of research results.

According to Regulation of the Minister of Health of the Republic of Indonesia Number 70 of 2016 concerning Standards and Requirements for Industrial Work Environment Health, the Threshold Limit Value (TLV) for the work environment is established as the maximum heat exposure for 8 hours per day, quantified in degrees Celsius (WBW) (degrees Celsius Wet and Bulb Temperature Index). The TLV for the work environment is determined by working hours, rest intervals, and metabolic rate. This study employed metabolic rate estimates to model age and gender cohorts characterized by elevated metabolic rates. The average body weight of Indonesians is derived from study conducted by Muljiati *et al.* (2016). The quantity of age and gender cohorts exhibiting a high metabolic rate was subsequently evaluated using the latest data from the Semarang City Central Statistics Agency (BPS), which pinpointed groups susceptible to heat stress. According to ISO 8996 of 2004, the estimated body weight for calculating metabolic rate is 70 kg for males and 60 kg for females. The subsequent formula for workload is derived from metabolic rate, as stipulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 70 of 2016:

$$Metabolic\ rate\ (correction) = \frac{Worker's\ weight\ (kg)}{70\ (kg)}\ x\ Metabolic\ rate\ (observed)$$

Metabolic rate categories refer to the Regulation of the Minister of Health of the Republic of Indonesia Number 70 of 2016 as follows: resting (115), light (180), moderate (300), heavy (415), and very heavy (520). The study of the environment focused on enhancing thermal comfort in Semarang City encompasses the adoption of green transportation (Primastuti, 2021), optimization of public and private green open spaces (RTH) (Ratnasari, 2015), the planting of trees for road shading (Zayadi, 2017), the implementation of green facades (vertical gardens) (Haryanto *et al.*, 2019), and the establishment of roof gardens (Arisanti *et al.*, 2010). Transformations to the lifestyle of Semarang City residents to mitigate heat stress include selecting appropriate fabric types and colors for outdoor attire (Mufida *et al.*, 2016) and ensuring adequate water and salt intake to prevent

3. Results and Discussion

3.1 Review of Climatic Conditions in Semarang City

The investigation of climatic conditions in Semarang City encompasses the parameters of minimum air temperature (°C), average air temperature (°C), maximum air temperature (°C), relative air humidity (%), and precipitation (mm) for a span of 13 years (2010-2022). The findings indicate that the minimum air temperature in Semarang City is 24.80°C, the average air temperature is 28.19°C, and the maximum air temperature attains 32.43°C. Over the course of 13 years, modifications have occurred annually for these three parameters, as illustrated in Figure 3. Figure 3 illustrates the variability of the values for each parameter. The peak yearly maximum air temperature was recorded in 2019, hitting 33.30°C. The peak average air temperature was recorded in 2016, measuring 28.53°C. The peak low air temperature was recorded in 2016 at 25.32°C.

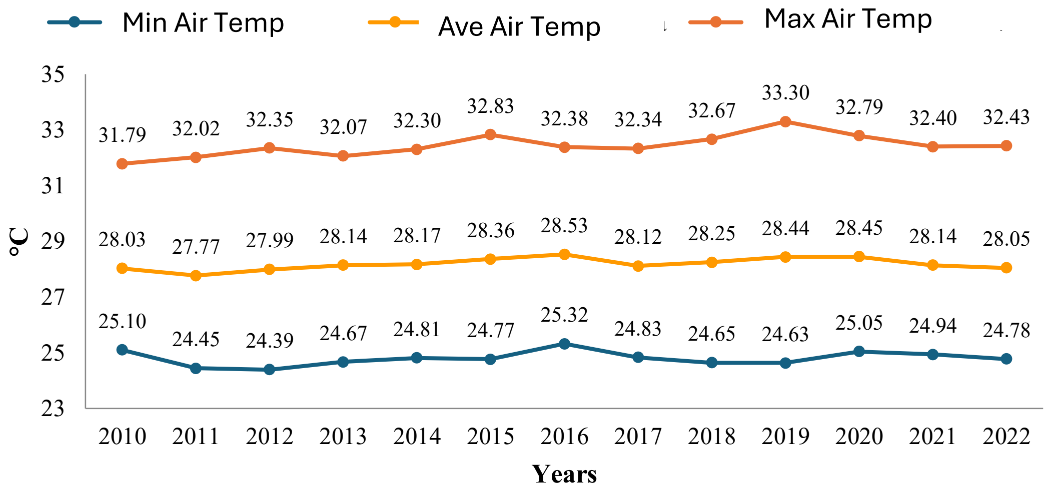

Figure 3. Climate Conditions (Air Temperature) of Semarang City 2010-2022

During 2010 to 2022, the average relative humidity in Semarang City was 76.18%. Over the 13-year period, the relative humidity in Semarang City ranged from 73.27% to 78.67% annually. The lowest recorded relative humidity was 73.27%, which happened in 2015. The result of 78.67% represented the greatest relative humidity, recorded in 2016. The specifics are illustrated in Figure 4.

