Journal of
Ge🌍grafika

THERMAL COMFORT ANALYSIS OF KECAMATAN MAKASAR DISTRICT, JAKARTA TIMUR USING THERMAL HUMIDITY INDEX (THI)

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Abstract: Hot and humid climatic conditions significantly influence the quality of life in urban areas, particularly in tropical regions. Urbanization and climate change pose challenges to thermal comfort in Kecamatan Makasar, Jakarta Timur, a densely populated urban area. This study analyzes the thermal comfort levels in the area using temperature and humidity data from the Halim Perdanakusuma Meteorological Station for the period 2019–2023. The Thermal Humidity Index (THI) was calculated using the Nieuwolt equation to categorize thermal comfort levels. The results show variations in thermal comfort throughout the year, with the worst conditions in 2023 due to the El Niño phenomenon, while 2022 was more comfortable due to the influence of La Niña. This study highlights the need for adaptation strategies, such as implementing eco-friendly building designs, vertical urban farming, and planting shade trees like Taiwan Beuty, Kingkip, and Pacing, to enhance thermal comfort in Kecamatan Makasar.

INTRODUCTION

Thermal comfort is a crucial aspect that affects the quality of life of urban communities such as Indonesia. High temperatures and humidity often become challenges in creating a comfortable environment. Not only does thermal comfort contribute to physical comfort, but it also significantly impacts health, productivity, and urban sustainability (Saputri et al., 2023). Good thermal comfort can reduce the risk of thermal stress, dehydration, fatigue, and work decline, thereby improving people's overall quality of life (Ratnasari & Asharhani, 2021).

Adequate thermal comfort is essential for public health, as it can reduce the risk of heat-related illnesses such as heatstroke and dehydration (Eddy Imam, 2012). In addition, an environment with excellent thermal comfort can increase worker productivity, reduce error rates, and improve job satisfaction (Mandey & Kindangen, 2017). On the other hand, efficient thermal comfort management also contributes to urban sustainability by reducing energy use for cooling and reducing the city's carbon footprint (Rahardjo & Afrianto, 2024). Thus, thermal comfort is not only important for individual well-being, but also for the sustainability of the urban environment and economy as a whole.

Temperature, climate, weather, as well as physical, physiological, and psychological factors, greatly influence thermal comfort, defined as a subjective view of environmental temperature (Binarti & Koerniawan, 2021). To determine the thermal comfort conditions objectively, measurement methods such as Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) are appropriate International Standard ISO 7730 (2005). However, in tropical areas such as

Indonesia, Thom (1959) introduced and The Neighborhood (1977) updated the Thermal Humidity Index (THI) in tropical areas like Indonesia, making it a more relevant method (Annisa et al., 2015; Fauzi et al., 2023)

This study focuses on Kecamatan Makasar, Jakarta Timur, which has a high population density and intensive economic activity. Kecamatan Makasar is located in Jakarta Timur and covers an area of 21.87 km². 208,365 people live in this district, according to the 2020 population census (Central Statistics Agency, East Jakarta, 2022). Due to the high population density, Kecamatan Makasar uses most of its land for various functions such as residential areas, business areas, public facilities, and social facilities. The Halim Perdanakusuma Air Force Complex, located in Halim Perdanakusuma Village, occupies about 77% of the total area of Kecamatan Makasar, which is equivalent to 1,700 hectares (Halim Perdanakusuma Air Force Base (KOOPSUD I), 2024). Housing and public facilities serve the growing population in the remaining 33% (Central Statistics Agency, East Jakarta, 2019).

Additionally, Kecamatan Makasar is well-known for its traffic jams. Based on initial observations, during rush hour there are long traffic jams, especially on Jalan Raya Pondok Gede and Jalan Raya Halim Perdanakusuma. The large number of haphazardly parked vehicles, busy market activities, and ongoing infrastructure projects all contribute to this congestion, narrowing the road and slowing down traffic flow. This congestion not only has an impact on longer travel times for drivers, but also causes stress and fatigue, as well as air pollution due to emissions from vehicles stuck in traffic jams(Napitu et al., 2020). Air pollution due to vehicle emissions stuck in traffic jams is also a serious problem that affects air quality and the health of local people (Matz et al., 2019).

