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Microclimate Environmental Impact in Campus: Case Study at Faculty of Built Environment and Faculty of Art and Design, UiTM Puncak Alam, Selangor

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Abstract

This study explores the effects of the thermal environment on the microclimatic conditions at the Faculty of Built Environment and the Faculty of Art and Design at UiTM Puncak Alam. It focuses on key microclimatic factors such as temperature, humidity, and wind speed, which significantly influence urban heat island (UHI) issues in urban settings. The research examines how thoughtful design elements such as building orientation, greenery, and water features can create a more comfortable and sustainable campus in a tropical climate. By combining field measurements with ENVI-met simulations, the study reveals that areas with well-placed vegetation and water features experience significantly lower temperatures and more stable humidity, contributing to a more pleasant outdoor atmosphere. Additionally, strategically designed building layouts enhance natural airflow and reduce stagnant air zones, further improving comfort. The study emphasizes that ENVI-met is a valuable tool for analysing and predicting microclimatic conditions, demonstrating how green infrastructure and sustainable planning can transform campuses into cooler and more resilient spaces. Results indicate that, during peak hours, the air temperature reaches a maximum of 32.8°C at 15:00, while the minimum temperature is 23.5°C at 22:00. In terms of relative humidity, the highest percentage recorded is 98% at 03:00, which decreases to 62% at 15:00. The wind speed recorded at the site shows a maximum of 1.16 m/s at 07:00, while the lowest measurement is 0.01 m/s at 06:00. These findings provide practical recommendations, including increasing green coverage, optimizing campus layouts, and incorporating water features. Such measures can help universities address environmental challenges, such as the UHI effect, and create healthier, more comfortable learning environments.

1.0 INTRODUCTION

A university campus is a vital space for individuals to gain knowledge, where education cultivates personal growth and character development (Brozovsky et al., 2019; Najad et al., 2018). In addition to supporting formal educational activities, the campus serves as a social environment that fosters interpersonal skills and enriches the overall educational experience (Zaki et al., 2020a). A well-planned campus environment enhances student well-being, which in turn supports overall educational success (Hasan et al., 2023).

Microclimate is a crucial aspect of the campus environment, particularly for outdoor learning spaces and indoor thermal comfort. This term refers to localized atmospheric conditions that differ from the broader regional climate and significantly impact university campuses (Camos, 2017). In tropical climates, factors such as temperature, humidity, and wind speed are essential characteristics of microclimates that contribute to sustainable environments (Zaki et al., 2020a; Misni et al., 2019; Misni, 2015). On university campuses, these microclimatic conditions are influenced by aspects such as building design, landscape features, and vegetation (Brozovsky et al., 2019; Wong et al., 2007).

The Urban Heat Island (UHI) effect occurs when urban areas are warmer than adjacent rural areas due to human activities, land use changes, and altered landscapes, all of which affect local climates (Brozovsky et al., 2019; Zaki et al., 2020a). University campuses, often located in urban settings, may be susceptible to UHI issues. Recent studies indicate that urban design, building layout, and the inclusion of green spaces can help mitigate heat and improve comfort levels, particularly in hot-humid climates (Zaki et al., 2020b). Trees and greenery play a crucial role in lowering outdoor temperatures and creating shaded areas for cooling (Najad et al., 2018). Additionally, selecting climate-appropriate plants and incorporating water features can further enhance the microclimate, making campuses more resilient to weather changes (Hasan et al., 2023; Xu et al., 2022).

The primary aim of this study is to evaluate how microclimatic factors specifically temperature, humidity, and wind speed affect the thermal environment at UiTM Puncak Alam and contribute to Urban Heat Island (UHI) conditions. The study seeks to assess how design strategies, such as building orientation, green infrastructure, and water features, can improve outdoor thermal comfort in a tropical campus setting. By combining field measurements with ENVI-met simulations, this research aims to provide practical planning recommendations for creating a cooler, more comfortable, and sustainable campus environment.

2.0 LITERATURE REVIEW

The campus environment is a dynamic space that not only supports academic activities but also significantly influences microclimatic conditions. A well-designed campus can positively affect its surrounding climate. Sustainable development on campuses emphasizes integrating green infrastructure, such as vegetation, shaded areas, and water bodies. These elements help regulate temperature, humidity, and air quality (Hasan et al., 2023; Wong et al., 2007). Additionally, they help reduce the urban heat island effect and enhance overall campus comfort (Zaki et al., 2020a). The interaction of various environmental variables such as temperature, humidity, wind speed, and solar radiation creates a unique microclimate that directly impacts the campus’s thermal comfort. Through strategic planning and the use of simulation tools such as ENVI-met, campus environments can be optimized to enhance user well-being (Ouyang et al., 2022). This research will focus on the Faculty of Business and the Faculty of Art and Design at UiTM Puncak Alam, Selangor, as a case study to explore how campus design and surrounding microclimatic conditions interact.

