

Typological Mapping of Thermal Comfort (THI): The Role of Urban Green Space and Carbon Emissions

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Abstract

The massive growth of urban areas in Kapanewon Depok has triggered microenvironmental degradation, which has resulted in a decrease in the thermal comfort of the community. This study aims to identify the level of vegetation density of Public Green Open Space (GOS), map CO₂ emission hotspots and thermal comfort (THI), and analyze the typology of the relationship between these variables. The method used is quantitative descriptive with the integration of remote sensing (NDVI Landsat 8) and spatial modeling. This study presents an original approach through a spatial typology analysis framework that synergizes THI, NDVI, and CO₂ emission variables to analyze the complexity of microclimate phenomena in urban areas in depth. The findings show that the study area is dominated by the Comfortable-Low Emission typology (28.93%), especially in areas with high vegetation density. However, an urban heat island phenomenon was found in the critical zone of 0.56% which forms a thermal hotspot due to the effect of the urban canyon on the commercial area. Other findings show the typology of the THI and NDVI relationship dominated by the Comfortable-Low NDVI typology (24.74%), covering more than 52% of the area thanks to the support of 28 Public Green Open Space points and the campus forest on the west side. Conversely, critical areas with an Uncomfortable-Low NDVI typology (1%) are concentrated in commercial areas. Therefore, a government strategy is needed to prioritize protecting rice fields and adding shade vegetation in commercial areas.

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Introduction

Urbanization is a complex, multidimensional phenomenon linked to various social, economic, cultural, demographic, and spatial processes and phenomena that lead to increased population concentration, administrative activities, and commercial activities in urban areas (Jati et al., 2022). This phenomenon brings about significant spatial changes and gradual shifts in land-use patterns and constitutes a diffusion process that spreads outward from urban centers toward suburban areas (Bitozor et al., 2024). Urbanization is prevalent in many countries, particularly developing nations such as those in ASEAN, which have continued to experience an upward trend from 2018 to 2022 (Qodhari & Khudhori, 2024).

The growing population, increasing ownership of motor vehicles, and land-use conversion impact the ecological balance of cities and lead to the loss of ecosystem services that play a role as carbon sinks, climate regulators, air quality maintainers, oxygen providers, and temperature regulators (Dzulfiqar et al., 2024). Additionally, land-use changes resulting from urbanization contribute to increased surface temperatures, which in turn affect thermal comfort levels in urban areas (Chairuman et al., 2023). This aligns with research conducted by Chairuman et al. (2023), which found that the reduction of Green Open Spaces and the increase in built-up area density positively contribute to the occurrence of the Urban Heat Island effect in the Caturtunggal area.

Depok Subdistrict is a subdistrict with a high population density from 2021 to 2024 (Fig 1). Depok Subdistrict also had the highest rate of land-use conversion in Sleman Regency from 2010 to 2020, driven by rapid urbanization (Table 1). The urbanization occurring in Depok Subdistrict is a spillover effect of Yogyakarta City's growth. This occurs because the designation of Yogyakarta City as a National Activity Center (PKN) under Yogyakarta City Regulation No. 2 of 2021 on the Yogyakarta City Spatial Plan (RTRW) for 2021–2041 has caused the area within Yogyakarta City to become increasingly constrained, leading to a shift toward Depok Subdistrict. This is a concrete manifestation of the theory of urban growth or Growth Poles in the form of the Spread effect (trickle-down), where growth in the city can spread to surrounding areas (Tambun et al., 2024).

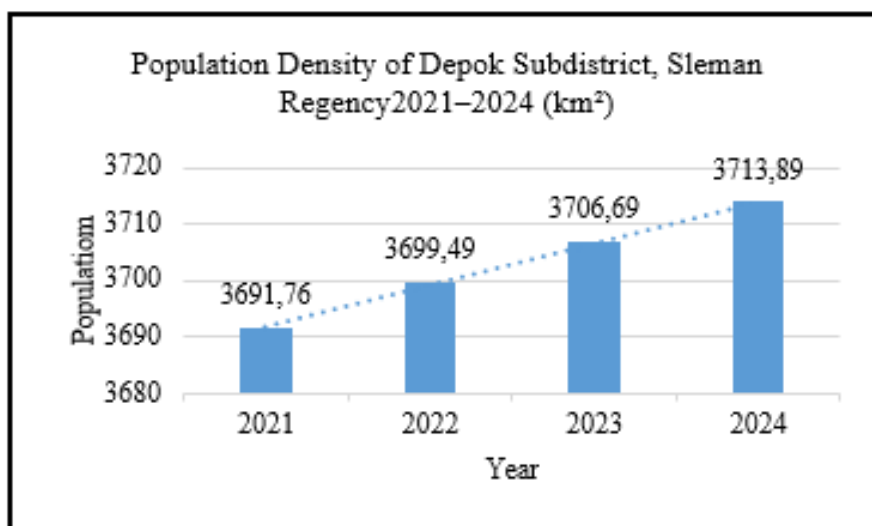


Fig 1. Graph of Population Density Increase in Depok Subdistrict, 2021–2024

Source: Sleman Regency Statistics Agency

Table 1. Land Use Change in Depok Subdistrict, 2010–2020

Land Use	Area in 2010 (ha)	Area in 2020 (ha)	Change in Area (ha)
Buildings	74,9	101,6	(+26,6)
Vacant Land	103,4	108,4	(+5,0)
Residential Areas	1326,4	1683,8	(+357,5)
Rice Fields	1200,5	947,1	(-253,4)
Scrubland	440,4	304,6	(-135,4)

Source: (Islami et al., 2020).

