

Microclimate-Based Assessment of Outdoor Thermal Comfort in The Provincial Police Headquarters Park Using Andrew Marsh's Sun Path Tool

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ABSTRACT

Urban parks play an important role in enhancing environmental quality and supporting public activities. Yet, studies integrating field-based microclimate measurements with solar path simulation to evaluate outdoor thermal comfort in tropical urban parks remain limited. This study analyses the microclimatic characteristics of Polda Park and their implications for outdoor thermal comfort. The novelty of this study lies in integrating field-based measurements with Andrew Marsh's Sun Path Tool to assess solar exposure and shading patterns for climate-responsive landscape design. Andrew Marsh's Sun Path Tool was selected to simulate solar paths and shading patterns for climate-responsive landscape assessment. A descriptive quantitative approach was employed using field measurements of air temperature and relative humidity across three observation zones: the jogging track, retention pond, and playground. Outdoor thermal comfort was evaluated using the Temperature Humidity Index (THI), while the Sun Path Tool was used to simulate solar exposure and shading patterns. The results showed that most areas were classified as partially uncomfortable during the morning and afternoon (THI = 25.5-28.9), whereas all observation zones were uncomfortable at midday (THI = 29.00-30.3) due to intense solar radiation and limited shading. The integration of field measurements with solar path simulation provides a reliable basis for climate-responsive landscape design. It supports evidence-based planning to improve outdoor thermal comfort in tropical urban parks. The proposed approach demonstrates how computational environmental simulation can support data-informed landscape decision-making within the context of Artificial Intelligence in Architecture.

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1. INTRODUCTION

Urban green spaces are essential components of sustainable cities because they regulate microclimatic conditions through shading, evapotranspiration, and improved air circulation. These ecological functions help reduce heat accumulation and create more comfortable outdoor environments. However, rapid urbanisation

and land-use change have reduced vegetation cover, resulting in higher air temperatures, reduced airflow, and declining outdoor thermal comfort. Consequently, evaluating the microclimatic performance of urban parks has become increasingly important for supporting climate-responsive landscape planning. Appropriate landscape design and spatial organisation not only enhance aesthetic value but also improve microclimatic performance, thereby contributing to greater outdoor thermal comfort [1]. Together, these factors shape the microclimatic conditions that determine the level of comfort experienced by park users [2].

Previous studies indicate that vegetation and water bodies in wetland parks play a crucial role in reducing ambient temperature and improving visitors' thermal comfort, particularly during periods of high solar radiation intensity [3]. Nevertheless, most studies have relied on field measurements or thermal comfort indices, which effectively describe existing conditions but provide limited information on the spatial distribution of solar exposure and areas requiring landscape intervention. Other studies also indicate that vegetation density, water features, and wind circulation strongly influence thermal comfort in urban parks. Areas with higher vegetation density generally exhibit better thermal comfort than zones dominated by hard surfaces and limited greenery [4]. Likewise, densely vegetated areas tend to provide more favourable thermal conditions than those with minimal shading and extensive impervious surfaces. These findings highlight the important role of landscape elements in shaping comfortable microclimatic conditions in public open spaces.

High temperatures combined with uneven humidity levels tend to reduce outdoor comfort for users. Therefore, regulating microclimatic factors is essential to achieving more stable and comfortable environmental conditions [5]. Well-managed urban green spaces create cooler, more comfortable environments for outdoor activities, particularly in areas exposed to high levels of solar radiation [6]. In Kambang Iwak Park, Palembang, areas with higher tree density tend to provide more favourable thermal conditions than open areas directly exposed to sunlight [7]. Vegetation also plays a significant role in reducing heat accumulation, thereby influencing the Temperature Humidity Index (THI), which is determined by air temperature and relative humidity, shaped by local microclimatic conditions. Therefore, vegetation significantly improves outdoor thermal comfort [8]. In Addition to environmental performance, the visual quality of urban parks, including vegetation composition, landscape arrangement, and design balance, contributes to users' perception of outdoor comfort [9].

Simulation-based studies using ENVI-met further demonstrated that areas with effective natural ventilation and lower solar radiation exposure provide better thermal conditions for users [10]. Integrating objective microclimatic measurements with users' thermal perceptions supports the development of more adaptive and climate-responsive urban spaces [11]. Furthermore, improved thermal comfort has been associated with more positive visitor perceptions of park quality, highlighting the importance of balancing functional and visual aspects in green space planning [12]. Field measurements and thermal comfort indices have been widely applied to assess existing environmental conditions. At the same time, several studies have highlighted the influence of canopy density, land cover and wind circulation on park microclimates. Although these approaches effectively describe thermal conditions, they provide limited information on the spatial distribution of solar exposure and shading, which are important for identifying locations that require landscape improvement.