2.1 Campus Environment

The campus environment significantly influences and adapts to microclimatic conditions, especially in urbanized and tropical areas. Key studies underscore the importance of sustainable campus designs, which include the incorporation of vegetation, shaded areas, and water bodies to mitigate the effects of urban heat islands (Hasan et al., 2023; Wong et al., 2007). Simulation tools like ENVI-met have been shown to effectively assess the microclimatic performance of green infrastructure (Ouyang et al., 2022). Furthermore, strategic spatial planning, such as the inclusion of courtyards and shaded areas, enhances user comfort (Misni et al., 2019; Zaki et al., 2020b). These findings highlight the necessity for sustainable approaches in campus development. A notable example is UiTM Puncak Alam, which serves as a case study to examine the relationship between design and microclimatic effects in tropical environments.

2.2 Sustainable Development in Campus

Sustainable campus development integrates environmental and social considerations to create resilient academic environments. This approach includes reducing ecological footprints through green infrastructure, such as vegetation and water features (Genta et al., 2022). These elements help improve air quality and mitigate heat (Wong et al., 2007; Hasan et al., 2023). Climate-responsive designs, like shaded areas and the use of sustainable materials, enhance thermal comfort and the overall environment (Zaki et al., 2020b). Advanced tools, such as ENVI-met, are utilized to assess microclimatic impacts and optimize green initiatives (Ouyang et al., 2022). These strategies promote healthier and more sustainable campuses, supporting education while minimizing environmental impact. By examining environmental sustainability efforts, we find that Universiti Teknologi Malaysia faces similar climatic challenges. Their studies emphasize the role of green infrastructure in balancing microclimatic variables and highlight the importance of integrating nature with urban structures (Ahmad et al., 2017). This integration helps regulate the local climate and improve campus liveability. Research like this reinforces the significance of strategic landscape and urban planning in managing microclimates in hot-humid environments (Najad et al., 2018; Ouyang et al., 2022).

2.3 Tropical Climate

Tropical climates are characterized by consistently high temperatures and humidity, along with slower wind flow (Chan, 2019). Unlike temperate regions, tropical areas feature a unique seasonal pattern. Significant temperature changes are uncommon; instead, seasons in these regions are primarily defined by variations in rainfall. Many tropical regions experience distinct dry and wet seasons. The wet season is characterized by a significant portion of the annual rainfall occurring within one or more months, often falling in the late afternoon and early evening (Wong et al., 2007; Zaki et al., 2020a).

2.4 Microclimate Elements

The interaction of various climate variables, such as air temperature, humidity, and wind speed, creates microclimate conditions that significantly impact the environment (Misni et al., 2019). Research indicates that the arrangement of buildings, green spaces, and hard surfaces affects local climate variables (Asmadi et al., 2024; Misni et al., 2019). This highlights the need for improved planning to reduce heat retention. The urban heat island (UHI) effect is a critical concern, as dense urban surfaces absorb more heat during the day, creating hotspots that disrupt thermal comfort. Additionally, urban morphology influences microclimate parameters, including temperature and wind patterns, within university campuses (Zaki et al., 2020b). These factors should be considered in campus planning to create comfortable outdoor spaces and mitigate the heat island effect.

2.5 Temperature

Temperature is one of the most critical variables in urban microclimate studies, especially in tropical regions. High temperatures, exacerbated by urbanization and a lack of vegetation, increase the thermal impact on outdoor spaces. Research has found that outdoor air temperatures in shaded areas of university campuses can significantly reduce surface temperatures compared to exposed areas (Zaki et al., 2020). Additionally, green elements play a crucial role in lowering ambient air temperature and enhancing thermal comfort in educational institutions (Najad et al., 2018; Misni, 2015). Without adequate green infrastructure, the urban heat island effect is likely to worsen, making the outdoor environments of campuses less comfortable, particularly during peak daytime hours (Asmadi et al., 2024; Misni et al., 2019).

There is a need for localized analysis of temperature variability in open spaces to determine how design features influence thermal comfort. This research contributes to current studies by examining temperature patterns on campuses, particularly in relation to the potential urban heat island effect (Genta et al., 2022).