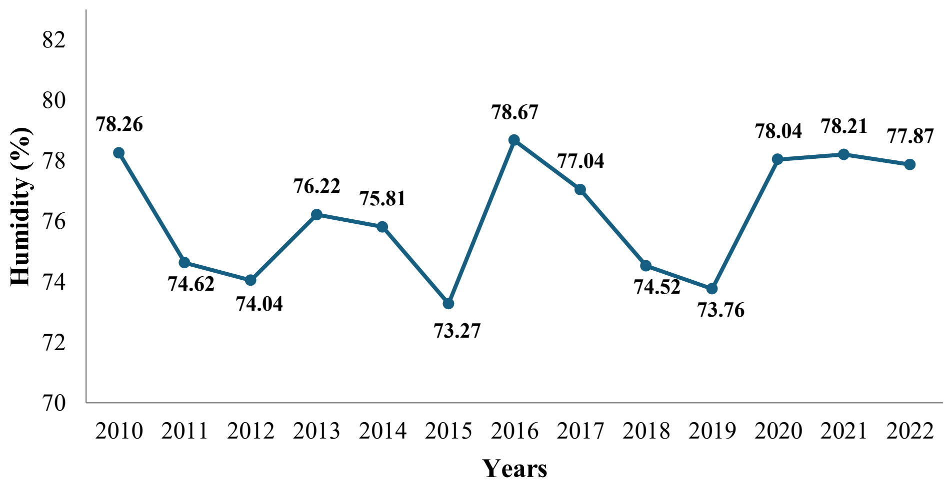

Figure 4. Climate Conditions (Relative Humidity) of Semarang City 2010-2022

This investigation furthermore explored the climate types of Semarang City utilizing Oldeman's estimates. The Oldeman classification of climatic types in Semarang City, derived from data from three stations, indicates that the rainy season (wet months) spans from November to February (four months). The humid months span from March to June and October, totaling five months. The arid season transpires from July to September, encompassing a duration of three months.

3.2 Analysis of Information Utilizing the Temperature Humidity Index (THI) Method

Based on the THI analysis, the THI index value for Semarang City ranges from 26.33°C to 27.42°C. The lowest (minimum) THI index value, at 26.33°C, occurred in August. The highest (maximum) THI index value, at 27.42°C, occurred in May. The overall THI index calculation results are shown in Table 1.

Table 1. THI Index Value of Semarang City

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
THI (°C)	26.38	26.42	26.80	27.25	27.42	26.81	26.35	26.33	26.80	27.35	27.32	26.85

The THI index value is calculated based on average air temperature and relative humidity. Consequently, the intensity of these two climatic conditions affects the THI index value. Figure 5 illustrates that a rise in average air temperature is exactly related to an increase in the THI index value, and conversely. This transpires in May and October. Figure 6 shows that high or low relative humidity does not always affect the THI index value. Instances of relative humidity affecting the THI index value encompass the period from July to September.

The THI index in Semarang City exhibits a bimodal peak season, occurring in May and October. The peak THI index value is recorded in May, attaining 27.42°C. Figure 5 illustrates the bimodal peak season for average air temperature, occurring in May and October, with the maximum value in October reaching 29.07°C. Figure 6 illustrates the peak season for relative humidity occurring in January and February, with the maximum value attaining 83.13% in February.