Despite extensive research on outdoor thermal comfort, studies integrating field-based microclimate measurements with solar path simulation remain limited, particularly in tropical institutional urban parks, as most previous investigations have not incorporated spatial solar analysis to identify thermally vulnerable areas. Located in a humid tropical climate, Palembang experiences consistently high air temperatures and humidity, which frequently reduce outdoor thermal comfort during the daytime [13]. Poldo Park, one of the principal institutional green spaces in Palembang, contains extensive vegetation but still experiences considerable solar exposure in several activity areas during midday. This condition highlights the need for a more comprehensive evaluation that combines field observations with computational environmental analysis.

To address this limitation, this study employs Andrew Marsh's Sun Path Tool, which was selected for its ability to efficiently visualise annual solar trajectories and shading patterns using relatively simple site information. The tool enables the identification of areas that receive prolonged solar exposure before physical design interventions are implemented, making it suitable for evaluating climate-responsive landscape performance. When integrated with field-based microclimate measurements, Andrew Marsh's Sun Path Tool provides a more comprehensive understanding of outdoor thermal conditions.

Although Andrew Marsh's Sun Path Tool is not an artificial intelligence model, it represents a computational environmental simulation approach that supports evidence-based design decisions. Within

the scope of Artificial Intelligence in Architecture, simulation-assisted environmental analysis contributes to intelligent digital design workflows by enabling objective environmental evaluation before design implementation. The novelty of this study lies in integrating field-based THI measurements with solar path simulation to evaluate solar exposure, shading performance, and outdoor thermal comfort in tropical institutional urban parks. This integrated approach demonstrates how computational environmental analysis can support climate-responsive landscape planning through data-informed decision-making.

This study aims to evaluate the microclimatic characteristics of Polda Park and their implications for outdoor thermal comfort by integrating field-based THI measurements with Andrew Marsh's Sun Path Tool. The findings are expected to provide scientific evidence to inform improvements in landscape design and management strategies that enhance thermal comfort and environmental sustainability in tropical urban green spaces.

2. RESEARCH METHOD

This study employed a descriptive quantitative approach to evaluate outdoor thermal comfort in Polda Park, Palembang, by integrating field-based microclimate measurements with digital environmental simulation using Andrew Marsh's Sun Path Tool. This study was conducted in April at Polda Park, located at JL. Demang Lebar Daun No. 65 Palembang City, South Sumatra. The research was conducted at three observation zones representing different landscape characteristics: the jogging track (Zone 1), the retention pond (Zone 2), and the playground (Zone 3). Air temperature (°C) and relative humidity (%) were measured using UT-333 and HTC-2 digital thermohygrometers during three observation periods (08:00, 10:00, and 4:00 PM).

The theoretical framework for outdoor thermal comfort in this study is based on the concept that thermal comfort in outdoor environments is influenced by the interaction among multiple microclimatic parameters, which should be considered key factors in urban planning and design, as discussed in [14]. These parameters describe the thermal characteristics of the study area and serve as inputs for simulation and thermal comfort analysis. Improvements in the quality of public open spaces can be achieved through design approaches that consider thermal comfort performance and site-specific microclimatic conditions [15]. Thermal comfort analysis in this study was conducted using the THI. THI was selected because it requires only air temperature and relative humidity, making it suitable for field-based microclimate assessment in tropical urban parks where comprehensive physiological indices such as PET or UTCI were not measured. In tropical regions, where high temperatures are often accompanied by elevated humidity, THI is a practical, widely accepted indicator of outdoor thermal comfort. The THI values were calculated using the established formulation proposed by Tika [13]. The research procedure consisted of four sequential stages:

- **Step 1. Field Measurement:** Microclimate data, including air temperature and relative humidity, were collected simultaneously in the three observation zones to represent morning, midday and afternoon environmental conditions.
- **Step 2. THI Analysis:** Outdoor thermal comfort was evaluated using the THI, calculated using the following equation:

$$THI = 0.8T + (RH.T)/500 \quad (1)$$

Where:

THI = Temperature Humidity Index (THI)

T = Air Temperature (C)

RH = Relative Humidity (%)

Table 1. Thermal Comfort Index Classification

Temperature Humidity Index	Category
< 23.0	Uncomfortable
23.0 - < 25.0	Partially Uncomfortable
25.0 - < 27.0	Comfortable
27.0 - < 29.0	Partially Uncomfortable
≥ 29.0	Uncomfortable

Source: Tika, 2010 [13]

Based on the Indonesian National Standard (SNI 03-6572-2001), thermal comfort conditions are defined within a temperature range of 20.5°C-27.1°C, a relative humidity range of 40%-60% and an air velocity of approximately 0.15-0.25 m/s. For outdoor environments, thermal comfort is commonly assessed using the THI, which is widely applied in microclimate studies in tropical regions for its ability to provide a simple yet representative indication of thermal comfort. Areas with higher vegetation cover generally exhibit more favourable thermal comfort index values than spaces dominated by hard surfaces and limited shading [16].