Maguwoharjo Village is one of the villages with the highest rate of land-use conversion in Depok Subdistrict, where the residential area increased by 52.72% (792 ha) and expanded by 1.33% (20 ha). On the other hand, the area of vacant land decreased by 1.83% (27.51 ha) in 2015. Land conversion from undeveloped land or agricultural land to developed land has been occurring since 1980 ([Septian dan Taryono, 2019](#)). Additionally, Kapanewon Depok is the sub-district with the highest rate of rice field loss in Sleman Regency at (-10.93%), followed by Kapanewon Tempel and Gamping at (-8.71%) and (-4.51%), respectively ([Rizkiani & Sudrajat, 2015](#)). The presence of universities and large higher education institutions is one of the reasons for the conversion of undeveloped land into developed land in Kapanewon Depok ([Rahmawati & Arif, 2023](#)).

The massive growth of urban areas in Kapanewon Depok, Sleman Regency, has had serious consequences for the quality of the microenvironment ([Sijabat et al., 2025](#)). In parts of Kapanewon Depok, the integration of educational centers, residential areas, and commercial zones, along with land-use changes, has occurred on a massive scale. The phenomenon of land conversion from vegetated areas to built-up areas such as concrete and asphalt has been shown to cause a local increase in surface temperature ([Bhaskara & Pratomo, 2023](#)). This condition can indirectly impact a decline in the thermal comfort index for urban residents, where the Thermal Humidity Index (THI) serves as a critical parameter in assessing urban quality of life ([Sijabat et al., 2025](#)). This issue of thermal comfort is no longer merely an aesthetic concern but has become a real threat to the health and productivity of people engaging in activities in public spaces ([Tarigan et al., 2024](#)).

Environmental issues in Kapanewon Depok stem from an imbalance between the pace of infrastructure development and the availability of a proportional amount of public green open space (RTH) in urban areas ([Anggraeni & Wibawa, 2024](#)). Vegetation, which theoretically plays a vital role as a natural cooler through shading mechanisms and evapotranspiration processes, is insufficient in creating thermal comfort due to high Daily Traffic Volume (DTV), which is the primary source of emissions on the Yogyakarta-Solo Road. The concentration of CO₂ emissions trapped between dense building structures creates an urban canyon effect, which accelerates the formation of thermal hotspots in high-density areas ([Tarigan et al., 2024](#)).

Numerous studies have been conducted on the impact of urbanization on environmental quality. However, previous research has generally focused only on analyzing carbon emissions from the transportation sector or mapping surface temperatures using the Normalized Difference Vegetation Index (NDVI) in isolation, without examining their spatial interactions within a single densely populated administrative region. For example, the study by [Kusumawardani & Navastara, \(2018\)](#) focused solely on analyzing carbon emissions from the transportation sector in the SIER

Industrial Area of Surabaya, and the study by [Rosyidy et al. \(2020\)](#) focused solely on analyzing the influence of green open space availability on thermal comfort levels (THI).

Unlike those two studies, this research adopts an integrative approach that combines THI, NDVI, and CO₂ emissions within a single spatial typology framework to comprehensively analyze the complexity of the urban microclimate. This is what constitutes the novelty of this study. Although the relationship between vegetation and temperature or thermal comfort index (THI) is well-established, there remains a research gap in understanding how motor vehicle emissions along arterial corridors interact with the scarcity of public open green spaces to create specific zones of thermal discomfort.

Based on this background, this study was conducted to address the urgent need for adaptive spatial planning in response to microclimate changes. Specifically, this study aims to: (1) Map the relationship between thermal comfort index (THI) and NDVI. (2) Map the relationship between thermal comfort index (THI) and emissions. (3) Formulate strategic recommendations for thermal mitigation and public open space management relevant to policymakers in Kapanewon Depok and the surrounding area.

Method

This study employed a quantitative approach using a typological methodology. The typological mapping in this study aimed to examine the spatial interrelationships among variables within a single geographical area. The typological approach in this study enabled the identification of more specific environmental characteristics.

Data collection in this study was carried out using two different sampling techniques tailored to the characteristics of the variables: Purposive Sampling to identify Public Open Spaces for validating the NDVI class, and Stratified Random Sampling to collect THI data on temperature and humidity. The integration of these two sampling methods was used to ensure that every land-use characteristic from emission hotspots to permanent vegetation zones is proportionally represented in the analysis.

The data analysis technique was carried out through several systematic stages. NDVI data obtained from the processing of Landsat-8 satellite imagery to depict vegetation density, and CO₂ emission data calculated using the IPCC formula derived from human respiration and motor vehicles:

$$Q = Ni \times Fe \times Ki \times L \dots \dots \dots \text{Equation (1)}$$

Notes:

- Q = Total emissions (g/hour)
- Ni = Number of Type-I motor vehicles (vehicles/hour)
- Fe = Emission factor
- Ki = Specific fuel consumption of Type-I (liters/100 km)
- L = Road length (km)

$$\text{CO}_2 \text{ emission} = n \times FE \dots \dots \dots \text{Equation (2)}$$

Notes:

- N = Population (people)
- FE = Emission factor (3,2 kg CO₂/person.day)

Next, the THI value is calculated using the formula from Nieuwolt (1998):

$$THI = 0,8T + (RH T)/500.....Equation (3)$$

Notes:

THI = Temperatur Humidity Index (Index of thermal comfort)

RH = Relative Humidity (%)

T = Temperature (°C)

Next, the data from each variable were interpolated using IDW to determine the distribution of NDVI, THI, and CO₂ emissions. Subsequently, NDVI and THI maps, as well as THI and CO₂ Emissions maps, were overlaid to determine the influence and relationship between NDVI and CO₂ Emissions on the THI (Thermal Humidity Index), and the process concluded with an overlay or superimposition using land use maps via spatial typology techniques. Using the relationship matrices between THI and NDVI, as well as between THI and CO₂ emissions, a problem-solving framework was developed for each typology to inform policy formulation. See [Fig 2](#).

