THE IMPACT OF URBAN BLUE GREEN SPACE DESIGN ON THERMAL COMFORT: WITH SPECIAL REFERENCE TO PARKS IN JAFFNA CITY CENTRE

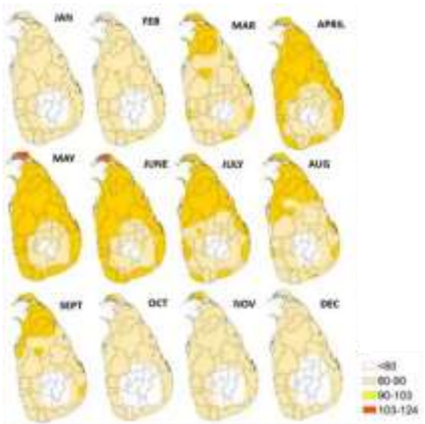
HARSANA. S.[1] & JAYAWEERA. N.[2]
[1, 2] Department of Architecture, University of Moratuwa, Moratuwa, Sri Lanka
[1]*harsasritharan@gmail.com*, [2]*nadika1982@yahoo.com*

Abstract: This study evaluates the effectiveness of blue-green space design strategies in enhancing thermal comfort in Jaffna, a rapidly urbanizing city in the Warm-Dry climatic zone. It focuses on the Aariyakulam Lake Trail and Pannai coastal promenade, each with unique microclimatic conditions. The research addresses how current urban parks provide thermal comfort and evaluates the success of landscape strategies in mitigating heat stress. Using Thermal Sensation Vote (TSV) for actual comfort assessments, validated by on-site meteorological data, and ENVI-met simulations for predicted comfort assessments through Predicted Mean Vote (PMV), the study examines thermal comfort variations across these parks. It highlights landscape features such as spatial layout, vegetation, shading, water elements, and surface materials in shaping thermal perceptions. By integrating quantitative and qualitative analyses of thermal sensations at four park locations, the study reveals the influence of microclimatic conditions on thermal comfort. It concludes that Pannai Park offers the most comfortable environment and provides design recommendations to improve thermal comfort through climate-responsive planning and well-designed blue-green spaces.

Keywords: *Thermal Comfort, Urban Blue-Green Space, Microclimatic Conditions, Heat Stress Mitigation, Climate-Responsive Urban Planning*

1. Introduction

Rising temperatures are increasingly causing discomfort in Sri Lanka, a trend recognized by the Sri Lankan Meteorological Department. They have pointed out that the Heat Index (HI), which combines air temperature and humidity, effectively measures the perceived temperature impacting human comfort. Natural factors contributing to this rising heat include reduced wind activity, higher humidity levels causing more sweating and discomfort, less shade due to cloud cover allowing direct sunlight and sea winds exacerbating these conditions. Man-made factors further intensify the heat, such as urban development that traps heat with concrete structures, insufficient green spaces, the use of heat-absorbing building materials, air pollution from vehicles and industries, and infrastructure designs that hinder heat dissipation. These factors together contribute to the Urban Heat Island (UHI) effect, worsening the thermal discomfort in urban areas. (Sri Lankan Meteorological Department, 2023)



Classification	Heat Index	Effect on the body
Caution	80°F - 90°F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90°F - 103°F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103°F - 124°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125°F or higher	Heat stroke highly likely

Figure 1 Average heat index of Sri Lanka in 2019 by drought.lk

Sri Lanka, particularly Jaffna, has undergone significant urbanization, transforming natural landscapes into urban environments. This urban expansion, driven by a population growth from 18.5% in 2012 to 45% today, has significantly altered local climates and increased heat stress (Emmanuel, 2005; Simath & Emmanuel, 2022). Jaffna's climate, classified as Warm-Dry according to ASHRAE 55 standards, features a tropical savanna climate with distinct wet and dry seasons.

*Corresponding author: Tel: +94774265205 Email Address: harsasritharan@gmail.com
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Grasping these climate patterns is essential for addressing urban heat challenges effectively. Current measures by municipal authorities, like water spraying on streets to cool them, offer only temporary relief, highlighting the need for more sustainable and long-term solutions. There is a noticeable deficit of outdoor spaces that provide thermal comfort, such as shaded green areas and designated relaxation zones within the urban core.

This study will investigate the extent to which current parks and green infrastructure promote thermal comfort for users to address the knowledge gap on thermal comfort in Jaffna's urban blue-green spaces. While there is substantial global research on the role of blue-green infrastructure in enhancing thermal comfort, there is limited understanding of these dynamics within the unique warm-dry climate of Jaffna. This study aims to evaluate the current thermal comfort levels in Jaffna's city centre parks, assess the suitability of existing thermal comfort scales for this climate, and identify user preferences and key factors influencing comfort in these spaces. The findings will offer insights into effective landscape strategies tailored to Jaffna, providing recommendations to improve thermal comfort through sustainable urban design and landscape architecture.

