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Sustainable Strategy for Malioboro's Pedestrian Area Using Thermal Comfort Simulation

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A B S T R A C T

Thermal comfort is an important factor in the development of the Malioboro Area, as part of the The Cosmological Axis of Yogyakarta and Its Historic Landmarks, which has been designated as a world cultural heritage. This area is planned to become a pedestrian zone with a ban on motor vehicles, supporting the city's sustainability in addressing microclimate issues that can reduce the comfort of both residents and tourists. This study aims to identify thermal comfort issues using microclimate indicators on Malioboro Street and develop strategies to create a comfortable and sustainable environment. The methods used include a qualitative approach with SWOT analysis and a quantitative approach through ENVI-met software simulations to analyze air temperature, surface temperature, relative humidity, wind speed, and CO2 emissions in December 2023. The results show that the air temperature in Segment 2 (from the south side of Grand Inna Mallioboro to the south side of the DPRD DIY building) reaches 31,44-31,81°C, and the surface temperature ranges from 38,62°C to 40,73°C, indicating significant challenges to thermal comfort. The recommendations include maximizing the use of private green open spaces, utilizing light and porous surface materials, maintaining shade-providing vegetation, and planning building geometry that supports air circulation. This study implies the importance of integrating physical elements in area planning to improve thermal comfort and enhance Malioboro's appeal as a cultural and tourism destination, also making it a functional, aesthetic, and sustainable public space.

A R T I C L E I N F O

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1. INTRODUCTION

The Special Region of Yogyakarta (Daerah Istimewa Yogyakarta or DIY) is known for its spatial planning concept based on the Javanese philosophy Hamemayu Hayuning Bawana, which emphasizes the importance of maintaining, caring for, and preserving the environment to create a better and more harmonious world. The Philosophical Axis area, part of the DIY region, has been recognized as a UNESCO World Heritage Site, reflecting universal values that must be preserved (Octarino, 2022). To maintain the integrity of this area, the DIY Government has established a Conservation Management Plan (CMP) through Governor Regulation Number 2 of 2024, concerning the management of the Yogyakarta Philosophical Axis World Heritage Site. The management of the Philosophical Axis area integrates environmental stewardship by enhancing key values and upholding the noble legacy of history, natural preservation, culture, and the philosophical traditions of Javanese civilization—traditions that continue to be preserved today and are intended to be sustained for future generations.

Malioboro, as part of the Strategic Spatial Unit (Satuan Ruang Strategis or SRS) of the Sumbu Filosofis area, is a unique cultural and economic icon of Yogyakarta City. However, it currently faces significant challenges related to air pollution and traffic congestion. Dinas Perhubungan Daerah Istimewa Yogyakarta (2022) (Yogyakarta Special Region Transportation Agency) notes that motorbikes are the largest contributors to CO, HC, PM10, and CO_2 emissions, while passenger cars dominate NO_x and SO_2 emissions. A study on the Malioboro semi-pedestrian area shows that under the “do something” scenario, the average volume-to-capacity (v/c) ratio on affected road sections could be reduced by up to 39% under existing 2019 conditions. However, a five-year projection estimates that the reduction will only reach 15%, indicating that road network performance-based solutions are not sufficient to address overall traffic problems (Nazar et al., 2022). The rapid increase in the number of motorized vehicles has led to higher emissions, which may alter the microclimate and reduce visitor comfort in Malioboro (R. D. Pratiwi et al., 2019). Therefore, to support the preservation of the SRS Sumbu Filosofis area, Malioboro must mitigate the environmental impacts caused by traffic and pollution.

As a concrete step, the City of Yogyakarta, through Mayor Regulation Number 49 of 2024, designates Jalan Malioboro and Jalan Margamulya as pedestrian areas. In these zones, motorized vehicles are planned to be restricted, allowing access only for pedestrians, non-motorized vehicles, certain public transport, emergency vehicles, state guest vehicles, and electric pedicabs. The main goal is to create a pedestrian-friendly environment while improving accessibility and comfort for visitors. Although motorized vehicles are still permitted along Jalan Malioboro at present, parking arrangements within the pedestrian areas have shown positive development over time. By limiting motorized vehicle access, it is expected that traffic congestion will be reduced and a more comfortable public space will be created (Nolasari et al., 2023).