2.6 Relative Humidity

Relative humidity (RH) and temperature play a crucial role in environmental impacts on human comfort. The interaction between these variables can cause significant discomfort, especially in hot, humid climates. Studies have shown that areas with higher vegetation and shaded regions provide better control of environmental humidity (Zaki et al., 2020). This helps to reduce heat stress in the surrounding environment. Natural elements can create microclimates that are cooler and less humid, contributing to a more comfortable atmosphere.

Another study analysed features such as courtyards that can help regulate environmental humidity levels, leading to a more balanced microclimate. The spatial arrangement of buildings and open spaces can also influence humidity control, even in hot and humid regions (Obeidat & Alsjayeb, 2017). In tropical climates like Malaysia, managing relative humidity is critical for ensuring comfort and minimizing environmental impacts in campus settings. Research has focused on the role of greenery in improving the microclimate and reducing humidity levels on campuses (Wong et al., 2007). The combination of high RH and elevated temperatures creates a challenging environment for outdoor activities (Misni, 2024; Misni et al., 2019).

2.7 Wind Speed

Microclimate management is significantly influenced by wind speed and direction, playing a critical role in regulating microclimates. Wind affects air circulation and helps cool the environment. Research has demonstrated that building orientation and massing can alter natural wind flows, reduce natural ventilation and leading to increased local temperatures (Misni, 2024; Misni et al., 2019).

Strategically placing buildings and vegetation can create wind corridors that enhance airflow, leading to more comfortable outdoor spaces. The microclimate of a Norwegian university campus highlights the importance of optimizing building layouts to improve wind flow and mitigate environmental impacts. Urban design has a substantial effect on wind patterns, which can either promote or hinder ventilation (Brozovsky et al., 2019).

This underscores the universal significance of wind in relation to environmental impacts. Additionally, strategically placing vegetation along wind corridors can help mitigate the effects of stagnant air on urban campuses and enhance outdoor thermal comfort (Zaki et al., 2020a).