Figure 2 Image of main street Jaffna on a hottest month by sundaytimes.lk

By addressing these objectives, the study aims to contribute to landscape architecture by suggesting design solutions that reduce urban heat, improve thermal comfort, enhance resilience to climate change, and address public health issues, thereby increasing the liveability of Jaffna's urban environment.

2. Literature review

Urban areas, characterized by dense development and high populations, often experience higher temperatures than surrounding rural areas due to the Urban Heat Island (UHI) effect. This effect, caused by a concentration of buildings, infrastructure, and human activities, results in elevated temperatures, exacerbating heat stress. Heat stress occurs when the body struggles to regulate its temperature, leading to dehydration, fatigue, and heat exhaustion, particularly in hot climates. Urban green spaces can mitigate the UHI effect by utilizing natural processes like transpiration and evapotranspiration, and through features such as vegetation, surface materials, shading, and water elements to lower temperatures (De Abreu-Harbich et al., 2015).

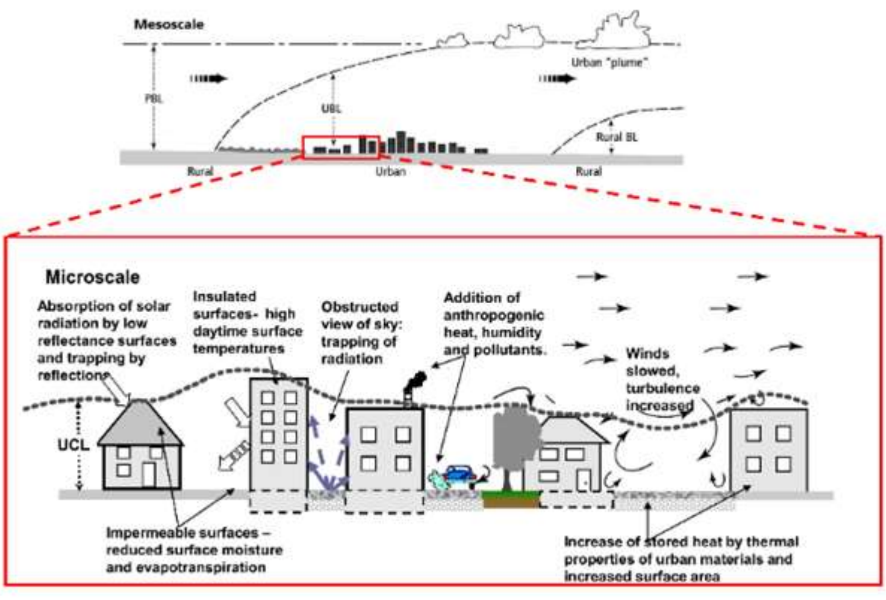
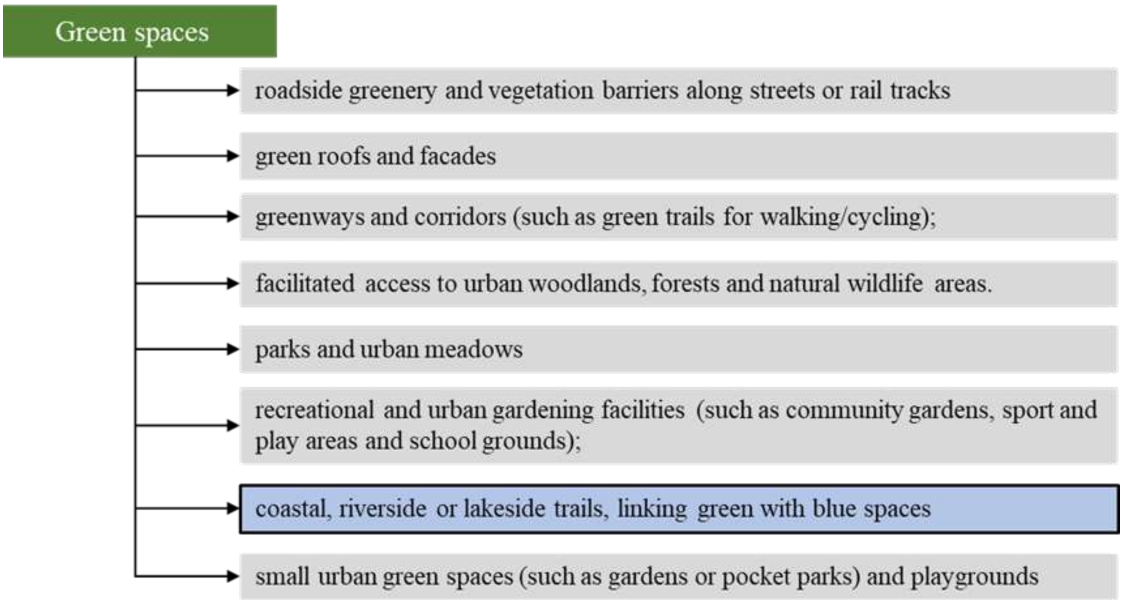