- **Step 3. Andrew Marsh's Sun Path Tool Simulation:** The digital simulation was performed using the geographical coordinates of the study site (2.96117°S, 104.73736°E). Simulation parameters included the observation date of 25 April 2026, observation times (08:00, 10:00, and 4:00 PM; UTC+7), True North orientation (0°), and clear-sky weather conditions. The simulation generated solar path diagrams, solar azimuth and altitude angles, sunrise and sunset times, daylight duration, and vegetation shadow patterns.
- **Step 4. Data Integration and Validation:** The simulated solar exposure and shading patterns were compared with field-measured THI values to assess the consistency between simulated environmental conditions and on-site observations. Areas predicted to receive prolonged solar exposure corresponded to locations with higher THI values, while shaded areas generally exhibited lower thermal stress. The integrated results were subsequently used to formulate evidence-based, climate-responsive landscape design recommendations for improving outdoor thermal comfort.



Figure 1. Study Area Map for Field Data Collection at Polda Park Palembang

Source: <https://maps.google.com>



Figure 2. Thermal Measurement Instruments UT-333 dan HTC-2

The UT-333 and HTC-2 thermal measurement devices are digital thermo-hygrometers that measure both air temperature and relative humidity. These instruments are applied to represent environmental conditions in accordance with established standards. The collected field data were then integrated with the Andrew Marsh simulation to analyse solar duration, shading patterns, and their effect on air temperature and heat radiation. The sun path simulation using Andrew Marsh software aims to identify solar movement patterns, exposure duration, and shadow distribution, all of which influence thermal comfort in the study area. Through shading-mask analysis of the sun path diagram, the level of solar exposure across the park throughout the year can be determined, enabling identification of both thermally comfortable zones and areas at risk of heat stress. The simulation results are further used to evaluate microclimatic characteristics and thermal comfort conditions in Polda Park Palembang. The simulation generated solar path, solar angles, daylight duration, and shading patterns. Simulation results were qualitatively validated against field measurements collected at the same observation times. Predicted areas of prolonged solar exposure corresponded to higher THI values. In contrast, shaded areas show lower thermal stress, demonstrating the reliability of Andrew Marsh's Sun Path Tool for climate-responsive landscape analysis.

Research Limitations

This study has several limitations related to the scope of the thermal comfort analysis and the spatial coverage of the study area. The limitations primarily concern the parameters used to assess thermal comfort and the selection of areas representing high human activity. Specifically, the limitations are as follows:

1. The thermal comfort analysis in this study is limited to air temperature and relative humidity parameters.
2. The study area focused on public zones with high levels of human activity.

3. RESULTS AND DISCUSSION

To facilitate systematic data collection, the observation area at Palembang Polda Park was divided into three zones representing different locations within the park. The zone covers the area near the jogging track and seating area, the area surrounding the retention pond, and the playground area. The spatial distribution of these observation zones is presented in Figure 3.

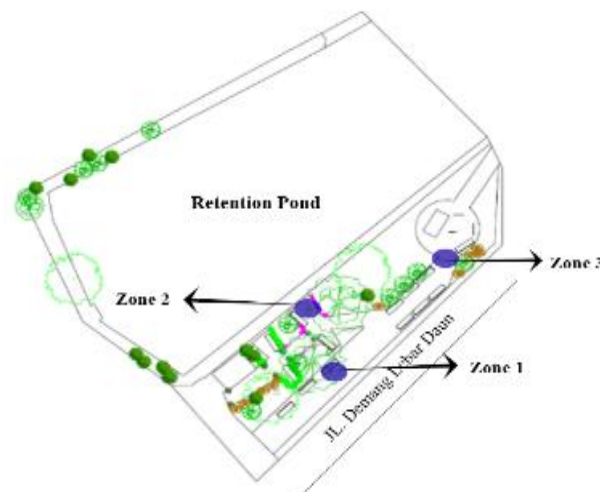


Figure 3. Observation Zoning for Data Collection at Palembang Polda Park

The data collection areas at Palembang Polda Park are divided into three zones:

1. Zone 1: Near the jogging track at seating area 4.
2. Zone 2: Near the retention pond.
3. Zone 3: Playground area.

3.1. Zone 1 Results – Near the jogging track at seating area 4.

Zone 1 is located near the jogging track and seating area 4 at Palembang Polda Park. Figure 4 shows the location of Zone 1 used for the field data collection. The field measurements were subsequently conducted at three observation periods to obtain temperature and humidity data for the analysis.