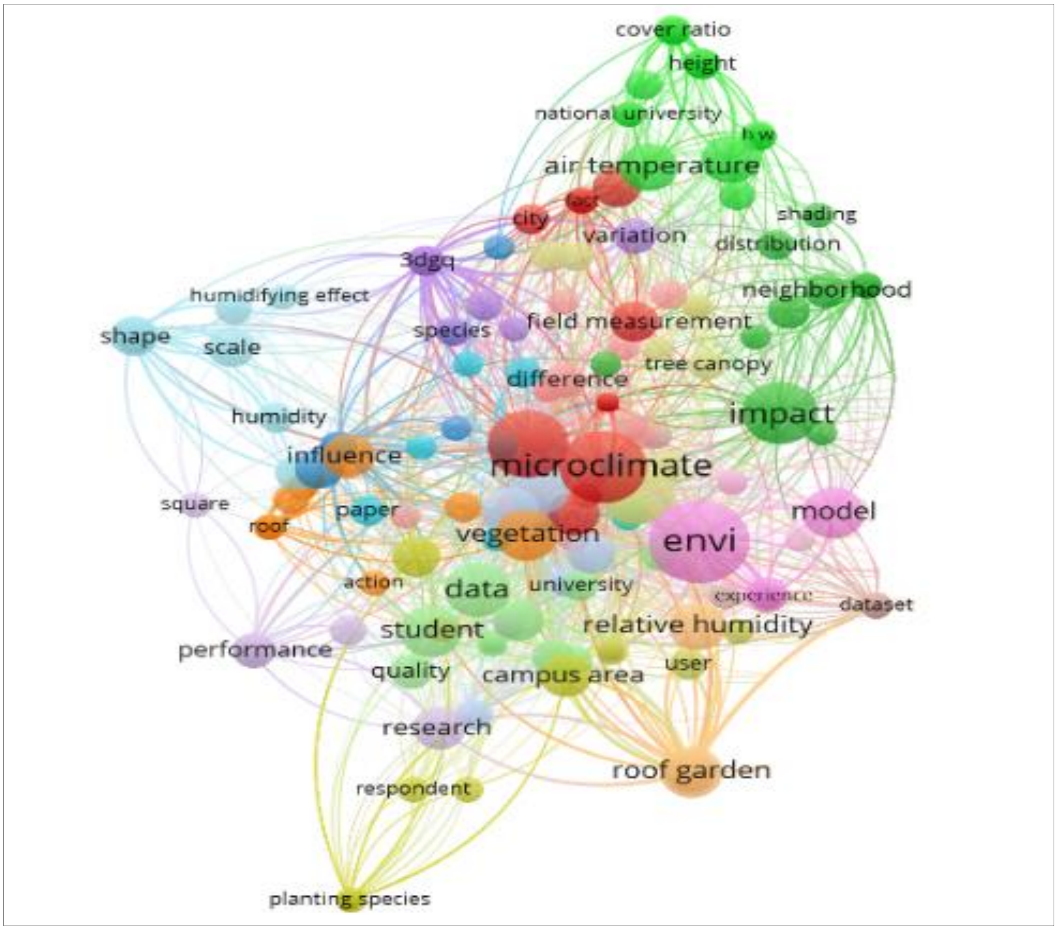

Figure 1. Latest keywords for campus microclimate study.

VOSviewer is a powerful tool used for analysing scientific literature. It enables visual representation of relationships among keywords, authors, and publications (Li et al., 2022). The software produces visualizations of nodes that represent individual concepts related to a study. Different colours indicate clusters of related themes, providing insights into the research structure. Firstly, the central theme, represented in grey, is the term "microclimate." This theme emphasizes how various factors interact to shape localized climate conditions.

Secondly, the red cluster focuses on the relationship between architectural elements and thermal comfort, highlighting the roles of shading, greenery, and thermal performance in campus settings. Lastly, the blue cluster emphasizes the importance of environmental modelling and methodologies, showcasing the application of field measurements and decision-making processes. This understanding aids in analysing microclimates within institutional and urban contexts.

Table 1 summarizes the latest research on urban microclimate studies and the techniques used, demonstrating the different methods adopted by researchers. This progression reflects a growing awareness of the influence of urban microclimates on environmental campus planning and outdoor thermal comfort. It also underscores the significance of green areas, which can significantly reduce temperatures and enhance outdoor thermal comfort, as well as mitigate urban heat island effects in tropical campus environments. The microclimate simulation modelling methods, such as ENVI-met, used for specific spatial areas within the campus are clearly outlined.

Table 1. Study on the impacts of microclimate on urban university campus and the methods applied

No.	Author	Study/Content	Method	Objectives/Findings	Site Study Area
1	Brozovsky et al. (2019)	Assessing energy-efficient strategies for campus design	Simulation and analysis	Improved energy efficiency strategies for university campuses	University Campus
2.	Genta et al. (2021)	Effects of Urban Morphology on Microclimate Parameters	Life Cycle Assessment (LCA)	Evaluated environmental impacts at the urban scale and ecological footprint	University Campus