Figure 3 UHI Effect processes; Source: (Tumini, 2014)

Urban blue-green spaces, which include water and vegetation features like rivers, lakes, forests, and grasslands, play a crucial role in cooling cities. Rising temperatures in urban areas, driven by human activities and natural factors, highlight the need for incorporating green and blue elements into city planning to enhance thermal comfort (Qiu et al., 2023; Norton et al., 2015).



Source : World Health Organization. Regional Office for Europe. (2016). Urban green spaces and health

Figure 4 Classification of urban green spaces by WHO

These spaces, recognized by the World Health Organization (WHO) for their benefits in improving thermal comfort, combine ecological and social values and are increasingly assessed using tools like satellite data for urban planning (Peng et al., 2016).

Urban blue-green spaces reduce the UHI effect by cooling the environment through natural processes like transpiration and radiation reflection. These spaces enhance outdoor comfort and reduce the urban heat impact (Yu et al., 2020). The effectiveness of these areas depends on vegetation type and density, with denser vegetation and the presence of water bodies offering greater cooling effects (Xiao et al., 2022). The spatial design of these areas also influences their ability to cool and humidify the urban environment, with well-planned parks that integrate water and green elements providing the most significant benefits (Taghvaei, n.d.).

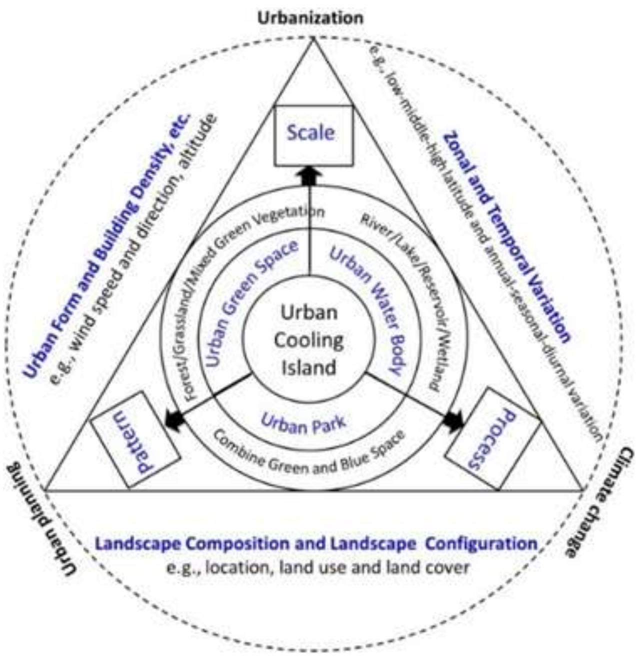


Figure 5 Cooling effect of urban blue-green space and threshold-size-based UHI mitigation studies

Thermal comfort, which refers to how comfortable people feel with the outdoor temperature, is influenced by various factors such as heat, vegetation, shading, and surface materials (Ahmed, 2003; Ali-Toudert & Mayer, 2006; Cheng & Ng, 2006). Assessing thermal comfort involves measuring people's sensations and satisfaction with the thermal environment using tools like the Thermal Sensation Vote (TSV) and Thermal Comfort Vote (TCV) (Zhou et al., 2015). Advanced tools like Rayman and ENVI-met help analyze thermal comfort, although they require technical expertise (Yang et al., 2021).

3. Research Methodology and Data Collection

This study adopts a mixed methods research design to explore how blue-green spaces in Jaffna affect thermal comfort. By combining quantitative analysis and qualitative analysis, we aim to get a complete picture of thermal comfort. The core of our quantitative analysis involves using ENVI-met software to simulate the Predicted Mean Vote (PMV), a measure of how comfortable people feel in different thermal conditions. The qualitative analysis will include surveys and interviews to validate and complement the quantitative data. Additionally, this study observes real user behaviors, focusing on time spent within the park and the specific areas where people naturally gather and wait.