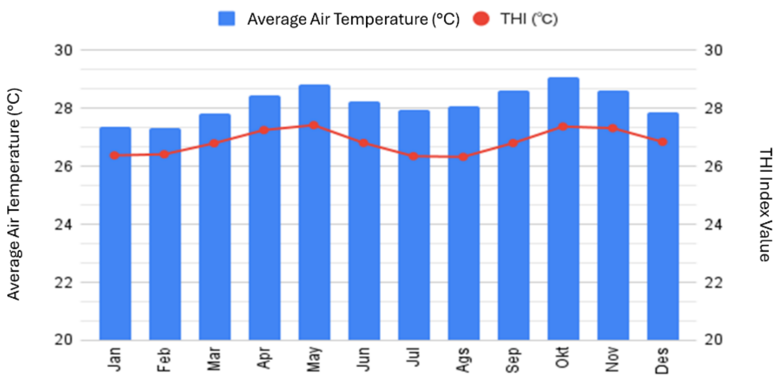

Figure 5. Correlation between Average Air Temperature and THI Index Value

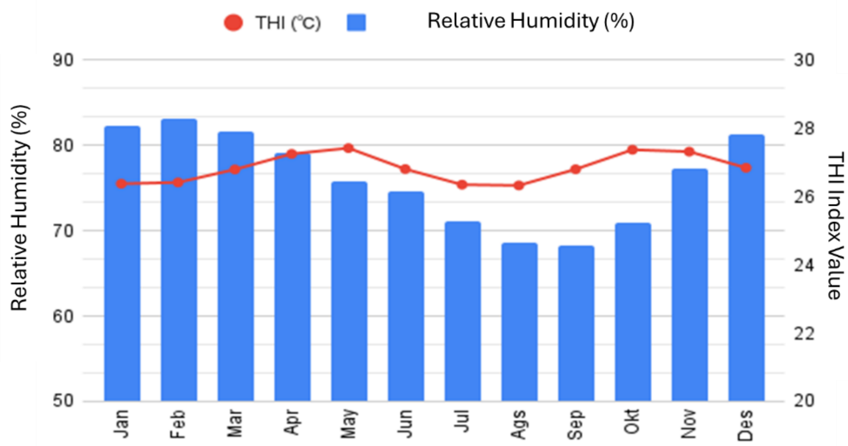

Figure 6. Correlation between relative air humidity and THI Index Value

The tropical climate of Indonesia results in minimal temperature variation in Semarang between the rainy, humid, and dry months. Nonetheless, this does not imply that it is devoid of any impact. Raharjo (2011) asserts that wet months exhibit greater temperatures compared to dry months. Elevated temperatures during humid months lead to increased water evaporation, potentially heightening the likelihood of precipitation. This renders wet months less conducive for outdoor activity. In Semarang, THI index readings exceeding 27°C are observed during the humid months of April, May, October, and November. Figure 7 illustrates the correlation between climatic type and Semarang's THI score.