3.	Najad et al. (2018)	Review of sustainability practices and green campus strategies	Review and analysis	Comprehensive insights into green campus initiatives	University Campus
4.	Hasan et al (2023)	Assessment of Outdoor Air Temperature Shaded Areas	Plant selection analysis	To assess the effect of different types of shade on air temperature in a hot-humid climate.	Open space
5.	Misni et al. (2017)	Microclimate environmental modelling for new built environments	ENVI-Met	Developed a model for optimising microclimate in campus designs	University Campus
6.	Obeidat et al. 2022)	Influence of courtyard microclimates on spatial behaviour	Observational study and analysis	Identified courtyards' effects on spatial behaviour under hot, dry climates	Campus
7.	Ouyang et al. (2022)	Evaluating ENVI-met for green infrastructure in subtropical climates	ENVI-Met	Assessed ENVI-Met's accuracy in modelling thermal-radiative effects of green infrastructures	Urban Environment
8.	Wong et al. (2007)	Impact of greenery on environmental performance in a tropical institutional campus	Field study and modelling	Greenery significantly reduces temperature and enhances thermal comfort	Campus
9.	Xu et al. (2022)	Effects of water body layout on campus square microclimate	Microclimate modelling and analysis	Optimized water body layouts enhance thermal comfort in campus squares	Campus
10.	Zaki et al. (2020a)	Effects of urban morphology on microclimate parameters	ENVI-met,	Urban morphology significantly affects microclimate; greener campuses have better thermal conditions	Urban University Campus
11.	Zaki et al. (2020b)	Assessment of shaded areas' impact on outdoor air temperature	Field measurement and ENVI-met modelling	Shaded areas effectively reduce outdoor air temperatures in hot-humid climates	Urban University Campus

3.0 METHODOLOGY

3.1 Site Study

This study conducts case research at the Faculty of Built Environment (FBE) and the Faculty of Art and Design (FAD) at Universiti Teknologi MARA in Puncak Alam, Selangor, Malaysia. It focuses on the microclimatic impacts and conditions within the campus environment by analysing the interactions between the built environment, surrounding vegetation, water bodies, and open spaces. The key and location plan are shown in Figure 2. The campus development is approximately nine years old and covers around 250 hectares. It is situated in a hot and humid tropical climate.