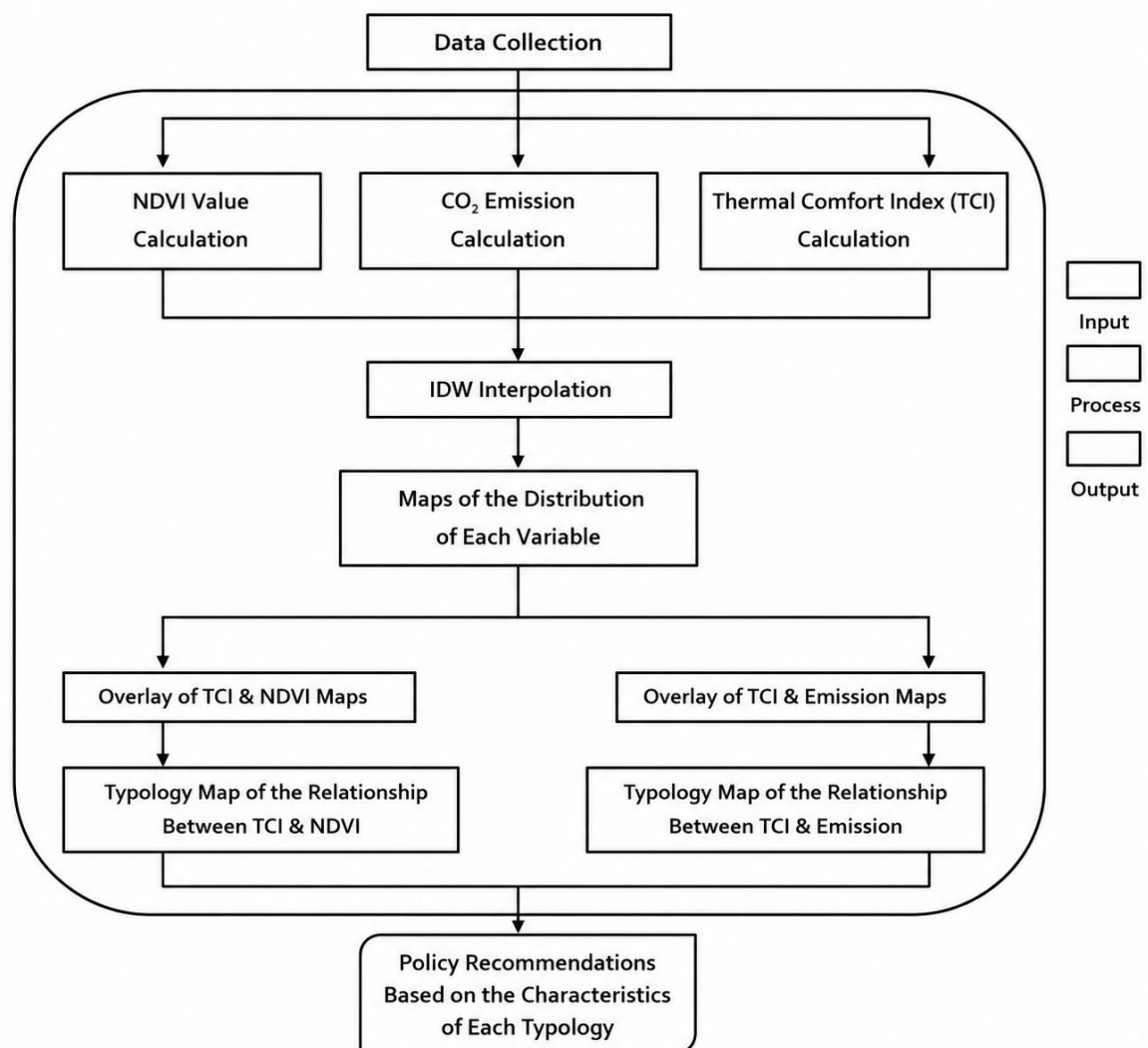


Fig 2. Research Flowchart

The typology classes of the relationship between THI and NDVI and the land use map of Kapanewon Depok are divided into 9 typology classes ([Table 2](#)).

Table 2. Typological Classes of the Relationship Between THI and NDVI

Typological Class	Description
1-1	Fairly Comfortable-High NDVI
1-2	Fairly Comfortable-Moderate NDVI
1-3	Fairly Comfortable-Low NDVI
2-1	Uncomfortable-High NDVI
2-2	Uncomfortable-Moderate NDVI
2-3	Uncomfortable-Low NDVI
3-1	Fairly Comfortable-High NDVI
3-2	Fairly Comfortable-Moderate NDVI
3-3	Fairly Comfortable-Low NDVI

Next, the typology of the relationship between THI and NDVI and land-use maps is divided into 18 types ([Table 3](#)).

Table 3. THI and NDVI Relationship Typology Types on Land Use Maps

No	Land Use Type: THI and NDVI Relationship Typology Class
1	Undeveloped Land: 1-1
2	Undeveloped Land: 1-2
3	Undeveloped Land: 1-3
4	Undeveloped Land: 2-1
5	Undeveloped Land: 2-2
6	Undeveloped Land: 2-3
7	Undeveloped Land: 3-1
8	Undeveloped Land: 3-2
9	Undeveloped Land: 3-3
10	Developed Land: 1-1
11	Developed Land: 1-2
12	Developed Land: 1-3
13	Developed Land: 2-1
14	Developed Land: 2-2
15	Developed Land: 2-3
16	Developed Land: 3-1
17	Developed Land: 3-2
18	Developed Land: 3-3

Just like the THI and NDVI Relationship Typology Classes, the THI and CO₂ Emissions Relationship Typology Classes for the Kapanewon Depok Land Use Map are divided into 9 typology classes ([Table 4](#)).