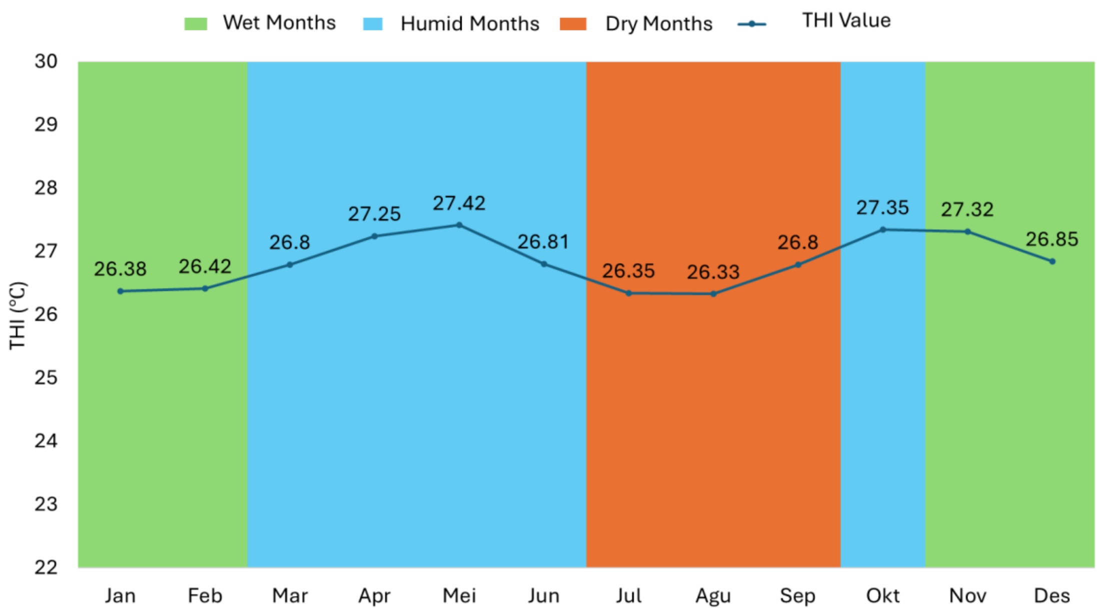

Figure 7. Correlation between Climate Type and THI Index Value in Semarang City

In the past year, the average Temperature-Humidity Index (THI) was 27.31°C, with THI values over 27°C in nearly all months except February and December. This transpired once more in 2020, with an average THI index value of 27.20°C. In that year, index readings below 27°C were recorded solely in February, July, and December. According to the study of Yuniasih *et al.* (2022) on El Niño and La Niña anomalies in Indonesia from 2013 to 2022, the sea surface temperature (SST) values for El Niño during the initial five months of 2016 ranged from "normal" to "very strong" levels. Between 2010 and 2022, there were three months with THI index readings over 28°C: November 2015 (28.03°C), May 2016 (28.07°C), and November 2019 (28.18°C). In these months, the SST data indicated that El Niño was classified as "very strong" (2.95°C), "normal" (0.3°C), and "weak" (0.51°C). In November 2015, the sea surface temperature (SST) reached 2.95°C, indicating a "very strong" El Niño, the most significant occurrence from 2013 to 2022. In the Indonesian region, El Niño results in reduced rainfall and fewer rainy days, elevated air temperatures, and extended dry conditions (Tongkukut, 2011).

3.3 Investigation of Comfort Levels Utilizing the Temperature Humidity Index (THI) Method and Its Correlation with Heat Stress

The climate comfort rating for tropical climates according to the THI is as follows: "comfortable" (THI index value 21-24°C); "partly comfortable" (THI index value 25-27°C); and "uncomfortable" (THI index value >27°C) (Wati & Fatkhuroyan, 2017). The THI index calculations for Semarang City indicate that the climate comfort level is classified into two categories: "partly comfortable" and "uncomfortable." The "partly comfortable" category constitutes 66.67%, corresponding to 8 months annually (244 days/year). The proportion in the "uncomfortable" group is 33.33%, corresponding to four months annually (122 days a year).

These findings contrast with prior studies conducted in other Indonesian cities. Research conducted by Melinda *et al.* (2022) in Palembang City revealed that "comfortable" conditions accounted for 6.4%, occurring on 23 days annually, while "partly comfortable" conditions comprised 73.9%, occurring on 270 days per year, and "uncomfortable" conditions represented 19.7%, occurring on 72 days per year. This differs from Kusuma's (2021) study in Yogyakarta City, which determined that the "comfortable" condition persisted for four months annually (33.33%), whereas the "partly comfortable" condition endured for eight months annually (66.67%).

In Semarang City, "partly comfortable" meteorological conditions were seen in January, February, March, June, July, August, September, and December. Simultaneously, the "uncomfortable" thermal comfort conditions manifested in April, May, October, and November. Information is presented in Table 2 and Figure 8.

Table 2. Ratio of Thermal Comfort Categories in Semarang City

Range THI (°C)	Category	Percentage (%)
21-24	Comfortable	-
25-27	Partly comfortable	66.67
>27	Uncomfortable	33.33