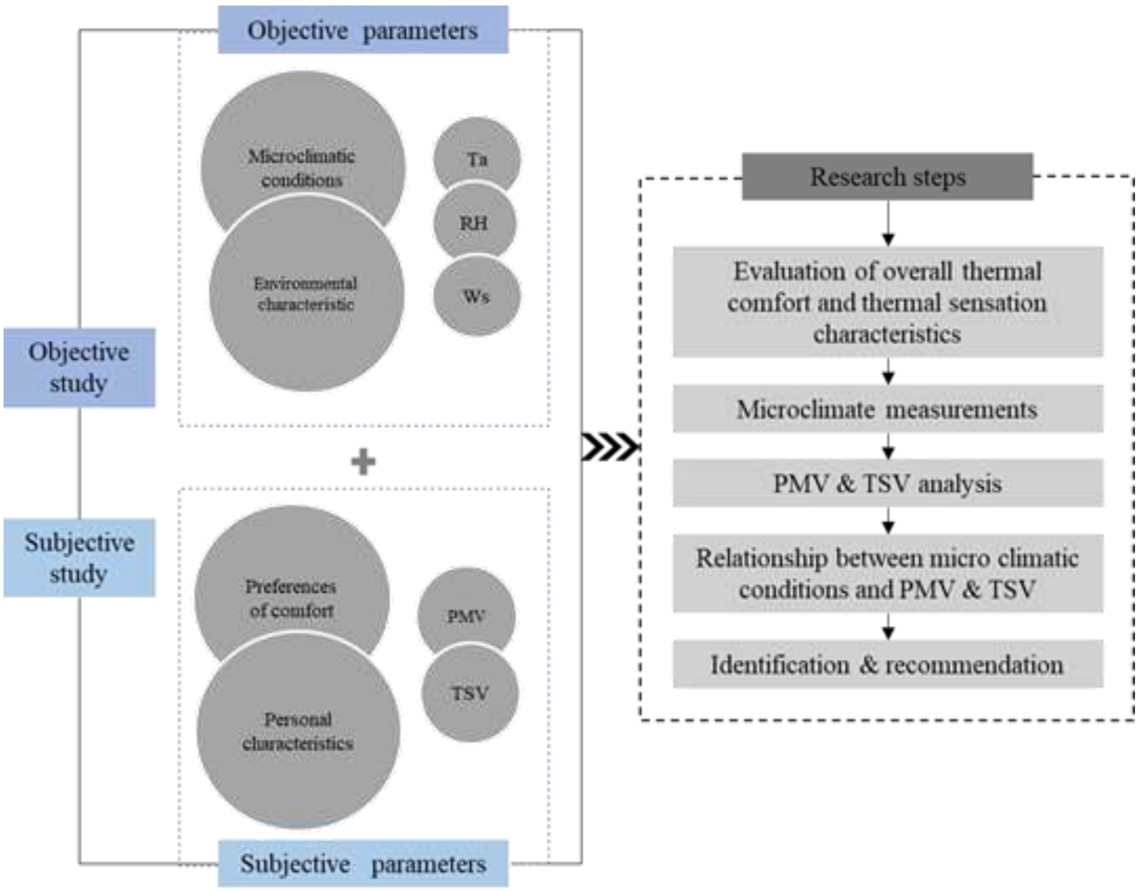


Figure 6 Research Methodology Framework by Author

3.1. THEORETICAL FRAMEWORK

The theoretical framework explores how people adapt to varying outdoor temperatures through both physiological and psychological means. Physiologically, adaptation occurs in three stages: initially, the body reduces stress by starting to adjust to heat, followed by physiological changes such as adjustments in heart rate and skin temperature, and finally, acclimatization, where the body becomes increasingly tolerant to heat over time. Psychologically, adaptation involves how habits, experiences, and expectations influence one's perception of temperature. For instance, if individuals anticipate hot weather, they may experience less discomfort. This framework is informed by two key theories: Protection Motivation Theory, which posits that adaptation to the environment is influenced by past experiences, and Self-Determination Theory, which emphasizes that psychological needs like feeling in control and competent affect thermal comfort. Additionally, environmental conditions and the concept of Alliesthesia, which asserts that comfort is contingent on both internal body conditions and external temperatures, play crucial roles in temperature perception. Together, these insights help us understand how both physiological and psychological factors contribute to how comfortable people feel outdoors (Lam et al., 2021).