With high population density and dense mobility, temperatures in this area tend to be higher compared to areas that have more green open spaces (Insan & Prasetya, 2021). Therefore, conducting a thermal comfort analysis in Kecamatan Makasar is crucial for identifying the trends in community thermal comfort. By understanding the condition of thermal comfort in the community, the government and the community can design effective strategies to improve thermal comfort.

This study aims to evaluate the level of thermal comfort in Kecamatan Makasar using THI and provide a better understanding of the thermal conditions in the area. Unlike previous studies, which were generally broader in scale or used different analyses, this study is specific to Kecamatan Makasar and uses the latest data for analysis. This study will make a significant contribution to the knowledge of thermal comfort in dense urban areas and provide recommendations for policymakers to improve the quality of life for people in Kecamatan Makasar. This study aims to identify effective strategies to mitigate the negative impacts of thermal conditions and enhance thermal comfort by analyzing temperature and humidity data.

LITERATURE REVIEW
1. Thermal Comfort
According to (Muhaimin et al., 2023) thermal comfort is an individual's subjective perception of the thermal environment around them. This is a very personal perception and varies between individuals. This is due to several factors, such as temperature, climate, weather, physical, physiological, and psychological (Binarti & Koerniawan, 2021). People's health, well-being, and productivity also closely correlate with thermal comfort. A study by Ratnasari and Asharhani (2021) shows that poor thermal conditions can trigger thermal stress, dehydration, and heatstroke, which ultimately reduces people's health and productivity.

2. Impact of Thermal Discomfort
Thermal discomfort can cause various health problems. Excessive heat exposure can cause serious health problems such as heatstroke and dehydration (Widiarini & Dwi, 2023). In addition, uncomfortable

thermal environments can reduce work productivity, increase work accident rates, and have a negative impact on work quality. Research indicates that workers in comfortable thermal environments typically exhibit enhanced performance and reduced error rates (Santoso & Rijanti, 2022).

3. Thermal Humidity Index (THI)

The community uses the Thermal Humidity Index (THI), also known as the Thermal Comfort Index in Indonesian, to gauge their level of thermal comfort (Azis et al., 2022). Using air temperature and humidity data as variables, the THI method can classify the community's thermal comfort index (Damayanti et al., 2023). Studies related to thermal comfort in urban environments frequently use THI, which provides an overview of the thermal conditions felt by humans. The temperature and humidity used are the average calculation results in 24 hours. If the temperature and humidity indicators are stable, the calculation results in the THI index are considered to be the most accurate measure of thermal comfort.

RESEARCH METHODS

To measure, analyze, and describe the level of thermal comfort in Makasar District, this study uses a descriptive research design with a quantitative approach. This type of study aims to describe and understand the current status of individuals, settings, conditions, or events (Salkind, 2013). The quantitative approach allows researchers to measure and analyze numerical data with high accuracy, which is key to understanding patterns and trends in the data (Purnomo, 2024).

The secondary data used for this study includes air temperature and humidity data from 2019 to 2023. The data was obtained from the Halim Perdanakusuma Meteorological Station located in Makasar District. The Halim Perdanakusuma Meteorological Station has a good track record in providing meteorological data. Additionally, its location in Makasar District makes it representative of the weather

conditions in the area. Data analysis is an important step in research because it allows researchers to understand patterns and relationships in the data collected (A. Fauzi & Pradipta, 2018). In this study, data analysis will use the Thermal Humidity Index (THI) analysis technique. The THI parameter is used to measure thermal comfort based on two main factors, namely temperature and air humidity (F. Fauzi et al., 2023). THI values are analyzed using the Niewolt equation (1977) as follows:

$$THI = 0,8T + (RH \times T)/500$$

Description:
THI = Thermal comfort index value
T = Air temperature (°C)
RH = Humidity (%)

Emanuel (Effendy et al., 2006) divides the comfort index into three categories: comfortable, fairly comfortable, and uncomfortable. The results of this analysis will produce comfort index values displayed in Table 1.