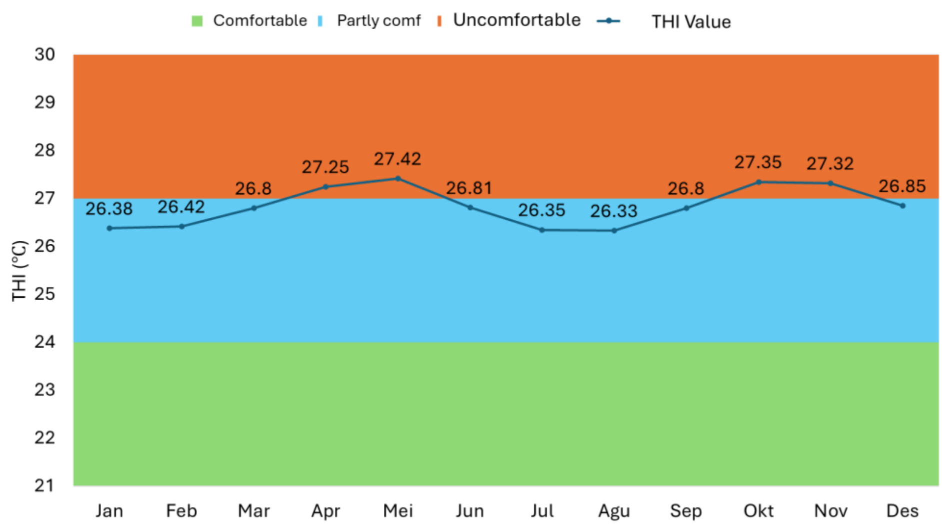

Figure 8. Thermal Comfort Index of Semarang City Based on THI Calculations

The climate comfort conditions in Semarang City, primarily categorized as "uncomfortable," may adversely affect the enjoyment of outdoor activities. ISO 8996:2004 provides examples of outdoor activities such as vocational training, athletics, and specialized labor. Outdoor activities are intricately linked to the metabolic rate of each individual. Engaging in vigorous activities in hot regions may result in heat stress.

As per the Regulation of the Minister of Health of the Republic of Indonesia Number 70 of 2016 regarding Standards and Requirements for Industrial Work Environment Health, metabolic rate is a determinant of the environmental climate threshold value (NAB), influencing the body's comfort level. Calculations of metabolic rate are conducted to classify metabolic rate groups according to body weight and age range, in order to assess the possibility for heat stress within the Semarang City community. ISO 8996:2004 stipulates that body weight for metabolic rate calculations is categorized as 70 kg for men and 60 kg for women. Table 3.3 displays the average body weight categorized by age group in Indonesia.

Table 3. Mean Body Weight by Age Demographic of Indonesian Population (Muljiati, et al., 2016)

Age	Weight	
	Man	Woman
15-24	52.4	48.5
25-30	60.9	56.2
31-34	62.9	58.6
35-44	62.9	58.6
45-54	61.9	57.7
55-59	60.9	56.8
60-64	60.9	56.8
65+	54.4	46.6

According to the metabolic rate calculations, nearly all age demographics and genders are classified under the high metabolic rate category. The sole demographic excluded from the high metabolic rate category is males aged 16 to 24. The Semarang City in Figures (2023) document indicates that the male population of Semarang City is 507,622, aged 25 to 75+, while the female population aged 15 to 75+ is 662,674.

The productive age range for Indonesians is from 15 to 64 years. As individuals reach this productive age bracket, labor activities increase in frequency, both indoors and outdoors. This will influence alterations in the body's metabolic rate, leading to heat stress. Analysis of these activities indicates that when metabolic rate is correlated with the Temperature Humidity Index (THI), males aged 25-64 and females aged 15-64 are more susceptible to heat stress. Residents of Semarang City have a risk of heat stress across nearly all months, with the peak risk happening in April, May, October, and November, as data analysis reveals that these months are classified inside the "uncomfortable" THI comfort group.

Physiologically, heat stress can enhance vascular capacity. This disease induces vasodilation and hypotension, manifested by symptoms such as dizziness, nausea, vomiting, weakness, loss of equilibrium, and syncope. If heat stress is not rapidly mitigated, it may result in heat rash (prickly heat), heat cramps (muscle spasms), heat exhaustion (fatigue), and heat stroke (overheating) (Budhiasih *et al.,* 2015).

Heat rash, or prickly heat, is marked by the emergence of pinpoint papular erythema, frequently accompanied by pruritus, usually in regions susceptible to perspiration, such as the face, upper limbs, and neck (Grubenhoff, 2007). Heat cramps arise from the depletion of sodium (Na) salts in the body, resulting in muscle spasm and stomach discomfort (Budhiasih *et al.,* 2015). Heat exhaustion is a syndrome characterized by a body temperature elevation between 37°C and 40°C, accompanied by symptoms such as malaise, fatigue, headache, heightened thirst, nausea, vomiting, muscle cramps, cool or wrinkled skin, and syncope (Ashar, 2019). Heat stroke is a syndrome characterized by a body temperature over 40°C, leading to central nervous system disturbances including irritability, ataxia, confusion, seizures, hallucinations, and even coma (Ashar, 2019).