Table 4. THI and CO₂ Emissions Relationship Typology Classes

Typology Class	Description
1-1	Comfortable-Low Emissions
1-2	Comfortable-Moderate Emissions
1-3	Comfortable-High Emissions
2-1	Fairly Comfortable-Low Emissions
2-2	Fairly Comfortable-Moderate Emissions
2-3	Fairly Comfortable-High Emissions
3-1	Uncomfortable-Low Emissions
3-2	Uncomfortable-Moderate Emissions
3-3	Uncomfortable-High Emissions

Next, the typological types of the relationship between THI and CO₂ emissions and the land use map are divided into 18 types ([Table 5](#)).

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Table 5. Tipe Typological Types of the Relationship Between THI and Emisi CO₂ Emissions and the Land Use Map

No	Land Use Type: Typological Class of the Relationship Between THI and CO ₂ Emissions
1	Undeveloped Land: 1-1
2	Undeveloped Land: 1-2
3	Undeveloped Land: 1-3
4	Undeveloped Land: 2-1
5	Undeveloped Land: 2-2
6	Undeveloped Land: 2-3
7	Undeveloped Land: 3-1
8	Undeveloped Land: 3-2
9	Undeveloped Land: 3-3
10	Developed Land: 1-1
11	Developed Land: 1-2
12	Developed Land: 1-3
13	Developed Land: 2-1
14	Developed Land: 2-2
15	Developed Land: 2-3
16	Developed Land: 3-1
17	Developed Land: 3-2
18	Developed Land: 3-3

Result and Discussion

The results of this study are divided into three categories: the typology of the relationship between THI and NDVI, the typology of the relationship between THI and emissions, and the policy implications for each typology. A more detailed discussion is presented below:

Typology of the Relationship Between THI and NDVI

The level of thermal comfort in Kapanewon Depok shows a strong dependence on vegetation density. Kapanewon Depok is dominated by the Comfortable-Low NDVI typology, which covers 24.74% of the total analysis area. Cumulatively, the comfortable zone in Kapanewon Depok reaches more than 52%, indicating that microclimate conditions still sufficiently support urban activities..

Nevertheless, there are still thermal comfort zones (High-NDVI Comfort Zones) concentrated in the Condongcatur and western parts of the Caturtunggal neighborhoods. This is supported by the presence of 28 public green spaces, including the UGM and UNY campus forests with dense vegetation and high coverage. Additionally, thermal comfort zones are also found on agricultural land on the northern side of Maguwoharjo Village, which plays a vital role as a natural cooler through the process of evapotranspiration. Rice fields have the ability to convert solar heat into energy for water evaporation, thereby keeping the air temperature above them low. However, the significant reduction in rice fields, particularly in Maguwoharjo Village, poses a real threat to surface temperature stability (Urban Heat Island) and future thermal comfort.

These results reinforce the findings [Rosyidy et al., \(2020\)](#) stating that the effectiveness of green open spaces in creating thermal comfort is not solely determined by their area but is also influenced by the structure and density of their vegetation canopy. Furthermore, this phenomenon aligns with research by [Rahmawati & Arif, \(2023\)](#) in the same location Depok Subdistrict which indicates that the land-use configuration in Depok Subdistrict, which still retains pockets of vegetation within residential areas, plays a crucial role in maintaining air temperature stability, thereby preventing extreme heat spikes across most of the region .

Development pressure is evident in the emergence of the “Moderately Comfortable-Low NDVI” typology, covering 11.33% of the area, which serves as a transition zone in the central and southern parts of Maguwoharjo Village. The conversion of agricultural land into commercial and residential areas has led to the loss of permanent vegetation cover. The replacement of vegetation with asphalt and concrete along the Yogyakarta-Solo corridor has created surfaces with low albedo that retain solar heat. The “Uncomfortable-Low NDVI” critical zone, accounting for 1%, is concentrated around shopping centers and transportation facilities such as Adisucipto Airport and several shopping centers including Lottemart Maguwoharjo, Superindo Seturan, fTransmart Maguwoharjo, the Ambarukmo Plaza area and Royal Ambarukmo, as well as LIPPO Plaza. The high building density in this area triggers a local temperature increase of more than 6 °C, which intensifies the Urban Heat Island phenomenon. See [Fig 3](#) and [Fig 4](#).

These results further support the findings of [Dwi et al. \(2024\)](#) who conducted a study on the impact of built-up area development on the Urban Heat Island (UHI) phenomenon in the Yogyakarta urban area. The results of that study found that the rapid development of the Yogyakarta urban area, extending into the outskirts, is supported by the presence of road networks such as ring roads, universities, and commercial centers. Consequently, there is a potential for the UHI phenomenon to occur.

Based on the results of the spatial typology analysis, priority zones for open space planning in Kapanewon Depok were subsequently identified to enhance urban thermal comfort. [Fig 5](#) presents a map of the priority zones for open space planning aimed at improving urban thermal comfort, which are divided into three zones: (1) High-Priority Zone (red), (2) Medium Priority Zone

(yellow), (3) Low-Priority Zone (green). Meanwhile, the spatial relationship between elevated THI values and emission-intensive urban activities is further illustrated in Fig. 6.