Table 1. The development of pedestrian facilities on Malioboro Street over time

Time	Description
 March 2015	Motorized vehicles are parked in the pedestrian area, and they are allowed to pass through 24 hours a day

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Time	Description
 March 2017	The revitalization of Malioboro involves relocating parking pockets, while motorized vehicles are still allowed to pass through 24 hours a day
 October 2024	The Malioboro pedestrian area is optimized for pedestrian use, while motorized vehicles are allowed to pass through except between 18:00 and 21:00.

Source: Google maps and Author's Analysis, 2024

The implementation of a comfortable pedestrian environment can be supported by identifying microclimate characteristics to inform the selection of appropriate physical elements in public space planning. According to Holton J.R., the environment influences microclimates in terms of factors such as air temperature, soil temperature, wind speed, radiation intensity received by surfaces, and air humidity (Santi et al., 2019). Research on the Malioboro area that considers microclimate characteristics has been conducted by (Octarino & Kristiadi, 2019), who demonstrated that thermal environmental conditioning can be achieved by paying attention to building mass patterns, green open spaces, and the selection of appropriate materials. Green open spaces along pedestrian paths should be designed with vegetation that provides shade, such as tall trees (10–20 meters in height), to reduce environmental temperatures. A planting distance of approximately 8 meters is recommended to create a visually comfortable space and to ensure optimal tree growth (Febriarto, 2016).

Sustainable development is a multidimensional paradigm that prioritizes meeting present needs without compromising the interests of future generations. The integration of economic, social, and environmental dimensions is reflected in indicators such as equity, comfort, and sustainability (N. Pratiwi et al., 2018). The implementation of sustainable strategies in the development of the Malioboro pedestrian area focuses on creating a comfortable environment. Thermal comfort in public spaces can enhance both the attractiveness of the area and the overall experience of its users. The high number of visits and socio-cultural activities in this area contributes to economic growth for local communities and small and medium enterprises. The government plays a crucial role in guiding urban planning and designing public spaces that consider thermal comfort. Furthermore, integrating thermal comfort into sustainability efforts not only supports economic development but also contributes to the preservation of cultural values, helping to maintain the significance of the Philosophical Axis SRS for future generations.

With the various challenges faced by the Malioboro area, such as air pollution and traffic congestion, sustainable development of pedestrian areas is very important to create thermal comfort. This study has an update on the research conducted by Octarino & Kristiadi (2019) who conducted microclimate research on the Malioboro Pedestrian Path by conducting direct field measurements, this study conducted an update with microclimate analysis using ENVI-met software. Research using ENVI-met software has also been conducted in other studies in

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Yogyakarta, namely the Kotabaru area (Adityo, 2016) and the Cik Di Tiro corridor (Prayoga & Kusumawanto, 2019). Furthermore, this study aims to identify problems that affect thermal comfort on Jalan Malioboro based on microclimate indicators. It is hoped that the results of this study can produce strategies for developing pedestrian areas that support improving environmental quality, sustainable development, and preserving cultural values.

2. LITERATURE REVIEW

The development policy for the Malioboro Area maintains building intensity in accordance with the Building and Environmental Plan (Rencana Tata Bangunan dan Lingkungan, RTBL). The land use intensity along the Malioboro Street corridor stipulates a maximum Basic Building Coefficient (KDB) of 80%, a maximum Building Floor Coefficient (KLB) of 3.5, and a minimum Green Base Area (KDH) of 10%. The maximum building height is limited to 18 meters, except for cultural heritage buildings (Bangunan Cagar Budaya, BCB) or existing designated structures. Additionally, the architectural style requirements for the corridor—from Jalan Abu Bakar Ali to the Beskalan Street intersection (including Jalan Malioboro)—specify the use of Indis or Chinese architectural styles. These regulations aim to control building mass and height to minimize environmental burdens and visual impacts that may detract from the area's cultural values.

The RTBL for the Malioboro Yogyakarta area outlines the selection of materials for pedestrian pathways, emphasizing the use of environmentally friendly materials that are also safe and comfortable for users. The surface materials along Malioboro Street include a uniform hardscape made of terrazzo, while other sections use asphalt pavement, as shown in Figure 1.