3.4 Environmental Engineering

Semarang City's THI index, which is in the "partially comfortable" and "uncomfortable" categories, requires environmental engineering to improve climate comfort and minimize heat stress symptoms among the city's residents. Several environmental engineering initiatives are possible, including the creation of green open spaces (GOS). With GOS, air temperature decreases and relative humidity increases, thereby improving human climate comfort (Shahidan *et al.,* 2010). Trees in GOS areas can provide protection from solar radiation and engineer a microclimate, thus providing comfort for those living nearby (Putra *et al.,* 2022). According to research by Asiani (2007), GOS in good condition can reduce air temperature by approximately 5.86% and increase humidity by approximately 4%. Furthermore, in addition to its ecological benefits, GOS also has aesthetic, economic, and social value. The government, through Law Number 26 of 2007 concerning Spatial Planning, requires each city/district to have green open space amounting to 30% of its total area. This figure consists of 20% public green open space and 10% private green open space. According to the National Waste Management Information System (SIPSN) page of the Ministry of Environment and Forestry (KLHK), the green open space area achieved in Semarang City in 2022 reached 109.33 km2 or approximately 29.25% of the total area. This means that the green open space achievement in Semarang City is less than 0.75% or approximately 27,659.72 km2. The types of green open space use in Semarang City are shown in Table 4.

Table 3. Semarang City Green Open Space SIPSN KLHK (11 Agustus 2023)

Type of Green Open Space (RTH) Land Use	Area (km^2)	Percentage (%)
City parks	2.15	0.58
Urban forests	28.69	7.68
Green belts along roads	14.65	3.92
River buffer zones	9.98	2.67
Coastal buffer zones	5.37	1.44
Public cemeteries	4.32	1.16
Railway buffer zones	0.46	0.12
High-voltage power line green corridors	0.30	0.08
Protection areas for raw water sources (springs)	43.41	11.61
Total Green Open Space (RTH)	**109.33**	**29.25**

The following table indicates that the predominant kind of green open space land use in Semarang City is spring water protection, encompassing 43.41 km^2 (11.61%), succeeded by urban woods, which cover 28.69 km^2 (7.68%). Per Government Regulation (PP) Number 63 of 2002 about Urban Forests, urban forests are defined as places characterized by thick, compact tree growth within urban locales, encompassing both state and private lands, and declared as such by competent authorities. Notwithstanding its second-place ranking, the urban forest area percentage in Semarang City (7.68%) fails to satisfy the requisite level of a minimum of 10% of the urban area, as stipulated by the aforementioned legislation. According to research by Rushayati *et al.* (2010), urban woods provide superior climate amelioration (air temperature and humidity) compared to other forms of green open space. Consequently, the Semarang City Government must establish new green open spaces or transform existing areas into urban forests to more efficiently mitigate thermal heat. Research by Febrianti (2022) revealed that in 2022, Semarang City retained 7.88 km^2 of unoccupied land, indicating potential for the development of green open spaces (GOS), particularly in urban and heavily populated regions. Moreover, Febrianti's (2022) study revealed that the extent of empty land in 2022 rose by 2.48 km^2 relative to 2019. She interprets this growth as resulting from the transformation of vegetated regions into unoccupied land, which will subsequently be redeveloped into built-up land.

Consequently, alongside the growth of green open spaces, it is imperative to enhance the current green open areas in Semarang City. Intensification is an endeavor to enhance the quality of green open spaces by augmenting the efficacy of their roles and functions (Kusuma, 2021). Methods for intensifying green open spaces encompass the replanting of several plant species, including trees, shrubs, and bushes. This can establish a stratified plant configuration, so enhancing the ecological, economic, aesthetic, and social benefits of green open areas. Alongside planting, enhancements and upkeep of green open space (GTH) in Semarang City are essential to maximize its utility.

Individuals, collectives, communities, governmental entities, and the private sector can establish green open spaces for residential, corporate, and commercial environments. These can be cultivated in available space, in containers, or through vertical gardening or rooftop gardens. Arisanti *et al.* (2010) assert that the implementation of roof gardens might transform the development paradigm from horizontal, which may diminish green space, to vertical. Consequently, potted, vertical, or rooftop gardens can be utilized in limited locations inside highly populated or urban environments. The establishment of roof gardens is in accordance with the directives of the Semarang City Government, as specified in the 2011-2031 Semarang City Spatial Plan, mandating that building proprietors and administrators in Semarang City provide green open spaces through the construction of rooftop gardens.