The High-Priority Zone (red) is concentrated in the southern part of Maguwoharjo Village, particularly along the Yogyakarta-Solo corridor and around commercial areas, including Adisucipto Airport and shopping centers. This zone is characterized by high THI values and very limited vegetation. Medium Priority Zone (yellow) spread across the central part of Maguwoharjo Village and parts of Condongcatut Village, resulting from the rapid transformation of developed land. This zone is characterized as a transitional area where the THI begins to rise as rice paddy land decreases. Low-Priority Zone (green) predominantly located in the western part of Caturtunggal Village and the northern part of Condongcatut Village, including the UGM and UNY campus areas. This zone has an environmental carrying capacity that remains very good, with the “comfortable” zone accounting for 52%. This is supported by the presence of extensive campus green open spaces with high density at the UGM and UNY campuses

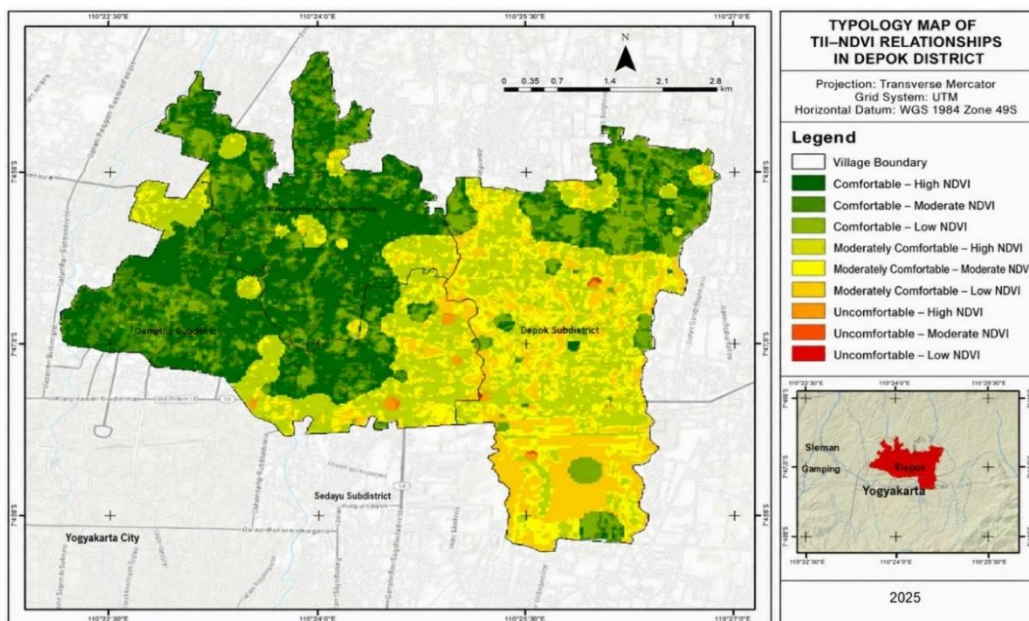


Fig 3. Map of the Relationship Between THI and NDVI in Depok Subdistrict

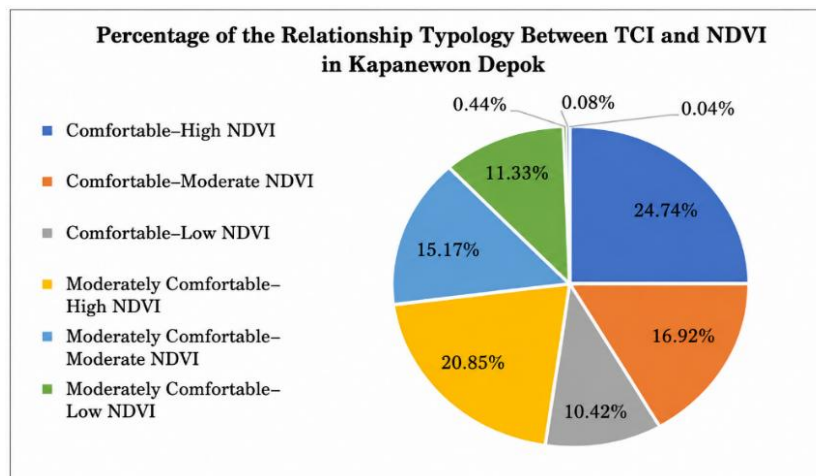


Fig 4. Percentage THI and NDVI Relationship Typology in Depok Subdistrict

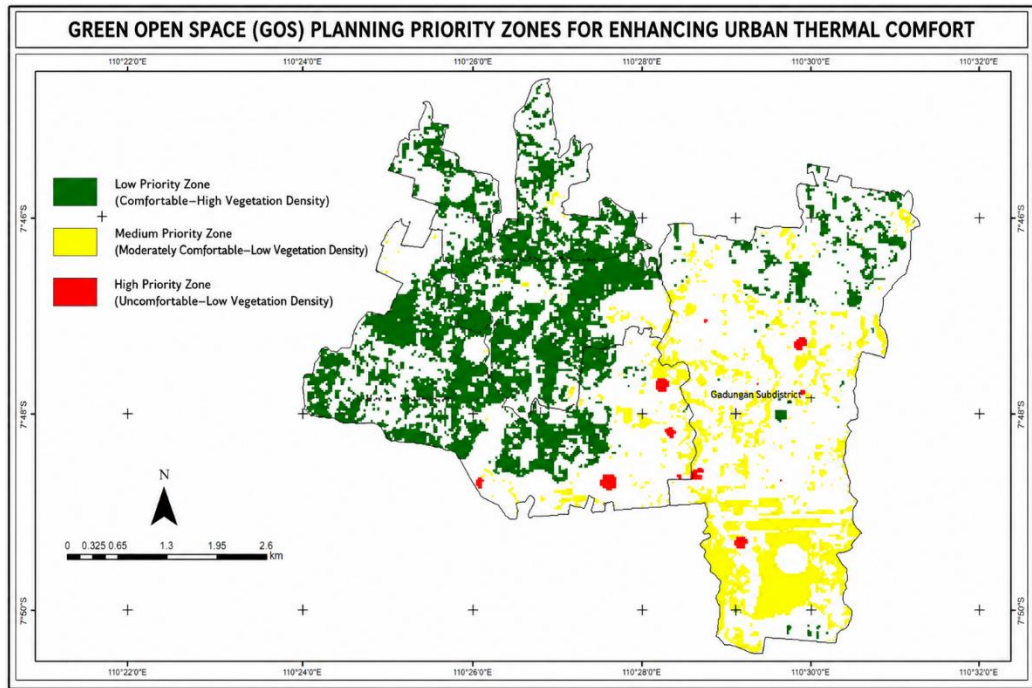


Fig 5. Map of Priority Zones for Green Open Space Planning to Enhance Urban Thermal Comfort