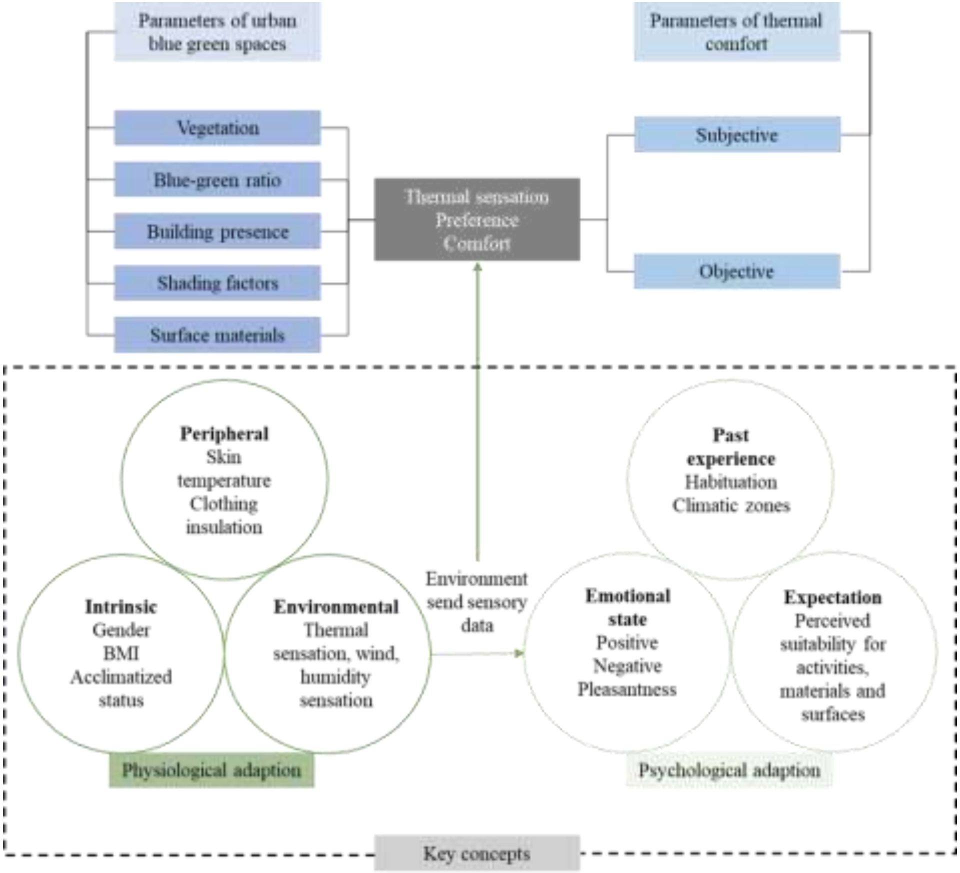


Figure 7 Theoretical Framework by Author

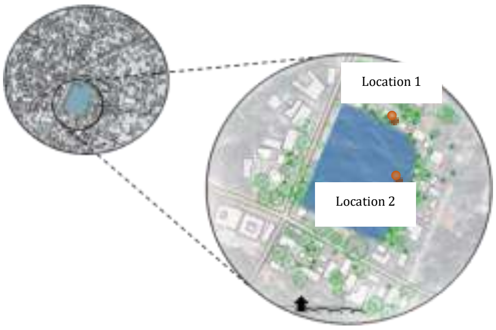
3.2. SELECTION OF CASE STUDY

Jaffna, falling within the warm dry climatic zone as per ASHRAE 55 standards, experiences a tropical savanna climate. It has a dry season from February to August and a wet season from September to January. Jaffna has Sri Lanka's highest average temperature, around 83°F (28.3°C), with the hottest months being April-May and August-September. The region primarily receives rainfall during the Northeast monsoon. (Sri Lanka Meteorological Department, 2023)

Table 1 Case study selection criteria

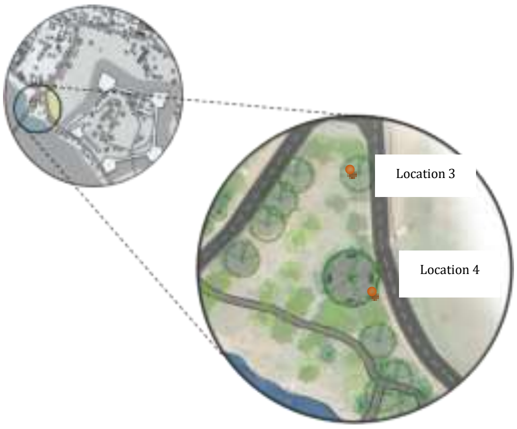
Urban blue green space	**Type**	**Condition**	**Accessibility**	**Current scenario**
Pullukulam	Urban recreational facility	Not functioning	No	
Aariyakulam	Lakeside trail	Functioning	Yes	
Vannan kulam	Abandoned lakeside greenery	Not functioning	No	
Pannai park	Coastal promenade	Functioning	Yes	

3.2.1 Case Study 1 - Aariyakulam Park



Aariyakulam Park, located at 9°40'5"N 80°1'8"E in Jaffna city, offers a natural space in an urban setting. For the study, two spots were chosen based on actual user behaviour, identifying locations that provide ample shade and are preferred by visitors.

3.2.2 Case Study 2 – Pannai Park



Pannai Park, at 9.6794° N, 80.0001° E along Jaffna Lagoon's shore, features walking trails, a children's play area, event spaces, and seating. Two spots were chosen based on seating, proximity to the shore, and varying microclimates.