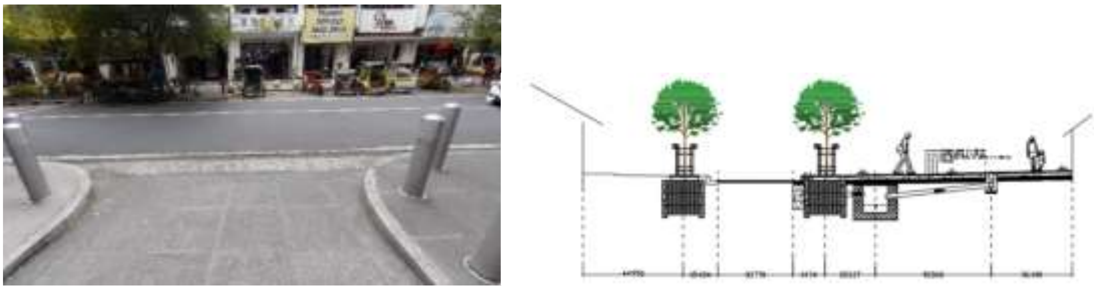

Figure 1. Photos and Sections of Malioboro Street with Terrazzo and Asphalt Paving (Source: Authors, 2024 and DPUPESDM DIY)

Permeable pavements have significant potential for reducing the effects of the Urban Heat Island (UHI) phenomenon. According to S. N. Pratiwi (2018), permeable pavements can lower surface temperatures compared to impermeable surfaces and reduce the accumulation of heat throughout the day, which is typically released at night (R. D. Pratiwi et al., 2019). Conversely, dark-colored surface materials can exacerbate UHI because they absorb 80–95% of heat radiation, thereby increasing both surface and ambient air temperatures—especially if the design does not account for appropriate thermal characteristics. (S. N. Pratiwi, 2018).

The environmentally friendly and sustainable development policy for the Malioboro Area prioritizes the preservation of vegetation and optimal green space planning. The selection of appropriate vegetation, particularly species that dominate the urban forest, can significantly influence temperature and humidity levels (R. D. Pratiwi et al., 2019). The types of vegetation in the Malioboro Area's Green Open Space (RTH), especially along the main corridor, primarily include Tamarind (*asam jawa*) and *Gayam* trees (Wali Kota Yogyakarta, 2024). Planting vegetation along Jalan Malioboro follows the philosophical concept of the Philosophical Axis, where the Tamarind tree symbolizes *sengsem* (attraction) and the *Gayam* tree symbolizes

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ayom (calmness). Both species represent the transition from youthful seriousness to maturity and tranquility (Balai Pengelolaan Kawasan Sumbu Filosofis, 2022).

Figure 2. Vegetation on the Pedestrian Street of Malioboro: (a) Tamarind Tree, (b) *Gayam* Tree, (c) *Soka* Plant
(Source: Author, 2024)

Vegetation plays an important role in shaping urban spaces and significantly contributes to the quality of the microclimate. Tall trees with wide crowns provide effective shade and absorb heat radiation, with planned increases in vegetation capable of lowering temperatures by up to 1.16 °C, increasing humidity, and creating a more comfortable environment both day and night (Adityo, 2016). Conversely, minimal vegetation often serves only an aesthetic function without providing shade, due to the small size of its crown (Octarino & Kristiadi, 2019).

Based on the Yogyakarta City RTBL, the development policy for the Malioboro Area aims to promote growth through the provision of urban infrastructure and facilities, with an emphasis on maximizing green open spaces as public areas. Additionally, green open spaces include planters or plant pots placed along pedestrian paths throughout the Malioboro road network. When selecting shade plants, consideration must be given to root growth areas to prevent damage to pavements and underground utilities. The provision of green open spaces is crucial for maintaining humidity and temperature, thereby enhancing human comfort (Aqila & Saputra, 2022). Plantation forests play a significant role in carbon storage, while residential areas contribute through their vegetation (Kurniawati, 2021).