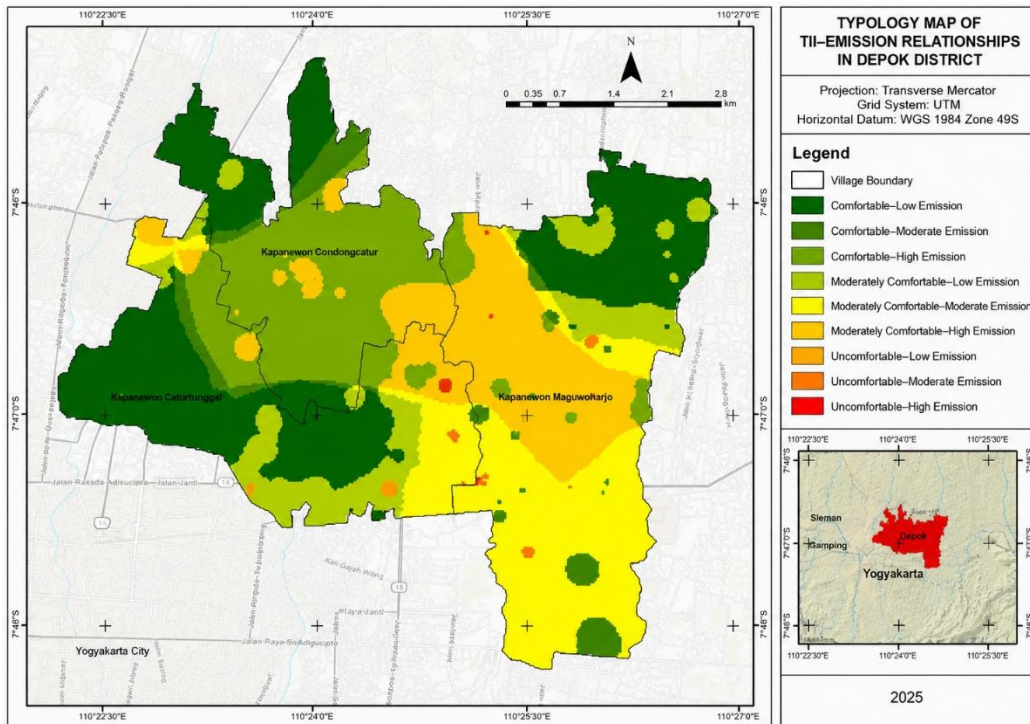


Fig 6. Map of THI and Emission Relationship Typology in Depok Subdistrict

Typology of the Relationship Between THI and Emissions

The spatial patterns of the relationship between THI and emissions were found to coincide with transportation hubs and economic activities. The Depok subdistrict is dominated by the “Comfortable-Low Emission” typology, accounting for 28.93%. This area is located in the northern part of Condongcatu Village and the western part of Caturtunggal Village. This is likely due to the

presence of extensive public open spaces, which facilitate smoother pollutant dispersion, thereby preventing significant heat accumulation. A detailed distribution of the THI–emission relationship typologies is shown in [Fig. 7](#).

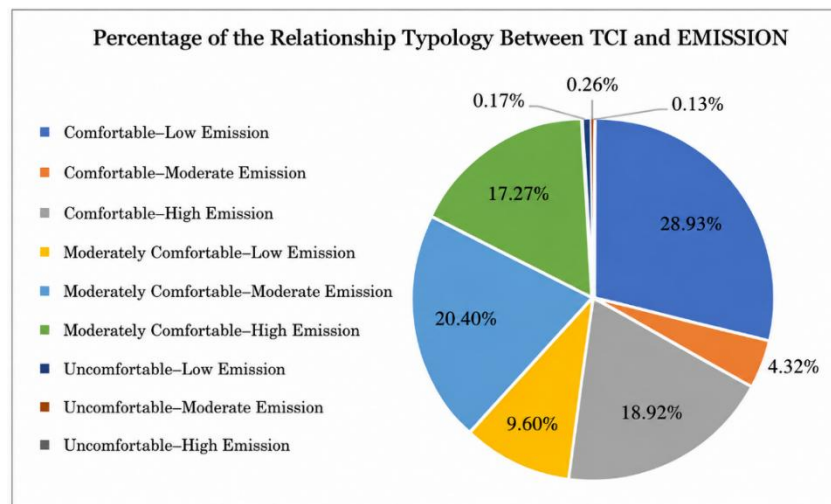


Fig 7. Percentage Distribution of THI Relationship Types and CO2 Emissions in Depok Subdistrict

An interesting finding emerged regarding the “Comfortable-High Emission” typology, which accounted for 18.29% of the total, highlighting the mitigating role of existing vegetation. Despite being located in an environment with high pollution levels, vegetation was able to keep temperatures low through shading and evapotranspiration. This aligns with findings from [Salsabella et al. \(2025\)](#), which confirm that dense vegetation is the most effective strategy for creating sustainable thermal comfort in tropical regions compared to artificial shading. According to that study, vegetation has the ability to regulate both temperature and air humidity through natural processes.