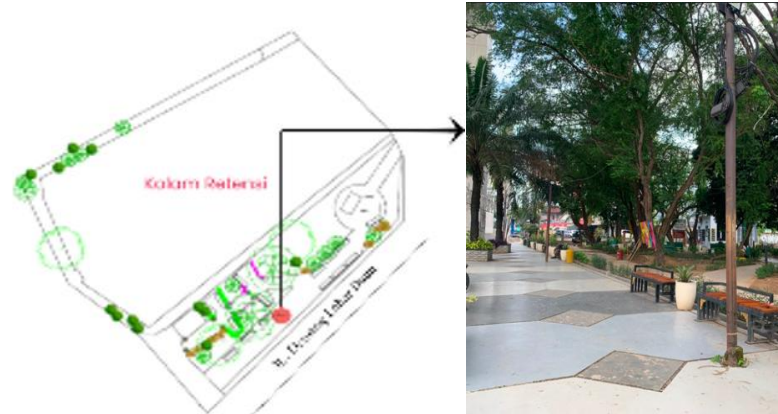
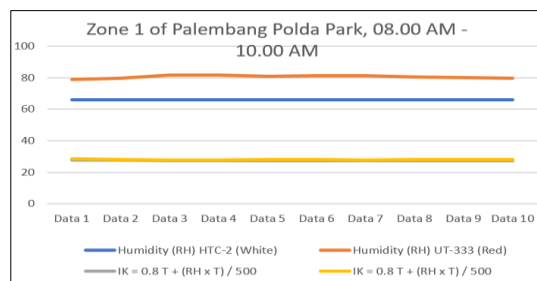


Figure 4. Zone 1 Data Collection Location at Palembang Polda Park

Data Collection conducted on 25 April 2026 (Zone 1):

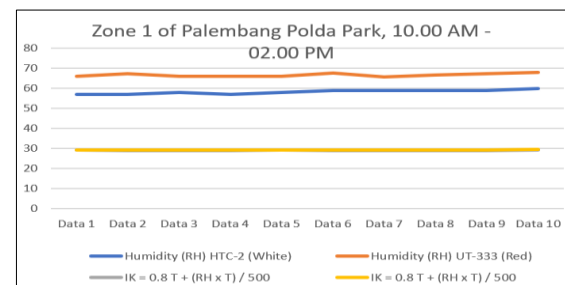
Field measurements in Zone 1 were conducted on 25 April 2026 at three observation periods: 08:00–10:00 AM, 10:00 AM–2:00 PM, and 2:00–4:00 PM. The measurements were conducted to obtain temperature and humidity data at the observation points within the zone. The results of the field measurements are presented in Figure 5, followed by the calculated Temperature Humidity Index (THI) results for each observation period in Table 2.

8:00 AM-10:00 AM:



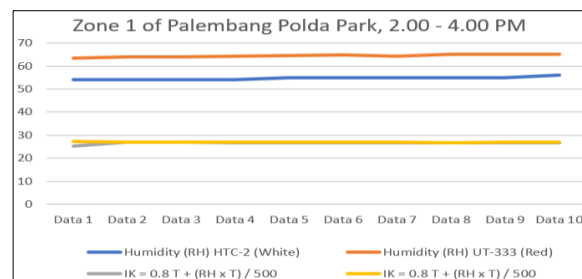
(a)

10:00 AM-2:00 PM:



(b)

2.00 PM-4.00 PM:



(c)

Figure 5. Results of Field Measurements in Zone 1 of Palembang Polda Park:

(a) 08.00 AM-10.00 AM, (b) 10.00 AM-2.00 PM, (c) 2.00 PM-4.00 PM

THI Calculation Result

Based on field-measured temperature and humidity data, the Temperature Humidity Index (THI) was calculated for each observation period. The results show the THI values and their corresponding categories for the morning, midday, and late-afternoon periods, as presented in Table 2.

Table 2. THI Calculation Results

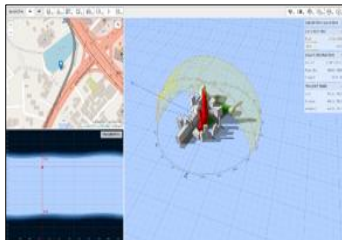
Time	Temperature Humidity Index	Category
Morning	26.405	Comfortable
Midday	29.095	Uncomfortable
Late Afternoon	27.711	Partially Uncomfortable

Source: Pertiwi, 2021 [17]

Analysis of Actual Results

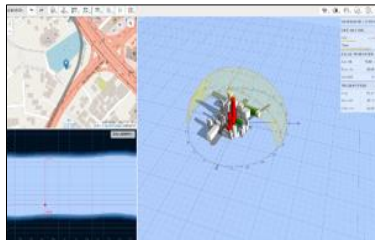
Zone 1 experienced a progressive increase in temperature from morning until midday, followed by a gradual decrease in the afternoon. The highest THI (29.095) occurred at midday, reflecting uncomfortable thermal conditions associated with intense solar radiation and limited tree cover. Similar observations were reported by Liu et al. [4] and Zhang et al. [3], who highlighted that inadequate vegetation and shading contribute to greater thermal stress during peak sunlight hours. The strong correspondence between field observations and Andrew Marsh's Sun Path Tool indicates that solar exposure is the dominant factor affecting thermal comfort. It demonstrates the usefulness of combining THI measurements with solar path analysis to identify priority areas for landscape improvement.