3. RESEARCH METHODS

This study aims to identify factors affecting thermal comfort using microclimate indicators on Malioboro Street. Through this identification, the study intends to develop strategies for enhancing pedestrian areas that support environmental quality improvement, sustainable development, and the preservation of cultural values. The methods employed include both quantitative and qualitative approaches. Data collection was carried out as follows:

1. A literature review was conducted by gathering data and reports, including documents from the DIY Government and the City of Yogyakarta. The data comprised information related to environmental policies, spatial plans, and previous studies relevant to the conditions of Malioboro Street.
2. Field observations were conducted through direct inspection of Malioboro Street, accompanied by photographic documentation to capture current conditions. This included factors affecting the microclimate such as vegetation, surface materials, green open spaces, and building geometry.

3.1 Quantitative Approach

This study involved simulating microclimate conditions using ENVI-met software to analyze the influence of architectural elements and urban planning on microclimate indicators such as air temperature, surface temperature, humidity, CO_2 emissions, visibility, and wind speed. The simulation was carried out through the following stages:

1. Reviewing the as-built drawings of the 2017 Malioboro Revitalization and analyzing current documentation photos of Malioboro to obtain initial data on the spatial elements;
2. Creating an initial model by reconstructing the Malioboro pedestrian area and its surroundings using ENVI-met software, including representations of buildings, roads, and other environmental features;
3. Conducting microclimate simulations of the Malioboro pedestrian area and its surroundings, focusing on data such as air temperature, surface temperature, humidity, CO_2 emissions, visibility, and wind speed;
4. Setting consistent simulation parameters based on data from the BMKG DIY Climatology Station. Input parameters were selected based on the hottest month of 2023 (December), as indicated in Table 1, to obtain representative results. The climate data used for the simulation are presented in Table 2 and Figure 3.

Table 2. Air Temperature and Humidity in Yogyakarta City in 2023

Months	Air temperature (°C)			Humidity (%)			Wind Speed (knot)
	Min.	Average	Max.	Min.	Average	Max.	
January	23,3	26,3	30,2	74	83	89	4
February	23,2	25,9	30,5	77	85	92	3
March	23,2	26,3	31,3	77	83	92	4
April	23,5	26,6	31,2	77	83	89	3
May	22,9	26,6	31,5	69	79	91	3
June	23	26,3	30,9	74	80	86	2.9
July	21,5	25	29,7	66	79	92	3.3
August	20,7	24,8	30,5	70	78	89	4
September	21,3	25,4	31,2	69	75	81	4
October	23,2	27,2	33	74	76	83	3
November	24,2	27,2	32,4	68	80	91	2
December	23,9	27,3	31,5	69	79	92	3

Source: https://jogjakota.bps.go.id/

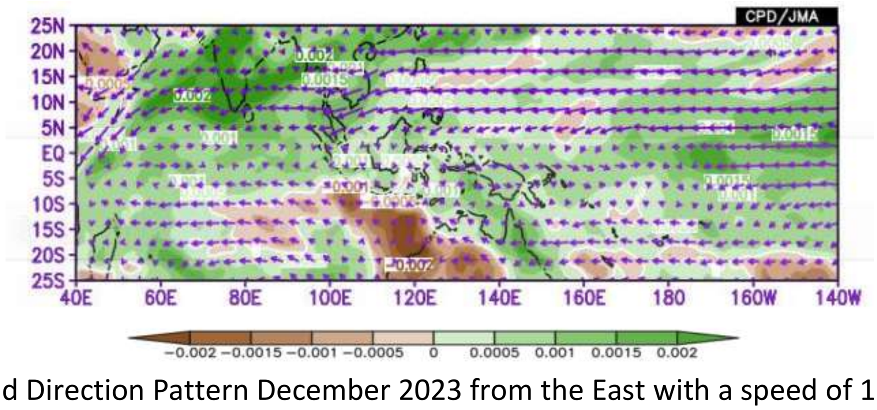

Figure 3. Wind Direction Pattern December 2023 from the East with a speed of 1.54 m/s (Source: BMKG DIY Climatology Station, 2023)

5. The simulation was conducted by dividing the study area along Malioboro Street into five segments, each measuring 150 meters in length. This segmentation was necessary due to the limitations of the ENVI-met software, which allows a maximum of 50 grids.