3.3. DATA COLLECTION

Field investigations measured air temperature (Ta), relative humidity (RH), and wind velocity (v) using ISO 7726-compliant instruments. Data loggers (Hobo H8) recorded Ta and RH, while anemometers measured wind velocity, with data collected from 9 am to 6 pm on August 12 and 13, 2023, at 1-minute intervals. Measurements were taken at 1.1 meters above ground in shaded areas, using two data loggers per location to capture microclimatic conditions. Thermal comfort was assessed using the Predicted Mean Vote (PMV) model, adapted for outdoor settings through the Klima-Michel Model (Fabbri et al., 2017). A guided questionnaire surveyed 60 park visitors, collecting data on thermal comfort and perception (Lin et al., 2010; ISO, 1998).

3.4. DATA ANALYSIS TECHNIQUES

3.4.1 ENVI-Met Simulation for PMV Calculation

ENVI-met was used to simulate PMV values in the parks. This tool assesses outdoor temperature conditions and creates PMV distribution maps, showing comfort levels in different areas. Simulation conditions included:

Table 2 Envi-met simulation steps and process

	Description
Spaces	to specify the general site layout and the properties of the materials making up the associated surfaces.
Config wizard	to establish the site's specific climate
Envi core	Performs configuring, running, and analyzing microclimatic simulations.
Biomet	to establish some set-point parameters to evaluate comfort condition thresholds, especially about metabolic activity (met), clothing (Clo), and the simulation day
Leonardo	to show the computations' outcomes on maps of the outdoor microclimate that are utilized to see the situation in both case studies

4. Data Analysis and Results

4.1. MEASURED MICROCLIMATIC DATA ANALYSIS

4.1.1 Microclimatic Analysis of Air Temperature in Case Study Locations

Figure 8 Spatial-Temporal Analysis of Air Temperature Measurements across Four Locations in the Case Study Areas

Air temperature significantly affects the thermal comfort in urban parks. Despite similar air temperatures, Aariyakulam and Pannai Park create different thermal sensations. Physical factors such as sunlight and wind patterns also play a role. In the evening, temperatures generally remain high because the heat stored in surfaces like soil continues to radiate even after sunset. In the morning, Pannai Park starts cooler at about 31°C due to its openness and coastal proximity, but it heats up quickly to 34°C by evening. Conversely, Aariyakulam, with its dense tree canopy, cools down more effectively in the evening, maintaining a lower temperature compared to Pannai Park. This difference illustrates how park design and natural elements can influence thermal comfort despite similar overall temperatures.

4.1.2 Microclimatic Analysis of relative humidity in Case Study Locations

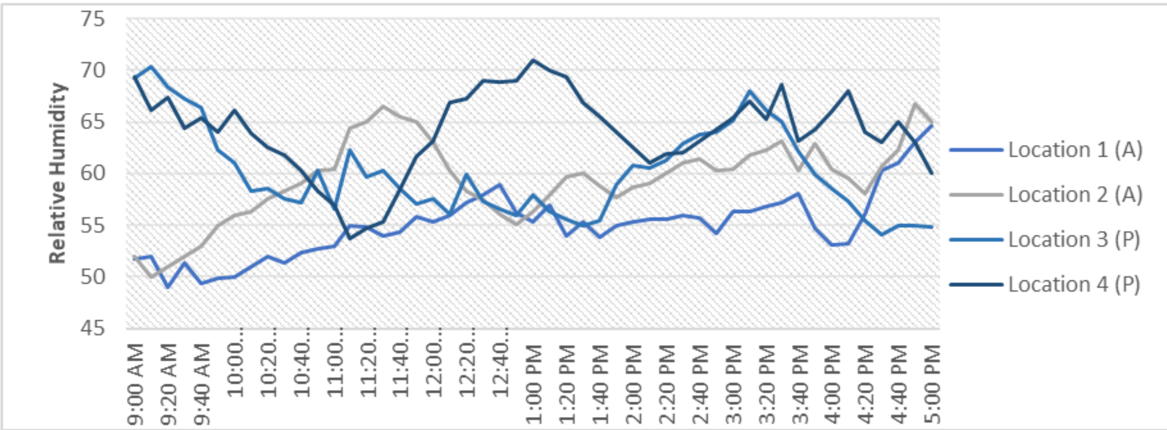


Figure 9 Spatial-Temporal Analysis of Relative humidity Measurements across Four Locations in the Case Study Areas

Microclimatic measurements at Aariyakulam Lake Trail and Pannai Coastal Park were conducted on August 12 and 13, 2023. The goal was to compare these areas under similar weather conditions. Both days were chosen to ensure that the climate was nearly identical. To confirm this, relative humidity was measured at four different spots in each area, showing consistent patterns with similar values. This consistency suggests that any microclimatic differences between the two locations were not due to varying sky conditions.