08.00 AM:



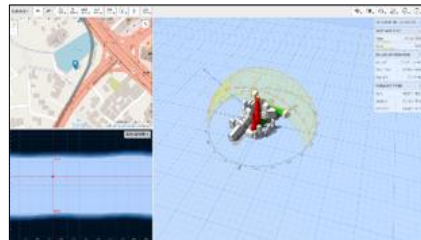
(a)

10.00 AM:



(b)

4.00 PM:



(c)

Figure 6. Results of The Andrew Marsh Sun Path Tool on 25 April 2026:
(a) 08.00 AM, (b) 10.00 AM, (c) 4.00 PM

Results of Andrew Marsh's Sun Path Tool

The simulation was performed using the study site's geographical coordinates (2.96117°S, 104.73736°E) and a north-oriented model. The simulation was conducted on 25 April 2026 at three observation times corresponding to the field measurements: 08.00, 10.00, 16.00 WIB (UTC+7). The weather settings were configured to clear (sky conditions), allowing the analysis to focus on the influence of solar geometry without cloud interference. The simulation generated solar azimuth and altitude angles, daily sun path, sunrise and sunset times, daylight duration, and building and vegetation shadow patterns.

These outputs were subsequently compared with the field-based microclimate measurements to evaluate the relationship between solar exposure and outdoor thermal comfort. The solar exposure patterns generated by Andrew Marsh's Sun Path Tool were compared with field observations conducted at identical dates and observation times. Locations predicted to receive prolonged direct solar radiation corresponded with the highest THI value measured in the field, particularly in Zone 1 and Zone 2 during midday. Likewise, shaded areas identified by the simulation exhibited lower THI values during morning and late afternoon observations. This consistency indicates that the simulation adequately represents actual site conditions and can be used to support landscape design decisions.

Beyond illustrating shadow, Andrew Marsh's Sun Path simulation provides a valuable decision-support tool for climate-responsive landscape design. By integrating field measurements with digital simulation, designers can identify locations that experience prolonged solar exposure and prioritise

interventions such as additional tree planting, pergolas or shading structures before physical implementation. This data-informed approach enables more effective landscape planning by linking microclimatic evidence with spatial design strategies, thereby improving outdoor thermal comfort while optimising resource allocation.

Data Integration and Validation

The simulated solar exposure closely matched the field-measured THI Values. The highest THI (29.095) occurred during midday, corresponding to prolonged direct solar exposure, while lower THI values in the morning and afternoon coincided with increased shading. These results validate the simulation and support additional shading interventions in Zone 1.

Design Recommendations Zone 1 (Jogging Track)

Table 3. Design Recommendations

Findings	Impact	Design Recommendations
High solar exposure, limited shade, and heat-retaining pavement increase thermal stress, particularly between 10.00 and 2.00 PM.	Reduced outdoor thermal comfort and heat accumulation.	Increase continuous tree canopy along the jogging track, introduce green pergolas at rest points, and replace conventional pavement with cool or permeable materials to reduce surface heat.

Based on the findings identified in Zone 1, several design recommendations are proposed to address the observed thermal conditions and their impact on outdoor thermal comfort. The recommendations focus on increasing shade, providing more comfortable resting areas, and reducing surface heat through appropriate landscape and paving interventions. The findings, impacts, and corresponding design recommendations for Zone 1 are summarised in Table 3.

3.2. Zone 2 Results – Near the Retention Pond.

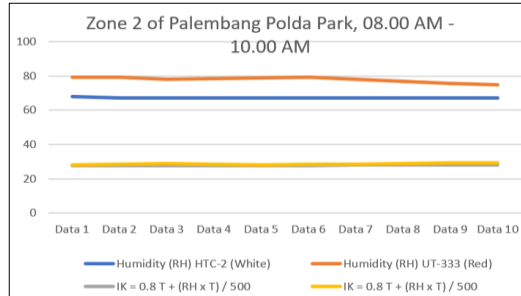
Zone 2 is located around the retention pond area of Palembang Polda Park. The observation area includes the surrounding seating area, as shown in Figure 7. Field observations and measurements were conducted at this location to assess the thermal conditions during the observation period.



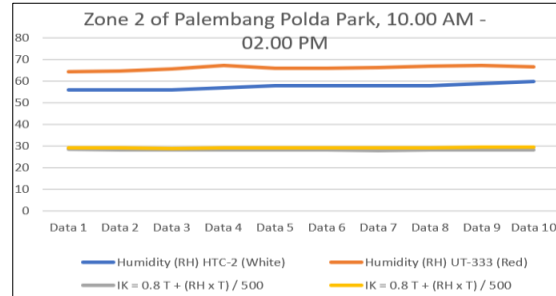
Figure 7. Zone 2 Data Collection at Palembang Polda Park

Data Collection conducted on 25 April 2026 from 8:00 AM - 10:00 AM (Zone 2):