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Each grid in ENVI-met represents 3 meters, making 150 meters the optimal segment length to ensure that the simulation remains detailed and aligned with actual conditions. The segmentation of Malioboro Street is illustrated in Figure 4, beginning at the Tugu Station railway tracks and extending to:

a. Segment 1: bounded by Toko Batik YOGYA - Hotel Grand Inna Malioboro (south side);
b. Segment 2: bounded by the DIY DPRD Building Area (south side) and Toko Kawedar;
c. Segment 3: bounded by Gang Sosrokusuma (south of Plaza Malioboro – Batik Janoko);
d. Segment 4: bounded by Gang Sosrokusuma (south of Plaza Malioboro – Batik Janoko);
e. Segment 5: bounded by the Pajeksan Road – Suryatmajan Road intersection.

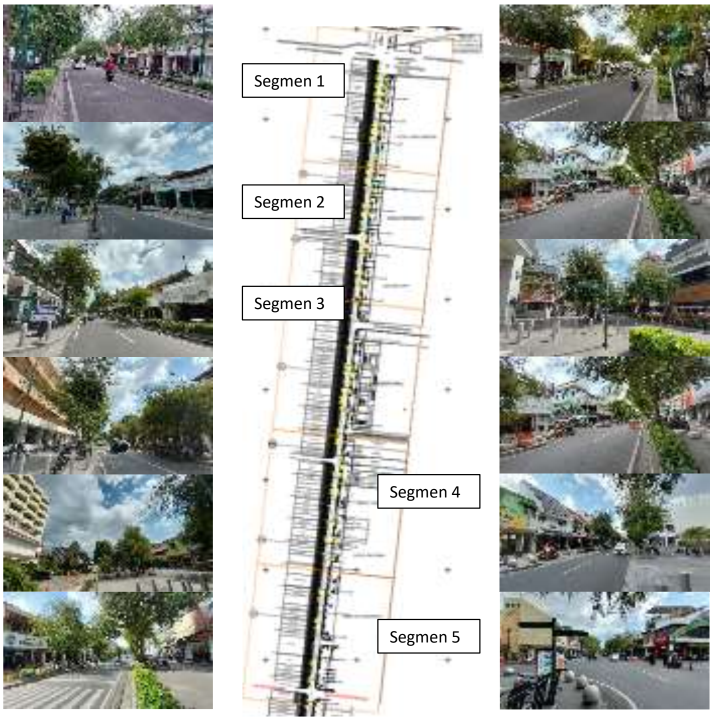

Figure 4. Malioboro Street Segmentation, Yogyakarta
(Source: Author, 2024)

3.2 Qualitative Approach

The simulation results using ENVI-met will produce a segmentation assessment with the study area boundaries shown in Figure 4. The assessment results will be used as evaluation material to identify microclimate problems in more depth. Evaluation of factors contributing to microclimate problems is carried out through a SWOT (Strength, Weakness, Opportunity, Threat) analysis, which is used to validate the condition of physical elements and clarify microclimate parameters that negatively affect environmental quality. This analysis aims to direct the research results towards strategic recommendations that can be applied to Jalan Malioboro in order to create an area with an optimal level of thermal comfort.

4. RESULT AND DISCUSSIONS

4.1 Thermal Comfort Assessment with ENVI-met Simulation

Thermal comfort assessment in pedestrian areas was conducted using simulation methods. The process involved collecting data on physical elements such as building