3.2 Field Measurement

This study utilized field measurement methods to collect data on humidity, temperature, and wind speed across a campus site using a 5-in-1 anemometer and a thermal anemometer, as detailed in Table 2. The measurement points were spaced 100 meters apart, focusing on areas with potential microclimate differences, including near buildings, green spaces, water bodies, parking lots, open spaces, and courtyards. Data collection was conducted every 30 minutes at eight designated points, as illustrated in Figure 3. The study area is characterized by a hot, humid tropical climate, located at 3° North Latitude and 101° East Longitude, with an elevation ranging from 41 to 46 meters. The physical elements in the selected area include vegetation, buildings, roads, paved areas, and a small secondary forest located on the east side. Most of the trees planted on campus, particularly around the lake and park, as well as along roadsides and in parking areas, have reached maturity. However, the trees in the open spaces vary in size, with some having large, medium, and small canopy spreads.

Figure 2. Key and location plan for the study area in Puncak Alam, Selangor, Malaysia

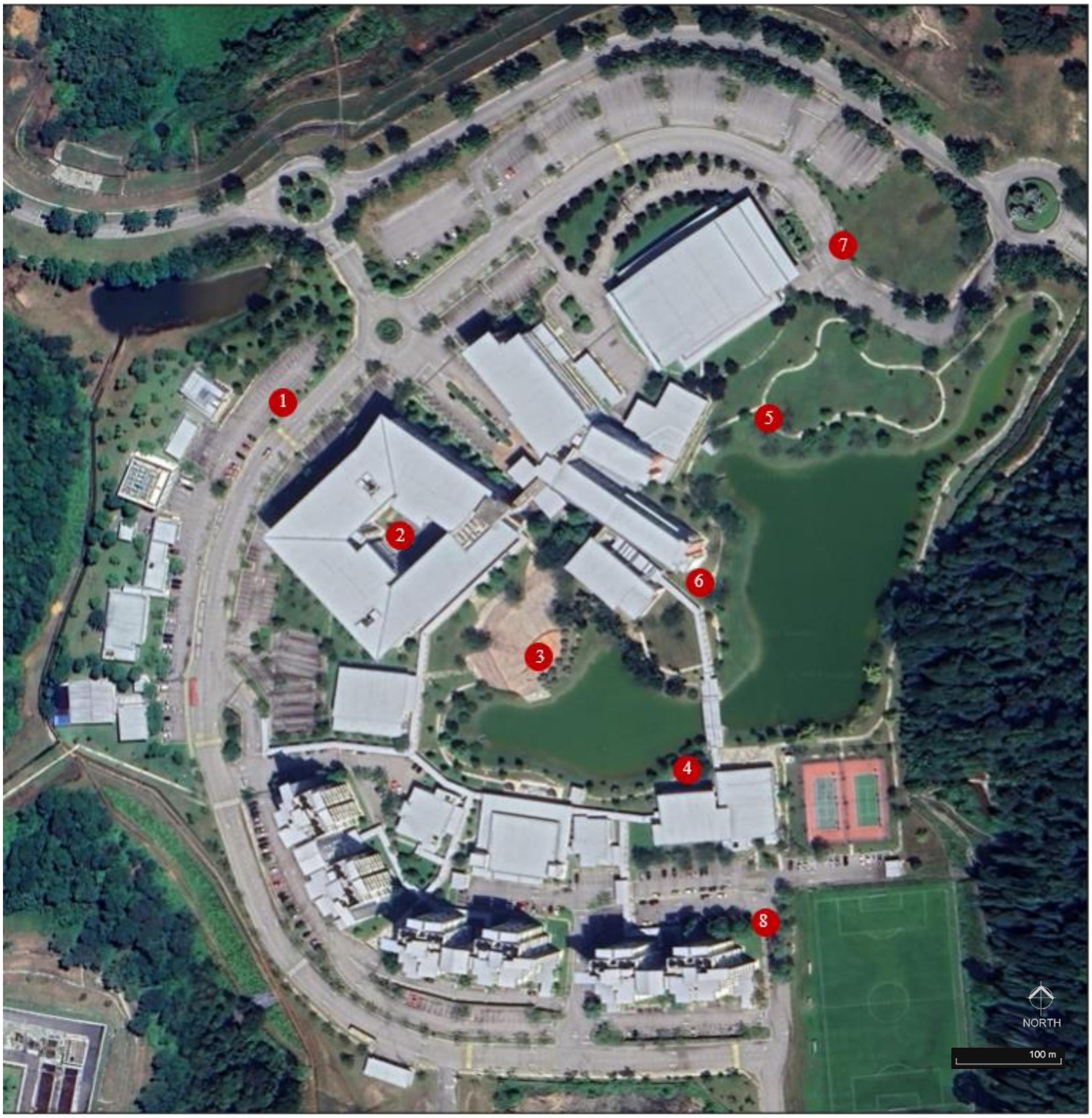

Figure 3. The site study of FBE and FAD at UiTM Puncak Alam, Selangor included the collection of microclimate data from eight different points.

3.3 Measurement of Meteorological Parameters

This study involved field measurements of meteorological parameters using the LT Lutron LM-8010, which was employed to measure air temperature and relative humidity. Additionally, the SW6086 thermal anemometer was used to measure wind speed in selected areas, operating in its designated modes. The LM-8010 model was set up at a standard height of 1.2 to 1.5 meters above ground level at eight different points (as shown in Figure 3). This height is recommended for meteorological measurements to minimize surface effects. The features of this instrument are detailed in Table 2.

3.4 The ENVI-Met Model and Leonardo: Basic Aspects of the Environmental Model

In this study, ENVI-met simulations were employed as both two-dimensional and three-dimensional non-hydrostatic microclimate models. This model can calculate and simulate climate data at a grid resolution of 0.5 to 10 meters in space and 10 seconds in time, making it suitable for high-resolution analysis of microclimates. ENVI-met was utilized to simulate microclimate dynamics over 24 hours, providing insights into daily variations. The primary prognostic factors considered include temperature, relative humidity, and wind speed. These elements are critical for understanding the spatial distribution of microclimate variables within the study area. Figure 4 illustrates the data structure used by the ENVI-met model. As a simulation tool, ENVI-met assesses the microclimate effects of campus layout and the surrounding environment. The widely used ENVI-met model relies on principles of fluid dynamics and heat transfer, aiming to analyse microscale thermal interactions in urban areas (Ouyang et al., 2022; Zaki et al., 2020a). The model is calibrated using real-world campus data, including information on vegetation, building geometry, and water bodies, to ensure accuracy and relevance (Hasan et al., 2023; Misni et al., 2019). For this study, a three-dimensional model was created using the ENVI-met Program Suite and Space to simulate the existing campus environment. This approach enables the simulation of variables such as air temperature, humidity, and wind flow. Input parameters were based on field measurements and campus-specific data to reflect the actual conditions accurately.