Research by [Salsabella et al. \(2025\)](#) shows that the evapotranspiration process in vegetation has been proven capable of maintaining a significantly lower average temperature (around 28.5°C) and keeping air humidity stable at around 78%, in contrast to areas without vegetation where temperatures can spike to 36.9°C. This cooling mechanism occurs through the interception of solar radiation by tree canopies and the release of water vapor into the atmosphere, which effectively reduces environmental heat. Conversely, the “Moderately Comfortable-High Emissions” typology, accounting for 17.27% of the transitional area in Maguwoharjo Village, indicates that increased emissions from the transportation sector are beginning to exceed the environment’s carrying capacity. The “Uncomfortable” critical zone accounts for 0.56%; although small in area, it can act as a hotspot at major intersections and in densely built-up areas in the southern part of Maguwoharjo Village. This location has experienced a high anthropogenic heat load and trapped emissions between closely spaced buildings (canyon effect).

This condition is similar to the phenomenon studied by [Tarigan et al. \(2024\)](#) along the MH Thamrin Road corridor in Jakarta, which found that building density and highway structures can create a “street canyon” pattern that traps heat. The findings of their study indicate that the dense building configuration on both sides of the road has impeded air circulation, causing exhaust emissions from motor vehicles to become trapped at the road surface and drastically increasing ambient temperatures.

Policy Implications

Based on the analysis of the relationships between THI and NDVI, as well as between THI and emissions, the following are the policy implications for each relationship type. These spatial relationships are illustrated in Fig 8 and Fig 9 and provide the basis for formulating targeted policy recommendations to improve urban thermal comfort and environmental sustainability in Kapanewon Depok. Policy decisions regarding the relationship between THI and NDVI and land-use maps are based on the matrix presented in Table 5, referring to Sleman Regency Local Regulation No. 11 of 2020 on the Management of Green Open Spaces, (2020) as well as (Sleman Regency Regent Regulation (Perbup) No. 99 of 2024 on the Implementation of Sleman Regency Local Regulation No. 11 of 2020, 2024): (1) Protect existing green open spaces (RTH) by strictly prohibiting land-use conversion. (2) Enhance vegetation layers by enriching plant species with canopy-forming foliage. (3) Enforce a minimum of 10% private green open space (KDH/RTH) in accordance with Article 27 of Sleman Regency Regulation No. 99 of 2024. (4) Plant trees with high carbon absorption capacity. (5) Modify green open spaces (RTH). (6) Implement transportation management through vehicle movement regulation. (7) Establishing RTH incentives. (8) Constructing with porous materials. (9) Arranging vegetation along green corridors. (10) Implementing zoning regulations to reduce pollution in educational centers. (11) Enhancing the social functions of RTH. (12) Conducting periodic monitoring and evaluation regarding the use of the RTH information system.

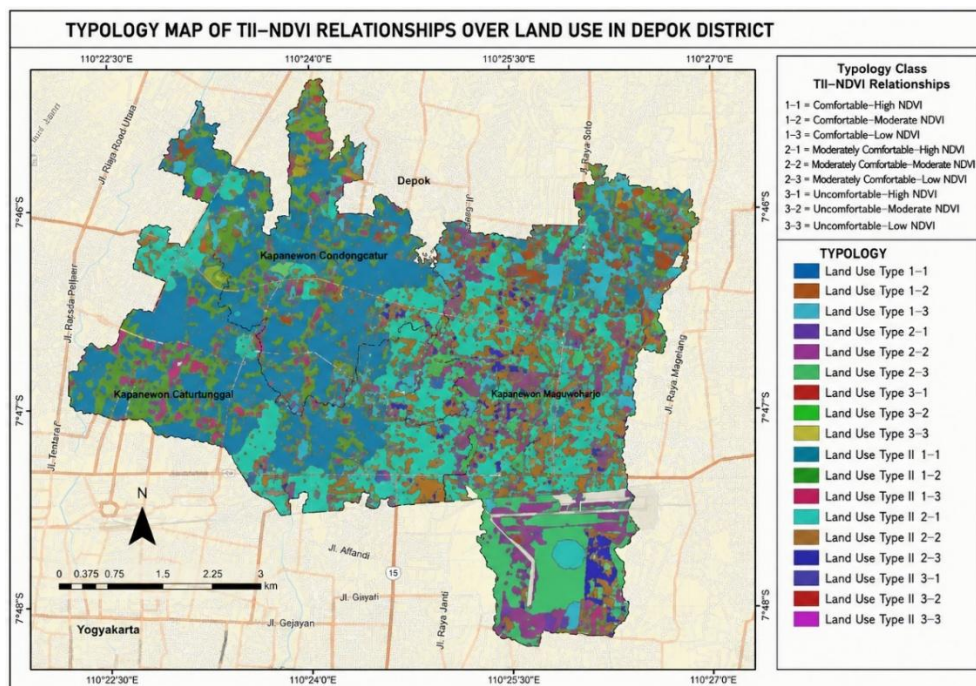


Fig 8. Map of the Relationship Typologies Between THI and NDVI and the Land Use Map of Kapanewon Depok

Table 5. Policy Implications Matrix for the Relationship Between THI and NDVI

Land Use	Typology of the Relationship Between THI and NDVI on Land Use Maps									Recommendations
	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	
Undeveloped Land	1 & 11	2 & 4	4 & 1	1 & 9	2 & 4	4 & 11	9 & 12	4 & 9	2,4,9	Recommendations
Built-up Land	3 & 7	3 & 7	3 & 6	4 & 8	3 & 5	5,6,10	5 & 8	5 & 8	5,8,10	

Policy decisions regarding the relationship between THI and CO₂ emissions and land-use maps are based on the matrix presented in [Table 6](#), as referenced in [Sleman Regency Local Regulation No. 10 of 2021 on the Implementation of Motor Vehicle Testing, \(2021\)](#) amending Perda No. 2 of 2005 on Motor Vehicle Testing as well as ([Sleman Regency Local Regulation \(Perda\) No. 6 of 2022 on the Implementation of Traffic Management and Engineering, \(2022\)](#)): (1) Prohibit the construction of buildings and illegal parking that obstruct airflow. (2) Conduct periodic vehicle emissions audits. (3) Implementing side obstacle management. (4) Providing bicycle lanes and pedestrian paths. (5) Implementing the ATCS (Area Traffic Control System). (6) Implementing one-way traffic or alternating traffic control. (7) Providing drop-off/pick-up facilities to prevent vehicles from idling. (8) Implement reflective or porous road surface materials to reduce surface heat. (9) Conduct on-the-spot emissions testing. (10) Implement zoning for heavy vehicles. (11) Construct bus stops and shelters with passive cooling. (12) Conduct real-time air quality monitoring.