Table 1. Thermal Comfort Index Criteria

No	THI Value	Description
1	21 < THI < 24	Comfortable
2	25 < THI < 27	Fairly Comfortable
3	THI > 27	Uncomfortable

Source: Emanuel (Effendy et al., 2006)

The THI method has several advantages and disadvantages in thermal comfort research. One of the main advantages of the THI method is its ease of application and interpretation. This method is widely recognized and has been used in various studies focusing on thermal comfort, especially in tropical regions. However, the THI method also has some limitations, one of which is its inability to account for other environmental factors that influence thermal comfort, such as wind speed and radiation

RESULTS AND DISCUSSION

Kecamatan Makasar is one of the areas in Jakarta Timur with a fairly large population and many economic and social

activities. Located at 6°18'06.4" - 6°14'21.6" S, 106°55'16.1"-106°52'19.3" E, Kecamatan Makasar borders Kecamatan Jatinegara, Kramat Jati, Cipayung, Pondok Gede, and Duren Sawit. With an extensive area of 21.87 km², there are 208,365 people living there, or 9,527 per km². They reside in five kecamatan: Pinang Ranti, Makasar, Halim Perdana Kusuma, Cipinang Melayu, and Kebon Pala.

This high population density makes Kecamatan Makasar a dynamic center of community activities with various challenges related to thermal comfort and environmental quality. This study uses meteorological data from Kecamatan Makasar, Jakarta Timur, which includes average monthly temperature and humidity.

This data was obtained from the Halim Perdanakusuma Meteorological Station located at 06º 17' 03" LS, 106º 53' 06" BT, and at an elevation of 26 meters above sea level. Based on the monthly temperature data for 2019–2023 in Table 2, it is known that the highest monthly temperature occurred in October 2023, namely 31.3°C, while the lowest monthly air temperature occurred in February 2021, which was 26.8°C. In addition, based on the average annual temperature, 2023 was the hottest year with an average annual temperature of 29.0 °C.

Figure 1. Administrative Map of Kecamatan Makasar
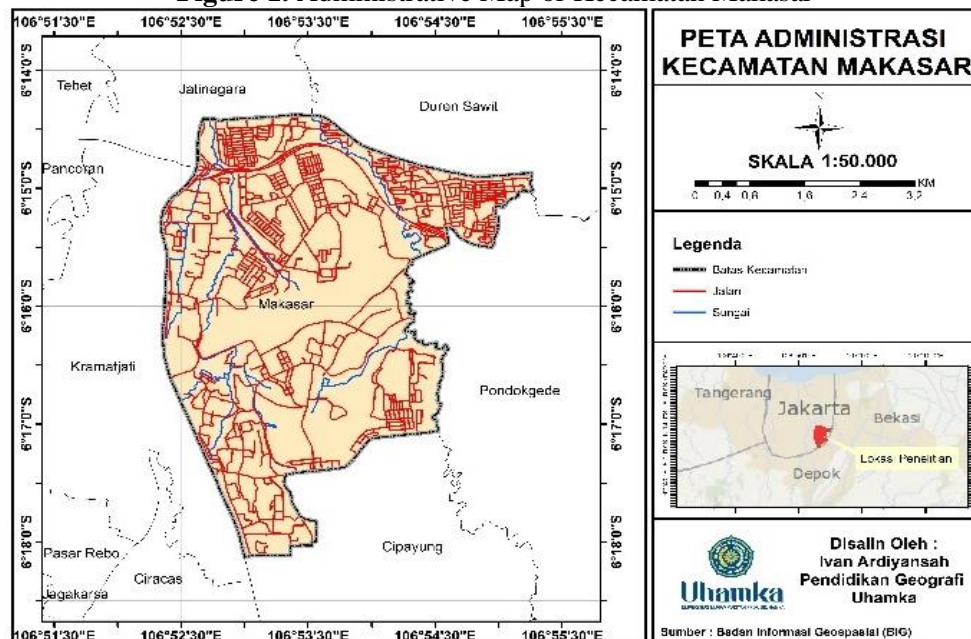
Source: secondary data processing

This study also uses monthly humidity data from the Halim Perdanakusuma Meteorological Station. Based on the monthly humidity data, as shown in Table 3, it is known that the highest monthly humidity occurred in January and February 2020, which was 87%. Conversely, the lowest monthly humidity occurred in September and October 2023.

These data provide an overview of the variations in temperature and humidity in Kecamatan Makasar during the study period and assist in the analysis of thermal comfort in the area.