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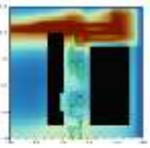
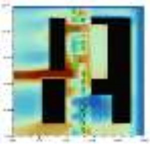
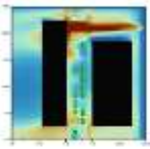
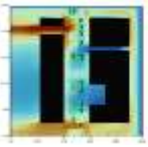
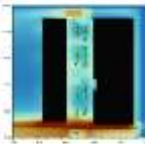
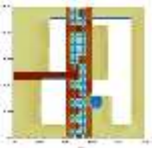
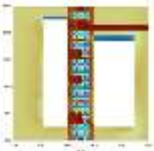
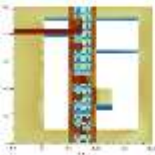
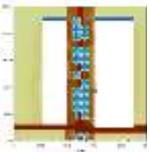
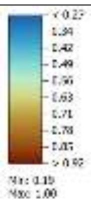
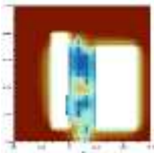
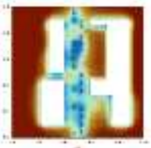
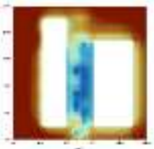
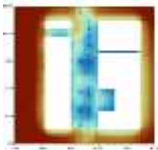
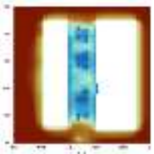
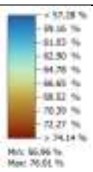
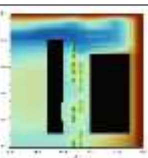
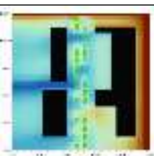
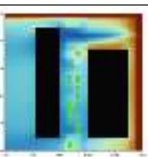
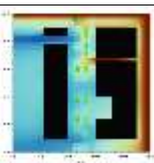
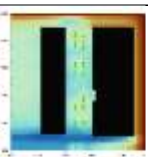
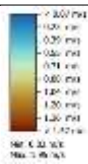
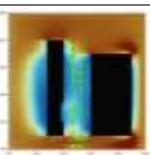
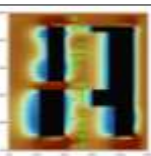
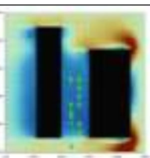
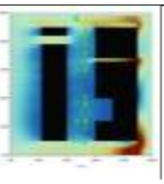
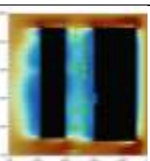
materials, the distance between buildings, dimensions of pedestrian paths, and pedestrian activities (Prayoga & Kusumawanto, 2019). This data was used to calculate microclimate conditions and assess thermal comfort based on the characteristics and values of microclimate indicators, including air temperature, relative humidity, and wind speed (Santi et al., 2019).

ENVI-met simulation data processing was used to identify the segments of Malioboro Street with poor microclimate quality. This allows for the formulation of regional planning strategies aimed at improving microclimate conditions to meet thermal comfort standards for visitors. The results of the ENVI-met simulation are presented in a table, grouped by five segments and associated indicators, as shown in Table 3.

Table 3. ENVI-met Simulation Results for Malioboro Street Segments

Indicator	Assessmen Standards	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Description
Air Tempera-ture							The worst air temperature is in Segment 2 with a temperature of 31.44°C-31.81°C, a very warm category.
	Point	**3**	**1**	**2**	**4**	**5**	
Surface Tempera-ture							The worst surface temperature is in Segment 2 with a temperature of 38.62°C-40.73°C in the hot category.
	Point	**2**	**1**	**4**	**5**	**3**	
Visibillity							Visibility in Segment 5 has the lowest value among the others because it is covered by vegetation, as seen from the even light blue color.
	Point	**5**	**4**	**3**	**2**	**1**	
Relative Humidity							The worst air humidity is in Segment 1 at 64.78%-66.65%, humid category, almost comfortable.
	Point	**1**	**2**	**5**	**3**	**4**	
Wind Speed and Direction							The average wind speed from the east with the worst conditions is in Segment 3 with a speed of 0.07 m/s-0.23 m/s, comfortable category, the air does not feel cold.
	Point	**4**	**5**	**1**	**2**	**3**	

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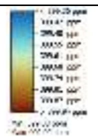
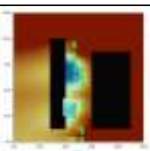
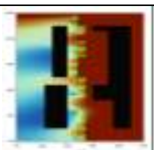
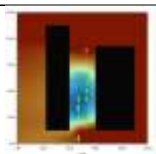
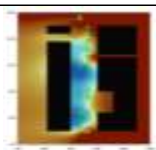
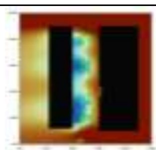
Indicator	Assessmen Standards	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Description
CO2 Emission							The CO2 emission levels of all five segments meet the standards, with Segment 3 having the worst value of 399.94 ppm.
	Point	**3**	**2**	**1**	**5**	**4**	
Total Point		**18**	**15**	**16**	**21**	**20**	