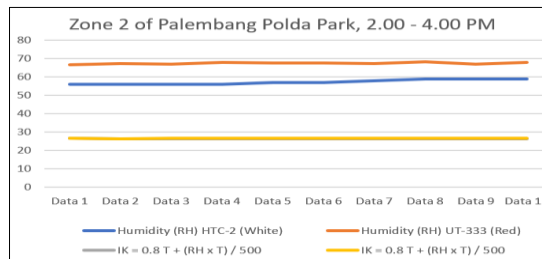
Field measurements in Zone 2 were conducted on 25 April 2026 at three observation periods: 08:00–10:00 AM, 10:00 AM–2:00 PM, and 2:00–4:00 PM. The measurements were conducted to obtain temperature and humidity data at the observation points within the zone. The results of the field measurements for each observation period are presented in Figure 8.

8:00 AM-10:00 AM:

(a)

10:00 AM-2:00 PM:

(b)

2:00 PM-4:00 PM:

(c)

Figure 8. Results of Field Measurements in Zone 2 of Palembang Polda Park:
(a) 08.00 AM-10.00 AM, (b) 10.00 AM-2.00 PM, (c) 2.00 PM-4.00 PM

THI Calculation Result

Based on the temperature and humidity measurements obtained in Zone 2, the Temperature Humidity Index (THI) was calculated for each observation period. The results indicate different THI categories for the morning, midday, and late-afternoon periods. The calculated THI values and their corresponding categories are presented in Table 4.

Table 4. THI Calculation Results

Time	Temperature Humidity Index	Category
Morning	28.235	Partially Uncomfortable
Midday	29.864	Uncomfortable
Late Afternoon	26.775	Comfortable

Analysis of Actual Results

The highest THI in Zone 2 (29.864) was observed at midday, reflecting uncomfortable thermal conditions despite the presence of a retention pond. This indicates that the water body's cooling effect was insufficient to offset the accumulation of heat under intense solar radiation. Zhang et al. [3] similarly reported that water features alone have a limited influence on outdoor thermal comfort unless supported by adequate vegetation. The consistency between field observations and Andrew Marsh's Sun Path Tool simulation suggested that expanding the tree canopy around the pond would provide greater thermal benefits and contribute to a more climate-responsive landscape.

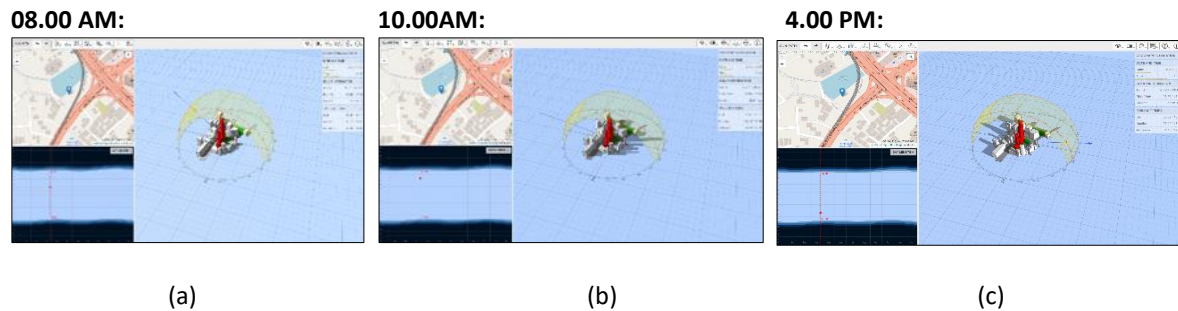


Figure 9. Results of The Andrew Marsh Sun Path Tool on 25 April 2026:
(a) 08.00 AM (b) 10.00 AM (c) 4.00 PM

Results of Andrew Marsh's Sun Path Tool

The sun path simulation was performed using Andrew Marsh's Sun Path Tool based on the study site coordinates (2.96096°S, 104.73744°E), with the model oriented to true north (0°). Simulations were conducted on 25 April 2026 at 08.00, 10.00 and 16.05 WIB (UTC+7) under clear-sky conditions. The simulation outputs included solar azimuth and altitude, the daily sun path, sunrise and sunset times (05.58-18.00 WIB), daylight duration (12.01 h), and vegetation shadow patterns. The results show that at 08.00 (azimuth 73.23°, altitude 28.59°), the low solar angle produced long shadows and limited direct solar exposure. At 10.00 (azimuth 60.63°, altitude 56.36°), the higher solar altitude reduced shadow coverage and increased solar exposure across open areas. By 16.00 (azimuth -73.58°, altitude 26.9°), the lower western sun generated elongated shadows, increasing shaded areas and reducing solar radiation. The simulation solar exposure closely matched the field-based microclimate measurements.

Areas receiving prolonged direct solar radiation, particularly Zone 1 and Zone 2, corresponded to the highest THI values, whereas shaded areas exhibited lower THI values during the morning and late afternoon. These findings demonstrate that Andrew Marsh's Sun Path Tool accurately represents the site's solar conditions and effectively supports data-informed landscape design decision-making to improve outdoor thermal comfort in tropical urban parks.