The temperature and humidity data were then analyzed using the Niewolt equation to produce monthly thermal comfort index values for the period 2019-2023. Table 4 shows that the average annual thermal comfort index (THI) value for Kecamatan Makasar exceeds 26.8. The highest THI value occurred in October 2023 with a value of 28.7, while the lowest occurred in August 2019, which was 25.8. These results indicate that thermal comfort in Kecamatan Makasar varies throughout the year, with some months showing lower levels of comfort compared to other month.

Table 2. Monthly Temperature (°C)

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
2019	27.3	27.3	27.5	28.1	28.6	28.5	28.0	27.7	28.5	29.5	29.1	27.8	28.2
2020	27.4	27.1	27.9	28.2	28.5	28.5	27.9	28.3	28.7	28.2	28.0	27.4	28.0
2021	27.1	26.8	27.4	27.8	28.5	27.6	28.0	28.1	28.4	28.3	27.4	28.2	27.8
2022	27.6	27.0	27.4	27.8	27.8	27.1	27.9	28.1	28.0	27.8	27.8	27.6	27.7
2023	27.5	27.4	27.8	29.4	28.9	28.5	28.4	29.4	30.0	31.3	29.8	29.9	29.0

Source: Halim Perdanakusuma Meteorological Station

Table 3. Monthly Humidity (%)

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
2019	80	82	78	80	75	70	66	65	65	63	71	83	73
2020	87	87	81	81	79	75	75	71	69	74	77	76	78
2021	80	83	81	78	81	84	73	72	73	76	80	78	78
2022	82	83	84	82	83	82	75	75	78	77	79	82	80
2023	76	80	80	73	76	74	68	65	59	59	71	69	71

Source: Halim Perdanakusuma Meteorological Station

Table 4. Monthly Thermal Comfort Index (THI) Values

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
2019	26.2	26.3	26.3	27.0	27.2	26.8	26.1	25.8	26.5	27.3	27.4	26.9	26.6
2020	26.7	26.4	26.8	27.1	27.3	27.1	26.5	26.7	26.9	26.7	26.7	26.1	26.8
2021	26.0	25.9	26.4	26.6	27.4	26.7	26.5	26.5	26.9	26.9	26.3	27.0	26.6
2022	26.6	26.1	26.5	26.8	26.9	26.1	26.5	26.7	26.8	26.5	26.6	26.6	26.6
2023	26.2	26.3	26.7	27.8	27.5	27.0	26.6	27.3	27.5	28.7	28.1	28.0	27.3

Source: Secondary Data Processing

Furthermore, Emanuel (Table 1) matches the THI value with the thermal comfort class to determine the level of thermal comfort in the Kecamatan Makasar community. In Table 4, the THI index value in Kecamatan Makasar shows significant variation. Emanuel's thermal comfort criteria revealed that most study period months in Table 5 fell into the "Quite Comfortable" category, with THI values ranging from 25.8 to 26.9. These months include January, February, March, June, July, August, September, and December in various years. However, there are several months that fall into the "Uncomfortable" category with THI values above 27. These months include April, May, October, and November in 2019; April and May in 2020; and most of the months in 2023, such as April, May, August, September, October, November, and December. There are no months that fall into the "Comfortable" category with THI values of 21-24 during the study period.

The results of the study showed that thermal comfort in Kecamatan Makasar changed throughout the year, with certain months experiencing a decrease in comfort levels. In 2023, October recorded the highest thermal discomfort, with a THI value of 28.7. Research by Patle & Ghuge (2024) also showed that variables such as community activities and rapid climate change in tropical regions can affect THI

variations. Climate conditions strongly influence variables such as air temperature, relative humidity, and rainfall patterns, leading to changes in thermal comfort (Arsad et al., 2023). These results also reveal that Kecamatan Makasar experiences uncomfortable conditions when the seasons change, either from the dry to the rainy or vice versa, a phenomenon known as Pancaroba.