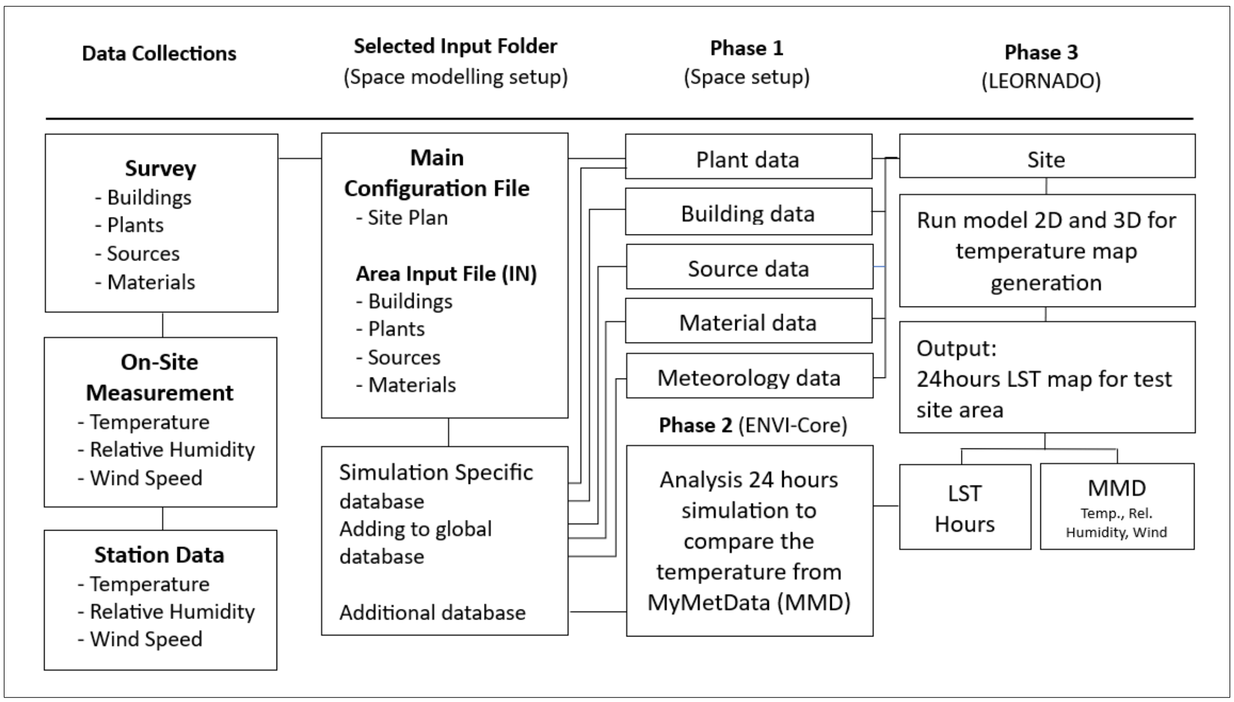

Figure 4. Methodological Conceptual Framework of the ENVI-met Model.

Table 2. Meteorological Measurement Instrument.

Parameter	Symbol	Unit	Instrument	Range	Accuracy	Probe Type
Air temperature	Ta	°C	LT Lutron LM-8010	0 to +50°C	±1.2°C	
Relative humidity	RH	%	LT Lutron LM-8010	10 to 95% RH	<70% RH: ±4% RH ≥70% RH: ± (4% of reading +1.2% RH)	
Wind speed	Va	m/s	SW6086 Thermal anemometer	+0.0 to +10.0 m/s	≤2m/s: ±0.1% + 5% of measured value ≥2m/s: ±0.3% + 5% of measured value	

Table 3. Input data and initial setting for the ENVI-Met Model.

Model Location	
Name of Location	Faculty of Built and Environment and Faculty of Arts and Design, Puncak Alam, Selangor.
Position (Latitude)	3°N
Position (Longitude)	101°E
Model Geometry	
Domine size	500m X 500m
Model dimension	x-Grid=50, y-Grid=50, z-Grid=40
Size of grid cell	Dx = 2m, dy = 2m, dz = 1m
Model rotation out of grid from north	20º
Height of 3D model TOP	35m
Difference model top to highest point	11m

Table 4. Settings of the ENVI-met simulation.

Simulation Setting	
Start date	7 December 2024
Start time	07:00
Total simulation	24 hours
Air temperature	24-hours cycle
Relative humidity	24-hours cycle
Wind speed	2.0 m/s

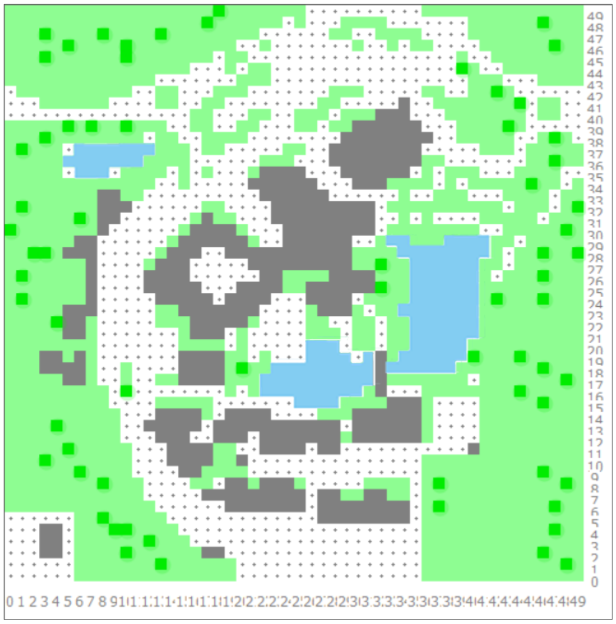	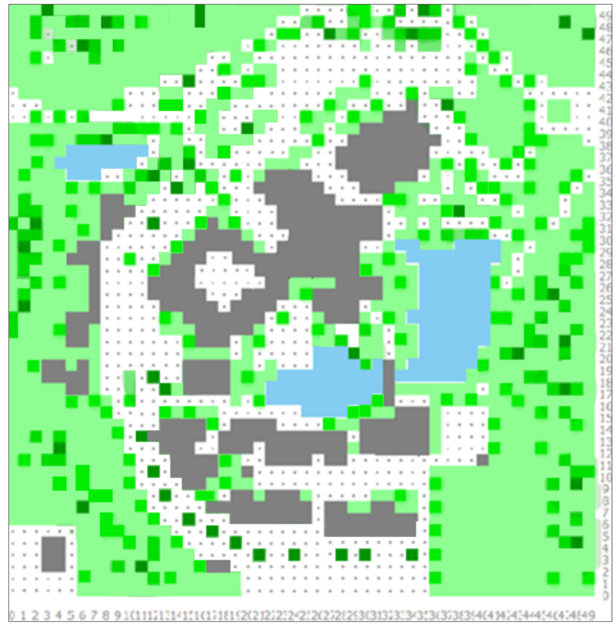
Scenario 01. Original area	Scenario 02. Greening the area