Design Recommendations Zone 2

In Zone 2, high midday solar exposure, limited pedestrian shade, and insufficient cooling from the retention pond were identified as factors reducing thermal comfort. These conditions result in increased heat stress and lower walkability. Therefore, the design recommendations focus on enhancing the retention pond's cooling performance through riparian vegetation, providing shaded pedestrian routes, and improving natural airflow through strategic vegetation arrangement, as summarised in Table 5.

Table 5. Design Recommendations

Findings	Impact	Design Recommendations
High midday solar exposure, limited pedestrian shade, and insufficient cooling from the retention pond reduce thermal comfort.	Increased heat stress and lower walkability.	Enhance the cooling performance of the retention pond by integrating riparian vegetation, providing shaded pedestrian routes, and improving natural airflow through strategic vegetation arrangement

Data Integration and Validation

The simulation showed extensive midday solar exposure, consistent with the highest THI values (29.864) recorded in the field. Although the retention pond helped cool the area, it was insufficient to reduce thermal stress during peak solar radiation. The integrated results support increasing shade vegetation and shading structures around the pond.

3.3. Zone 3 Results – Playground Area

Zone 3 is in the playground area of Palembang Polda Park, as shown in Figure 10. The location includes the playground area where the field measurements were conducted on 25 April 2026.

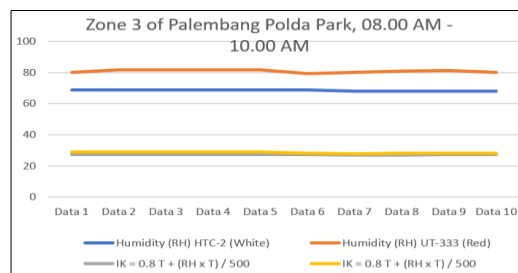


Figure 10. Zone 3 location in The Playground Area of Palembang Polda Park

Data Collection conducted on 25 April 2026 from 8:00 - 10:00 AM (Zone 3):

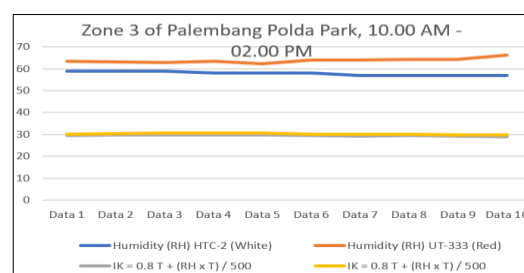
Field measurements in Zone 3 were conducted on 25 April 2026 at three observation periods: 08:00–10:00 AM, 10:00 AM–2:00 PM, and 2:00–4:00 PM. The measurements were conducted to obtain temperature and humidity data in Zone 3. The results of the field measurements for each observation period are presented in Figure 11.

8:00 AM-10:00 AM:



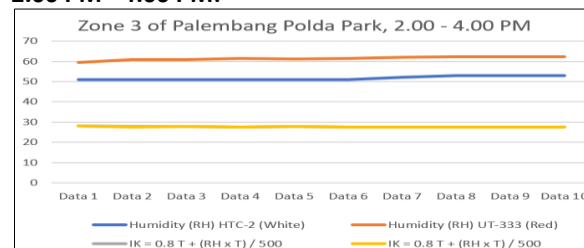
(a)

10:00 AM-2:00 PM:



(b)

2:00 PM - 4:00 PM:



(c)

Figure 11. Results of Field Measurements at Palembang Polda Park, Zone 3:

(a) 8.00AM-10.00 AM, (b) 10.00 AM-2.00 PM, (c) 2.00-4.00 PM

THI Calculation Result

The temperature and humidity data obtained from the field measurements were used to calculate the Temperature Humidity Index (THI) for each observation period. The calculated THI results for Zone 3 are presented in Table 6, including the corresponding categories for the morning, midday, and late-afternoon periods.

Table 6. THI Calculation Results

Time	Temperature Humidity Index	Category
Morning	28.192	Partially Uncomfortable
Midday	28.8015	Partially Uncomfortable
Late Afternoon	26.508	Comfortable

Analysis of Actual Results

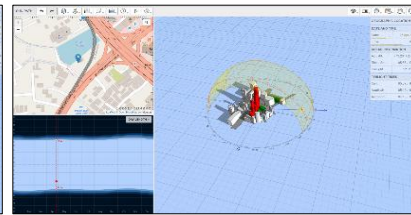
Zone 3 provided the most favourable thermal conditions among the tree observation areas, as reflected by its consistently lower THI values. Dense trees reduce direct solar exposure and limit heat accumulation, contributing to a more stable microclimate. This observation supports the findings of Liu et al. [4] and Varsak et al. [9], which identified vegetation as a key factor in alleviating thermal stress. The strong correspondence between measured data and Andrew Marsh's Sun Path Tool also demonstrates the effectiveness of preserving and expanding tree canopy to enhance thermal comfort in tropical urban parks.