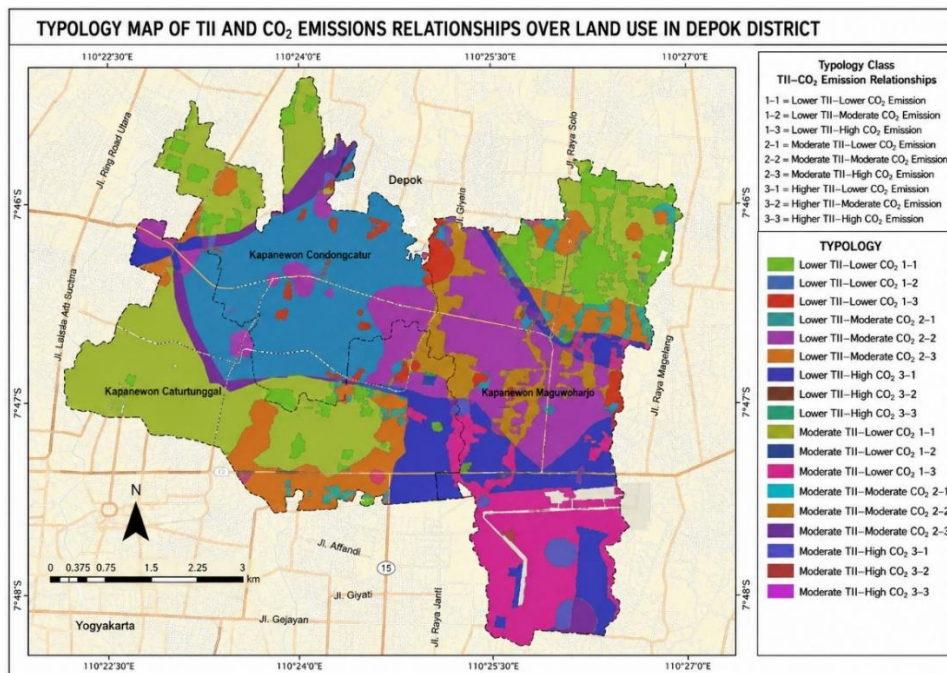


Fig 9. Map of the Relationship Between THI and CO₂ Emissions and Land Use in Kapanewon Depok

Table 6. Policy Implication Matrix for the Relationship Between THI and CO₂ Emissions

Land Use	Typological Types of the Relationship Between THI and NDVI on Land Use Maps									Recommendations
	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3	
Undeveloped Land	1 & 11	2 & 4	4 & 9	2 & 1	11 & 4	4 & 9	2 & 8	4 & 2	9 & 4	Recommendations
Built-up Land	3 & 7	3 & 12	6 & 10	3 & 8	6 & 10	6 & 10	8 & 5	5 & 8	5,8,10	

Conclusion

This study successfully identified the complex relationships between vegetation dynamics, vehicle CO₂ emissions, and thermal comfort in Kapanewon Depok through a spatial typology approach. The results indicate that Kapanewon Depok still possesses a fairly good environmental carrying capacity, with “comfortable” zones dominating 52% of the area, supported by the presence

of 28 public green open spaces and campus forests. This condition indicates that green open spaces play a crucial role in mitigating the microclimate, as evidenced by the “Comfortable-High Emissions” typology covering 18.29%, which confirms that vegetation can neutralize pollution loads through shading and evapotranspiration mechanisms. Conversely, the “Uncomfortable” critical zone is concentrated in the southern part of Maguwoharjo Village due to a double heat burden.

This study reveals a novelty in the form of the identification of a 1% critical zone (thermal hotspot) in commercial and transportation areas due to the urban canyon effect. The novelty of this study lies in the use of a spatial typology analysis approach employing three variables: vegetation, vehicle CO₂ emissions, and thermal comfort, which demonstrates that thermal comfort is highly localized. Even in areas with high emissions, the presence of high-density vegetation has been proven to significantly mitigate anthropogenic heat, thereby keeping the area within the “comfortable” category. This study makes a theoretical contribution by strengthening the theory of Urban Ecosystems, demonstrating that the effectiveness of vegetation in creating thermal comfort depends not only on its area but also on its ability to mitigate heat in dense building corridors (street canyons). This finding provides a new theoretical basis for the development of climate-sensitive urban design concepts in suburban areas undergoing massive transition into built-up zones.

The practical recommendation proposed is the need for local governments to integrate the results of this typological mapping into the Detailed Spatial Plan (RDTR) of Kapanewon Depok. Priority strategies should focus on protecting rice fields as natural cooling assets and mandating the implementation of rooftop gardens and green facades on buildings in high-emission critical zones. For further research, a temporal analysis is recommended to examine the dynamics of changes in thermal comfort typology in tandem with the pace of ongoing infrastructure development, as well as the inclusion of building material variables (albedo) to enhance the accuracy of heat mitigation models in densely populated urban areas.

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Author Contribution

All authors contributed equally to this work. All authors participated in the conception and design of the study, data collection, data analysis and interpretation, manuscript writing, revision of the manuscript, and approval of the final version.

Data Availability Statement

All data generated or analyzed during this study are presented in the tables and figures within this article.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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