Table 5. Monthly Thermal Comfort Analysis

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
2019	CN	CN	CN	CN	TN	CN	CN	CN	CN	TN	TN	CN	CN
2020	CN	CN	CN	TN	TN	TN	CN	CN	CN	CN	CN	CN	CN
2021	CN	CN	CN	CN	TN	CN	CN	CN	CN	CN	CN	CN	CN
2022	CN	CN	CN	CN	CN	CN	CN	CN	CN	CN	CN	CN	CN
2023	CN	CN	CN	TN	TN	TN	CN	TN	TN	TN	TN	TN	TN

Source: Analysis Results Table 4. Thermal Comfort Index Value
Description: CN: Quite Comfortable, TN: Not Comfortable

Transitional periods, or periods of changing seasons from the rainy season to the dry season or vice versa, are characterized by rapid and unpredictable changes in the weather (Wiratmo, 2018). The weather can change significantly from day to day, and there are significant temperature variations during this transition period. Indonesia experiences two transition periods in a year, which take place in March-May and September-November (Tukidi, 2010). Temperature and humidity increase during this period, especially during the transition from the rainy season to the dry season from March to June. This causes uncomfortable thermal conditions in the district from April to June and September to November.

2022 is a relatively comfortable year, due to the La Niña climate event, which causes several areas in Indonesia to experience increased rainfall and decreased temperatures. La Niña is a climate phenomenon that occurs when sea surface temperatures in the central and eastern tropical Pacific Ocean are lower than usual, which has an impact on global weather (Treasures & Literature, 2017). This increases thermal comfort in several areas, including Kecamatan Makasar. Higher rainfall will sustain soil moisture and reduce air temperatures, thereby fostering a more comfortable environment for the residents. As a result, Kecamatan Makasar includes every month in 2022 under the "Quite Comfortable" category, indicating that climate conditions are becoming more stable and providing comfort to the community throughout the year.

On the other hand, in 2023 Indonesia will experience an El Niño event. An El Niño event is a climate phenomenon caused by an increase in sea surface temperatures above normal in the central and eastern Pacific Ocean, which has an impact on global weather (Treasures & Literature, 2017). n Indonesia, El Niño typically causes drier and hotter conditions that increase air temperatures and decrease relative humidity. Therefore, 2023 is a year marked by numerous instances of thermal discomfort.

Urbanization and land conversion also contribute to increasing temperatures in Jakarta, which affects the thermal comfort index (Hermawan, 2015). Increasing population density causes the need for buildings and infrastructure to increase. Tall concrete buildings and asphalt increasingly replace green open spaces, absorbing and emitting heat and obstructing the natural flow of wind. Intensive human activities, such as the use of motor vehicles and industrial activities, also produce heat and pollution, which exacerbate thermal conditions (Ismiyati et al., 2014).

Arsad et al. (2023) highlight the importance of behavioral adaptation in dealing with changing thermal conditions.

This study shows that adaptations such as clothing adjustments, building design, and green open space creation can help improve thermal comfort. Optimizing urban farming with vertical methods is a solution to address the issue of thermal comfort in Kecamatan Makasar. By utilizing increasingly narrow urban land, urban farming with vertical methods not only helps reduce air temperature but also improves air quality (Aini & Daniah, 2020). This practice enables the utilization of limited land, including roofs, walls, and yards, to cultivate a variety of plants that can contribute to a cooler and more comfortable environment for residents. Some plants that can effectively reduce pollution and cool the air are Taiwan Beuty, Kingkip, and Pacing (Kusminingrum, 2018).

CONCLUSION

The Halim Perdanakusuma Meteorological Station's temperature and humidity data from 2019 to 2023 revealed that Kecamatan Makasar experiences seasonal variations in thermal comfort. The highest THI value occurred in October 2023 with a value of 28.7, while the lowest value occurred in August 2019 with a value of 25.8. The results of the analysis show that most months in the study period fall into the "Quite Comfortable" category with THI values between 25.8 and 26.9. However, several months showed high levels of discomfort, especially in 2023. Factors such as urbanization and rapid climate change in tropical areas such as Jakarta contribute to this THI variation.

This study is in line with the findings Kartika et al. (2021) in Surabaya City, which also found that urbanization and reduced green open space contributed to increasing THI and decreasing thermal comfort in urban areas. To address the issue of thermal comfort in Kecamatan Makasar, optimizing urban farming through vertical methods presents a viable solution. Therefore, this study offers valuable insights for urban planning in Kecamatan Makasar, Jakarta Timur, with the aim of enhancing thermal comfort for its residents. We can recommend the implementation of building designs that

maximize vertical use and the planting of trees. Taiwan Beuty, Kingkip, and Pacing have the ability to filter pollution and reduce temperatures.

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