Source: Author, 2024

Based on Table 3, the assessment of environmental indicators along the Malioboro Street segments shows that the worst air temperature was recorded in Segment 2, ranging from 31.44 ℃ to 31.81 ℃ (very warm category). Surface temperature was also highest in Segment 2, with values between 38.62 ℃ and 40.73 ℃ (hot category). The best visibility was observed in Segment 1, while the lowest was in Segment 5 due to vegetation cover. The highest relative humidity, classified as humid, was found in Segment 1, ranging from 64.78% to 66.65%. The lowest wind speed was recorded in Segment 3 (0.07–0.23 m/s), although it still falls within the comfortable category. CO_2 emissions met acceptable standards across all segments, with the highest value recorded in Segment 3 at 399.94 ppm.

Based on the five segments of Malioboro Street, the segment with the best thermal conditions is Segment 4, which extends from the Gang Sosrokusuman area to the Mutiara Baru Hotel on the south side, adjacent to the DIY Governor's Kepatihan Office. In contrast, the segment with the poorest microclimate conditions is Segment 2, which spans from the YOGYA Batik Shop to the Grand Inna Malioboro Hotel (south side), and continues to the DIY DPRD Building Area (south side) and Toko Kawedar, with a total of 15 points. This is followed by Segment 3, covering the area from the DIY DPRD Building Area (south side) and Toko Kawedar to Gang Sosrokusuma (south of Plaza Malioboro – Batik Janoko), with a total of 16 points.

4.2. Factors Affecting Thermal Comfort

The identification of thermal comfort in Segments 2 and 3 aims to formulate strategies for developing a more comfortable pedestrian area. Factors influencing thermal comfort include surface materials, vegetation, green open spaces, and building geometry. A SWOT analysis was conducted to identify the elements affecting thermal comfort, as shown in Table 4.

Table 4. SWOT Analysis of the Influence of Thermal Comfort on Variables

		Internal Factors	
		Strength	**Weakness**
External Factors	**Opportunity**	• Environmentally friendly surface materials: The use of terrazzo designed with aggregates helps absorb water and reduce accumulated heat. • Vegetation: The types of trees planted have philosophical value and wide crowns that absorb heat radiation, such as Tamarind and *Gayam trees*, which provide shade. • Green Open Space: Parks and green areas designed within green open spaces help maintain humidity and temperature, creating a comfortable environment.	• Dark-colored materials: The large hardscape surface results in heat storage, and dark-colored asphalt materials absorb more heat, which increases the ambient temperature. • Availability of vegetation: The quality of thermal comfort is highly dependent on the availability of vegetation. • Limited green space: The area of green space is insufficient to balance the impact of increasing infrastructure development, especially in public spaces dominated by hardscape.

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		Internal Factors	
		Strength	**Weakness**
		• Supportive building geometry: Building setbacks create effective transition areas for air movement and reduce heat exposure from buildings directly affecting pedestrians.	• Geometry of the west-side buildings: The buildings on the west side of the road are quite massive and elongated compared to the east side, which can affect wind movement.
	Threat	• Material innovation: Developing surface materials with higher albedo can help reduce heat absorption. • Vegetation quality improvement: Encouraging the planting of more vegetation and promoting community, shophouse, and building owners' participation in providing private green open spaces. • Green open space development: Designing and implementing more green open spaces to increase water absorption and reduce temperature.	• Climate change: Changing climate patterns can affect vegetation growth and, consequently, thermal comfort. • Unplanned development: Infrastructure development without considering thermal impacts can exacerbate the Urban Heat Island (UHI) effect. • Increased visitor numbers: A rise in visitor numbers can increase thermal loads and reduce comfort. • Vegetation maintenance: Poorly managed vegetation can reduce shade and increase local temperatures.