Humidity is mainly influenced by temperature and the proximity of water. In Pannai Park, which is near the coast, humidity tends to be higher in the afternoon due to the nearby sea and evaporation. Factors such as temperature and park layout also affect humidity. In contrast, Aariyakulam shows steady humidity levels throughout the day, indicating that internal watercourses have little effect on its overall humidity and outdoor comfort. These findings highlight how coastal and inland settings impact humidity and microclimatic conditions differently.

4.1.3 Microclimatic Analysis of wind speed in Case Study Locations

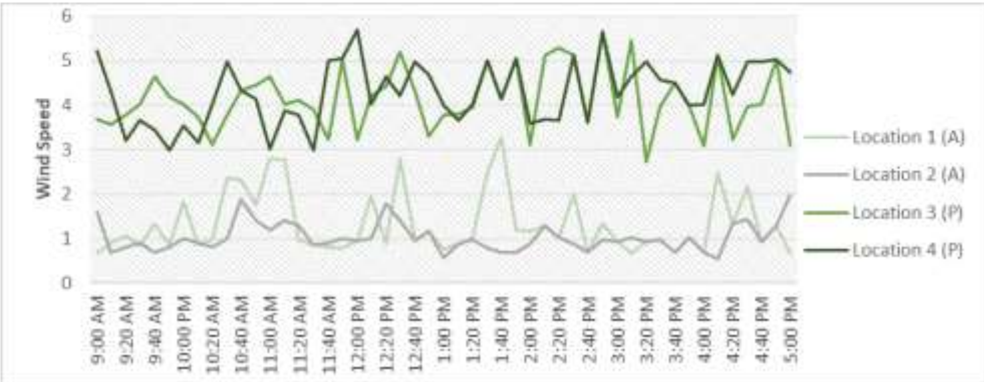


Figure 10 Spatial-Temporal Analysis of Wind Speed Measurements across Four Locations in the Case Study Areas

At Pannai Park, Sites 3 and 4 have stronger sea breezes than Sites 1 and 2 at Aariyakulam Park. This is due to temperature differences between land and sea, which boost wind speed along the coast, improving comfort. Site 4 is very open, allowing more wind, while Site 3 has some trees that block the wind a bit. At Aariyakulam Park, buildings and wind shelters block the wind more, changing how people feel about the temperature there. These differences in wind patterns directly affect how comfortable people feel at these locations.

4.2. PMV ANALYSIS OF THERMAL COMFORT IN BOTH CASE STUDIES.

4.2.1 PMV Analysis in Aariyakulam Lake Trail Area

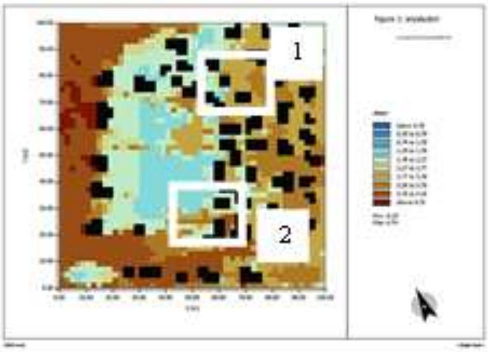


Figure 11 PMV simulation for Aariyakulam area by ENVI met

Table shows how the Predicted Mean Vote (PMV) varies across different areas. Near the lake, including sites 1 and 2, PMV values range from 1.29 to 3.26, indicating it is slightly warm to warm. The road area has higher PMV values (3.75-4.25), meaning it is hot to very hot. These differences are mainly due to the cooling effect of the lake and the layout of the landscape, including vegetation and surface materials.

4.2.2 PMV Analysis in Pannai park

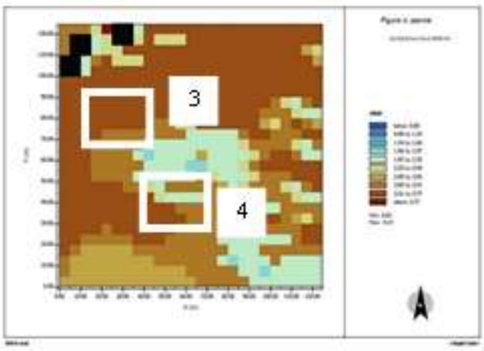


Figure 12 PMV simulation for Pannai park area by ENVI met

The table shows the PMV distribution in Pannai Park, where PMV values are lower compared to Aariyakulam Lake Trail. This is because Pannai Park, located by the coast with plenty of blue areas and coastal winds, offers better thermal comfort. Areas 1 and 2 in Pannai Park have PMV values ranging from 1.6 to 2.33, indicating slightly warm conditions. These spots are shaded with dense tree cover, making them more comfortable than open areas with fewer trees, where PMV values range from 3.05 to 3.77, categorized as warm to hot.