According to the Regulation of the Minister of Public Works Number 5 of 2008 regarding Guidelines for the Provision and Utilization of Green Open Spaces in Urban Areas, the criteria for vegetation in yard green open spaces are classified into two categories: (1) those planted directly in the ground, and (2) those in containers and utilizing a roof garden system. The requirements for tree selection pertain to the Regulation of the Minister of Public Works Number 5 of 2008. The law additionally delineates examples of flora suitable for cultivation in a rooftop garden system. Subsequently, three plants from each category were selected based on recommendations, as illustrated in Table 5.

Table 5. Examples of Plants for Roof Gardens based on Shrubs and Ground Cover (Minister of Public Works Regulation Number 5 of 2008)

No.	Plant Type and Name	Description
	Trees	
1	Yellow rubber fig (*Ficus elastica* variegata)	Dense canopy
2	Jasmine (*Jasminum sambac*)	Flowering
3	Red shoot (*Syzygium myrtifolium*)	Colored leaves
	Shrubs/Bushes	
4	Allamanda	Climbing, flowering
5	Red Nusa Indah (*Mussaenda erythrophylla*)	Flowering
6	Cup plant / Mangkokan (*Polyscias scutellaria*)	Unique leaves
	Ground Cover	
7	Elephant grass (*Pennisetum purpureum*)	Coarse texture
8	Purple lantana (*Lantana camara*)	Flowering
9	Wire grass	Medium texture

The Semarang City Government can following that improve the development of green open spaces (GTH) in roadside zones, railway corridors, riverbanks, coastal regions, and the separations between collector and arterial roads. According to Minister of Public Works Regulation Number 5 of 2008, the boundary line is defined as the outside safety limit for the construction of structures and/or fences. Santoso *et al.* (2012) assert that shade trees fulfill both ecological and aesthetic functions. Ecologically, shade trees enhance microclimate comfort while simultaneously sequestering contaminants from motor vehicles, primarily lead (Pb). As of 2021, the Central Java Statistics Agency reported that Semarang City had 1,875,781 registered motorized vehicles. Consequently, it is essential to optimize green open space (GTH) along roadside peripheries. The specifications for vegetation suitable for roadside planting are delineated in the Regulation of the Minister of Public Works Number 5 of 2008. A selection of several plants suitable for providing shade along highways and pedestrian walkways, which meet the established requirements, has been compiled, with three plants from each of the most recommended categories as seen in Table 6.

Table 6. Examples of Plants for Shading Roads and Pedestrian Paths based on Regulation of the Minister of Public Works Number 5 of 2008

No.	Plant Type and Name	Height (m)	Planting Distance (m)
Trees			
1	Butterfly flower (*Bauhinia purpurea*)	8	12
2	Tanjung (*Mimusops elengi*)	15	12
3	Trengguli (*Cassia fistula*)	15	12
Shrubs / Ground Cover			
1	Croton (*Codiaeum variegatum*)	0.7	0.3
2	Sword plant (*Cordyline fruticosa*)	0.5	0.2
3	Spider lily (*Chlorophytum comosum*)	0.3	0.15

Transportation is a vital necessity for people to support mobility. Transportation impacts several aspects, such as development, regional development, the economy, the environment, and the spatial structure of an area. However, the benefits of transportation are also accompanied by various intertwined negative impacts, such as increased use of private vehicles, the use of non-environmentally friendly fuels, and increased carbon emissions, which also impact the microclimate. Therefore, to minimize the increase in the microclimate in Semarang City, the concept of green transportation needs to be implemented. Green transportation is a concept for developing and constructing a transportation system that supports the implementation of a green city, with the principles of minimizing negative impacts on the environment, efficient fuel use, and a human-oriented approach (Primastuti, 2021). According to Andriani & Yuliastuti (2013), the concept of green transportation refers to transportation means with a low negative impact on the surrounding environment. For example, non-motorized modes of transportation such as walking and cycling; carsharing to prioritize the use of public transportation; and efforts to build an urban transportation system that minimizes space and energy use, thereby minimizing greenhouse gas emissions and maintaining green open spaces in urban areas.

3.5 Adaptation of Community Lifestyle Patterns

Semarang City is classified within the "partially comfortable" and "uncomfortable" categories of the THI index year-round. Consequently, alongside environmental engineering aimed at enhancing thermal comfort, people of Semarang must modify their habits to mitigate the risk of heat stress. Two factors can affect the emergence of heat stress symptoms in humans: (1) hydration levels and (2) apparel selection.