Source: Author, 2024

4.3. Recommendations and Strategies

To improve thermal comfort in Segment 2 of Jalan Malioboro, it is necessary to revitalize the Malioboro Terrace 2 yard by replacing the paving and asphalt pavement with green open spaces using softscape, such as mini elephant grass. Additionally, the maintenance of wide-canopied vegetation, such as Tamarind and *Gayam* trees, which are planted in accordance with the philosophy of the Sumbu Filosofis area, is important. Vegetation plays a crucial role in modifying the microclimate in urban areas. By retaining solar heat radiation, vegetation can reduce air temperature increases and enhance thermal comfort. Moreover, vegetation helps create cleaner air and reduces noise and air pollution in urban environments (Prayoga & Kusumawanto, 2019). In Segment 3, the utilization of building geometry can be improved by setting back buildings. The proximity of buildings to the road affects thermal comfort (Bao et al., 2023). Setbacks create a transition area that functions as both a circulation path and green open space, thereby improving thermal quality (Octarino & Kristiadi, 2019). Management of private green open spaces also needs to be encouraged, in line with the Malioboro RTBL regulation, which mandates the allocation of at least 10% of land area for green space. Maximizing private green open space can be achieved by providing vertical gardens and rooftop gardens.

The Malioboro area is planned to become a pedestrian zone with restrictions on motorized vehicles, which is expected to reduce the carbon emission burden on Malioboro Street. The asphalt surface material of Malioboro Street can be engineered or replaced with lighter materials to reduce heat absorption from solar radiation, thereby improving thermal comfort (Prayoga & Kusumawanto, 2019). Light colors, such as white and gray, increase albedo and reflect sunlight more effectively than dark surfaces like black asphalt, helping to lower temperatures (Ihsan et al., 2022).

Furthermore, the Government also needs to adopt an Internet of Things (IoT)-based microclimate monitoring system to monitor temperature, humidity, and carbon emissions in real-time, so that policies can be adjusted based on the latest data. By implementing this strategy, Malioboro will not only become a more comfortable and environmentally friendly area, but will also contribute to achieving sustainable development goals.

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5. CONCLUSION

Penelitian ini berhasil mengidentifikasi permasalahan kenyamanan termal dengan menggunakan indikator iklim mikro pada Jalan Malioboro. Analisis menunjukkan bahwa kenyamanan termal di kawasan ini sangat dipengaruhi oleh berbagai faktor, termasuk vegetasi, material permukaan, ruang terbuka hijau, dan geometri bangunan. Pengolahan data dengan software ENVI-met mengungkapkan bahwa Segmen 2 (sisi selatan Hotel Grand Inna Malioboro hingga sisi selatan Gedung DPRD DIY) memiliki kondisi iklim mikro yang paling tidak mendukung kenyamanan pengunjung, dengan suhu udara mencapai 31,44℃–31,81℃ (kategori sangat hangat), sementara suhu permukaan dengan rentang 38,62℃–40,73℃ (kategori panas). Temuan ini menegaskan perlunya langkah strategis seperti memaksimalkan ruang terbuka hijau privat, penggunaan material permukaan yang cerah dan berpori, perawatan vegetasi peneduh, serta perencanaan geometri bangunan yang dapat meningkatkan sirkulasi udara.

Penelitian ini mengusulkan penelitian selanjutnya dengan tetap memanfaatkan simulasi lanjutan menggunakan software ENVI-met atau teknologi digital lainnya, seperti VR-AR, untuk mengukur iklim mikro dengan menerapkan desain ulang elemen fisik kawasan di Jalan Malioboro. Usulan mencakup optimalisasi ruang terbuka hijau privat, penggantian material, serta pemilihan vegetasi dan elemen softscape yang lebih sesuai. Penelitian kuantitatif dengan metode komparasi (sebelum dan sesudah) dilakukan untuk memperoleh data perbandingan yang akuntabel.

Penelitian ini mengimplikasikan pentingnya integrasi elemen fisik dalam perencanaan kawasan untuk meningkatkan kenyamanan termal dan daya tarik Malioboro sebagai destinasi wisata pada ruang publik, serta meningkatkan nilai penting terhadap pelestarian budaya dan berkelanjutan.

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