4.3. TSV & TCV ANALYSIS IN CASE STUDY LOCATIONS

Percentage of hot sensation in TSV is calculated by:

$$\frac{no\ of\ votes\ for\ (+1), (+2), (+3)}{total\ no\ of\ votes} \times 100$$

Percentage of satisfied in TCV is calculated by:

$$\frac{no\ of\ votes\ for\ (+1), (+2), (+3)}{total\ no\ of\ votes} \times 100$$

Table 7 below compares air temperatures and thermal comfort at four locations. It shows minimum, maximum, and average temperatures, along with percentages of people feeling hot (TSV) and those satisfied with thermal comfort (TCV). Location 3, with the highest average temperature (32.76 °C), was surprisingly the most comfortable, with 73.33% satisfied despite 48.33% feeling hot. Location 1 had the highest air temperature (33.59 °C), with 68.33% feeling hot and only 46.66% moderately satisfied. Location 2, at 32 °C, saw 60% feeling hot but had better comfort, with 53.33% satisfied. Both Locations 3 and 4 had similar temperatures (around 32 °C) and thermal sensation (1.6-2.33 PMV) yet had lower percentages of people feeling hot (48.33% and 55%) and higher comfort levels (73.33% and 60%). These findings suggest that wind patterns and thermal adaptability significantly influence people's comfort.

Table 3 Correlation between microclimatic measurements, TSV & PMV in the study locations

Locations	Air temperature	Percentage sensed hot in TSV	Percentage satisfied TCV	PMV
Location 1	Min 30.22	68.33%	46.66%	1.29-3.26
	Max 33.98			
	Median 33.59			
Location 2	Min 30.21	60%	53.33%	3.05-3.77
	Max 33.81			
	Median 32			
Location 3	Min 31.52	48.33%	73.33%	1.6-2.33
	Max 34.85			
	Median 32.76			
Location 4	Min 30.52	55%	60%	1.6-2.33
	Max 34.85			
	Median 32.05			

4.4. TIME SPENT BY USERS AT STUDY LOCATIONS BASED ON THE OBSERVED BEHAVIOR

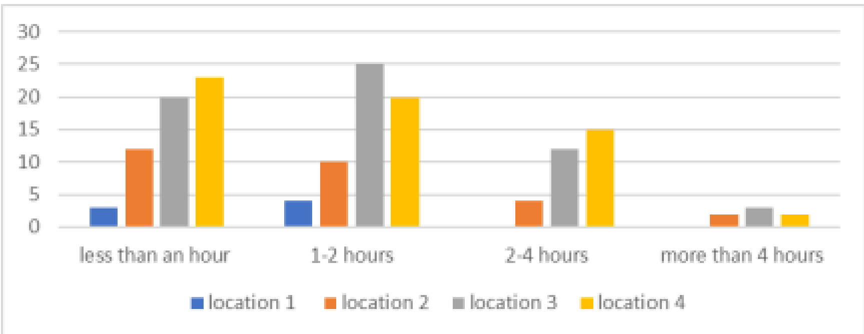


Figure 13 User Time Spent and Preferences at Study Locations Based on Observed Behaviour

The chart 8 illustrates the time users spend at four study locations, highlighting preferences based on observed behaviour. Location 3 is the most popular, with the highest user presence in the "1-2 hours" and "2-4 hours" categories, suggesting it provides an appealing environment for extended stays. Location 4 also attracts users within these time ranges, though to a lesser extent than Location 3. In contrast, Locations 1 and 2 show lower levels of engagement, particularly for stays exceeding one hour. Overall, Location 3 is the most favoured based on users' actual time.

5. Conclusion

This study examines thermal comfort in Jaffna's urban parks, specifically Aariyakulam Lake Trail and Pannai Coastal Park. The findings highlight significant differences in user comfort, with Pannai Coastal Park, particularly Location 3, offering optimal comfort due to effective shading, dense vegetation, and favourable air movement. In contrast, the Aariyakulam Lake Trail was less comfortable, primarily due to the lack of shaded areas and seating, which led to higher thermal sensation under direct sunlight. The study reveals a clear statistical relationship between microclimatic conditions—such as temperature, humidity, wind and users' thermal perception. It also underscores the role of acclimatization and actual behaviour in shaping thermal comfort. Based on these insights, recommendations for enhancing comfort through improved shading, seating, and temperature moderating materials are proposed, emphasizing the critical role of thoughtful landscape planning in urban blue-green environments.

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