Engaging in outdoor activities at elevated temperatures leads to considerable fluid depletion. Utama (2019) states that adults lose 2.5 liters of fluid daily. This fluid is eliminated via urine (1.5 liters), sweat (0.5 liters), respiration (0.4 liters), and feces (0.1 liters). Excessive fluid loss may result in dehydration (Wahyuni et al., 2020). Consequently, people of Semarang must be vigilant regarding their consumption of drinking water and salt to prevent dehydration. Water consumption is a vital cooling mechanism in elevated temperatures (Sari, 2017). The Regulation of the Minister of Health of the Republic of Indonesia Number 28 of 2019 regarding the Recommended Nutritional Adequacy Intake for the Indonesian populace indicates that variations in gender and age influence the overall water intake requirements, as illustrated in Table 7.

Table 7. Hydrating Spending by Gender and Age Demographic based on Minister of Health Regulation Number 28 of 2019

Age (Years)	Daily Water Intake Requirement (Liters)	
	Male	Female
13–15	2.1	2.1
16–18	2.3	2.15
19–29	2.5	2.35
30–49	2.5	2.35
50–64	2.5	2.35
65–80	1.8	1.55

Making changes to the type of clothing worn by Semarang residents during outdoor activities is one necessary adaptation to minimize the potential for heat stress. Apparel primarily functions to shield the human body from solar radiation and frigid air, in addition to augmenting one's aesthetic appeal (Riyanto, 2003). Two parameters for selecting apparel that can reduce heat stress are textiles that promote adequate air circulation and vivid hues (Mufida *et al.,* 2016). Both criteria affect the degree of heat absorption and heat emission.

Ariyanti (2018) asserts that cotton is the optimal fabric for hot conditions. Cotton possesses a thin layer that facilitates optimal air circulation and efficient absorption of water and moisture, hence enhancing body temperature decrease. Research by Mufida *et al.* (2016) reveals that vibrant colors, including white, green, and blue, are appropriate for wear in hot climates. This is due to the fact that light-colored garments possess a minimal heat absorption capacity while facilitating efficient heat discharge. In contrast, dark-hued materials, such as black, absorb sunlight due to their high emissivity, indicating effective heat absorption.

4. Conclusion

This study maintains plenty of constraints that warrant consideration. The climate comfort analysis relies exclusively on air temperature and relative humidity parameters through the Temperature Humidity Index (THI) approach, omitting other elements such as wind speed, solar radiation, and cloud cover that can affect thermal comfort. The spatial depiction of Semarang City's climatic conditions is based on data from three meteorological stations, thereby failing to properly account for microclimate differences at the level of residential neighborhoods or urban blocks. This study is a quantitative descriptive analysis and does not examine the causal relationship between alterations in land use, reduction of green open spaces, and heightened heat stress. Consequently, more research is advised to incorporate high-resolution geographical analysis, supplementary climate variables, and inferential statistical methodologies or urban climate models.Considering the study "Heat Stress Analysis in Semarang City Utilizing the Temperature and Humidity Index (THI) Method," numerous findings may be inferred:

The peak THI index values (uncomfortable) manifest during humid and wet months. This transpires during the three rainy months of April, May, and October, as well as the humid month of November. This condition signifies that the interplay of elevated average air temperature and relative humidity directly exacerbates heat stress and the likelihood of heat-related issues in Semarang City, particularly among the working-age population involved in outdoor activities. According to the THI index calculation, the climate comfort level in Semarang City is classified into two categories: "partly comfortable" at 66.67% (8 months or 244 days per year) and "uncomfortable" at 33.33% (4 months or 122 days per year). The aforementioned conditions affect the likelihood of heat stress happening during the months, with the greatest likelihood observed in April, May, October, and November for males aged 25 to 64 and females aged 15 to 64.

The months with the highest THI values—April, May, October, and November—are designated as priority intervention periods. Consequently, environmental engineering proposals emphasize the enhancement and expansion of green open areas, namely urban forests and street-shading flora, which have been substantiated in the literature to lower air temperature and ameliorate the microclimate. Moreover, suggestions for lifestyle modifications, including enhanced hydration intake and the selection of suitable clothing types and colors, are especially pertinent for those of working age participating in outdoor activities during times of significant thermal discomfort.

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