08.00 AM:



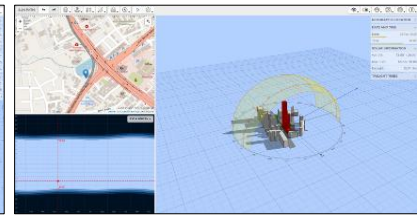
(a)

10.00 AM:



(b)

4.00 PM:



(c)

Figure 12. Results of The Andrew Marsh Sun Path Tool on 25 April 2026:

(a) 08.00 AM, (b) 10.00 AM, (c) 04.00 PM

Results of Andrew Marsh's Sun Path Tool

Based on the study site's geographic coordinates (2.96083°S, 104.73760°E), the model is oriented to True North (0°). Simulations were conducted on 25 April 2026 at 08.00, 10.00 and 16.00 WIB (UTC+7) under clear-sky conditions. The simulation generated solar azimuth and altitude angles, the daily sun path, sunrise and sunset times (05.58-18.00 WIB), daylight duration (12.01 h), and vegetation shadow patterns. These outputs were compared with the field-based microclimate measurements to evaluate the relationship between solar exposure and outdoor thermal comfort. The results indicate that at 08.00 (azimuth 72.96°, altitude 29.79°), the low solar angle produced long shadows that limited direct solar radiation across much of the study area. At 10.00 (azimuth 59.61°, altitude 57.44°), the higher solar altitude reduced shadow coverage and increased solar exposure in open spaces. By 16.00 (azimuth -73.58°, altitude 26.90°), the lower western sun generated elongated shadows, increasing shaded areas and reducing solar radiation. The simulated solar exposure patterns closely matched field observations, with Zones 1 and 2 exhibiting the highest THI values during prolonged direct solar radiation. In contrast, shaded areas recorded lower THI values during the morning and late afternoon. These findings indicate that the simulation reliably represents the site's solar conditions and provides valuable support for data-informed landscape design decisions aimed at improving outdoor thermal comfort in tropical urban parks.

Data Integration and Validation

The simulation identified greater canopy shading in Zone 3, which corresponded with lower THI values compared to Zones 1 and 2. The agreement between simulated shading and field measurements confirms the effectiveness of existing vegetation in improving thermal comfort and supports the maintenance and strengthening of canopy coverage.

Design Recommendations Zone 3

Overall, the findings indicate that the tree canopy has a stronger influence on outdoor thermal comfort than water features do. Higher THI Values in Zones 1 and 2, which were associated with lower thermal stress in Zone 3, contributed to lower thermal stress. The consistency between field observations

and the Sun Path Tool simulation demonstrates the value of combining environmental measurements with digital simulation to support climate-responsive landscape planning.

Table 7. Design Recommendations

Findings	Impact	Design Recommendations
A good tree canopy improves thermal comfort; however, some areas remain exposed to heat-retaining pavement.	Localised thermal stress and uneven user comfort.	Introduce children’s shade structures, increase the use of reflective play surfaces, and optimise seating and activity areas under existing tree canopies to enhance user comfort and safety.

(Source: Author, 2026)

3.4. Research Contribution

This study integrates field-based microclimate measurements with Andrew Marsh’s Sun Path Tools to improve the assessment of outdoor thermal comfort in a tropical urban park. The findings demonstrate the value of computational environmental simulation in supporting evidence-based landscape design and climate-responsive planning by objectively evaluating solar exposure and shading conditions. Future studies should integrate THI with PET, UTCI, ENVI-met, CFD simulation, and matching learning approaches to predict outdoor thermal comfort under future climate scenarios.

4. CONCLUSION

The findings of this study indicate that microclimatic conditions significantly influence outdoor thermal comfort in Polda Park. Several activity areas experienced partially uncomfortable to uncomfortable thermal conditions, particularly during midday, primarily due to intense solar radiation and insufficient shading. These results suggest that the existing landscape configuration does not fully support comfortable outdoor activities.

The combination of field measurements and the Andrew Marsh Sun Path Tool enabled a detailed assessment of solar exposure and shading patterns across the study area. Based on the findings, increasing tree canopy coverage, improving shading facilities, using permeable paving materials, and refining the landscape configuration are recommended to enhance thermal comfort and environmental quality. This study expands the current understanding of microclimate assessment in institutional urban green spaces by integrating field measurements with simulation-based analysis. The integration of field observations with Andrew Marsh’s Sun Path Tool demonstrates how digital environmental simulation can support data-informed design decision-making by objectively identifying solar exposure, shading performance, and priority areas for landscape intervention. This approach extends the use of computational simulation in architecture and landscape planning to improve the design of climate-responsive urban green spaces. The proposed approach provides practical guidance for climate-responsive landscape planning and supports the sustainable management of urban green spaces in tropical environments.

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