Figure 5. Scenarios 1 and 2 represent building configuration on site study (left) to compare with greening area and water element (right).

3.5 Simulation Setting

The simulation was conducted using ENVI-Guide over 24 hours, starting at 07:00 on 7 December 2024, and concluding at 06:00 the following day. This timeframe was selected to align with peak human activity on campus, particularly during morning, afternoon, and evening sessions when students and staff are more likely to be outside. The meteorological data used to configure the simulation, including temperature, humidity, and wind speed, was sourced from the Malaysian Meteorological Department (MMD), ensuring accuracy with site-specific information. The ENVI-met model, known for its effectiveness in assessing microclimate dynamics at the campus level, was calibrated using local data from UiTM Puncak Alam. Key environmental parameters such as air temperature, humidity, and wind speed were incorporated into the study. These factors are essential for understanding microclimate variability and validating the simulation results (Brozovsky et al., 2019; Ouyang et al., 2022). The initial settings and simulation criteria for ENVI-met are detailed in Tables 3 and 4.

3.6 Simulation Scenario

The simulations conducted using ENVI-Met software are illustrated in Figure 5. This site simulation allows for the evaluation of the impacts of buildings, vegetation, water bodies, and materials on the campus microclimate and outdoor thermal comfort. The simulation began with the arrangement of buildings and their layouts, based on their heights. Next, vegetation such as trees and grass were incorporated. Additionally, various on-site materials, including concrete, asphalt, and water bodies, were included in the model simulation.

3.7 Scenarios 01

This scenario focuses on understanding the current microclimatic conditions at the Faculty of Built Environment, UiTM Puncak Alam, Selangor. By examining the details of the campus's buildings, soil, and surfaces, we have created a realistic representation of the existing environment. This simulation allows us to explore how the surrounding environment and campus structures influence the microclimate, providing a clearer understanding of how these factors affect thermal comfort and environmental conditions for both students and staff, as illustrated in Figure 5.

3.8 Scenarios 02

The focus is on enhancing green spaces by incorporating vegetation and water features across the area. This greening concept not only enhances the campus's visual appeal but also aligns with the Sustainable Development Goals. It offers environmental benefits, such as improved thermal comfort and reduced urban heat islands surrounding the campus. By integrating landscape design features, this approach aims to create a more liveable environment within the campus (Figure 5)

4.0 RESULTS AND DISCUSSION

4.1 Analysis of The Measurement Data and Simulated Data

Air Temperature

Air temperature is a key metric for comparison in this study, essential for validating the accuracy of the ENVI-met simulation. It plays a crucial role in understanding the microclimatic environmental impact on the campus. Ambient air temperature can vary due to factors such as the materials used in surrounding surfaces and the presence of various landscape elements. As shown in Figure 6, the simulation results closely matched the actual measurements collected at five specific locations over 24 hours, from 7:00 am to 7:00 am the following day.

Below is the equation for a linear fit regression model.

$$y = b_0 + b_1 x_1 + b_2 x^2_1 + b_2 x^3_1 + \ldots\ldots\ldots b_n x^n_1 \qquad (1)$$

Where:

y = is the dependent variable

x = is the dependent variable

b_0-b_n = are the parameters that can optimize

The R^2 values are categorized as follows: 0.3-0.5 indicates a medium correlation, 0.5-0.7 indicates a good correlation, and 0.8-0.9 indicates excellent connections (Turney, 2023). Values of medium or higher suggest that the data are reliable, valid, and accurate. The correlation coefficient (R^2) ranged from 0.8414 to 0.94909, indicating a high level of agreement and confirming the simulation model's reliability.

Metrological Parameters in Site

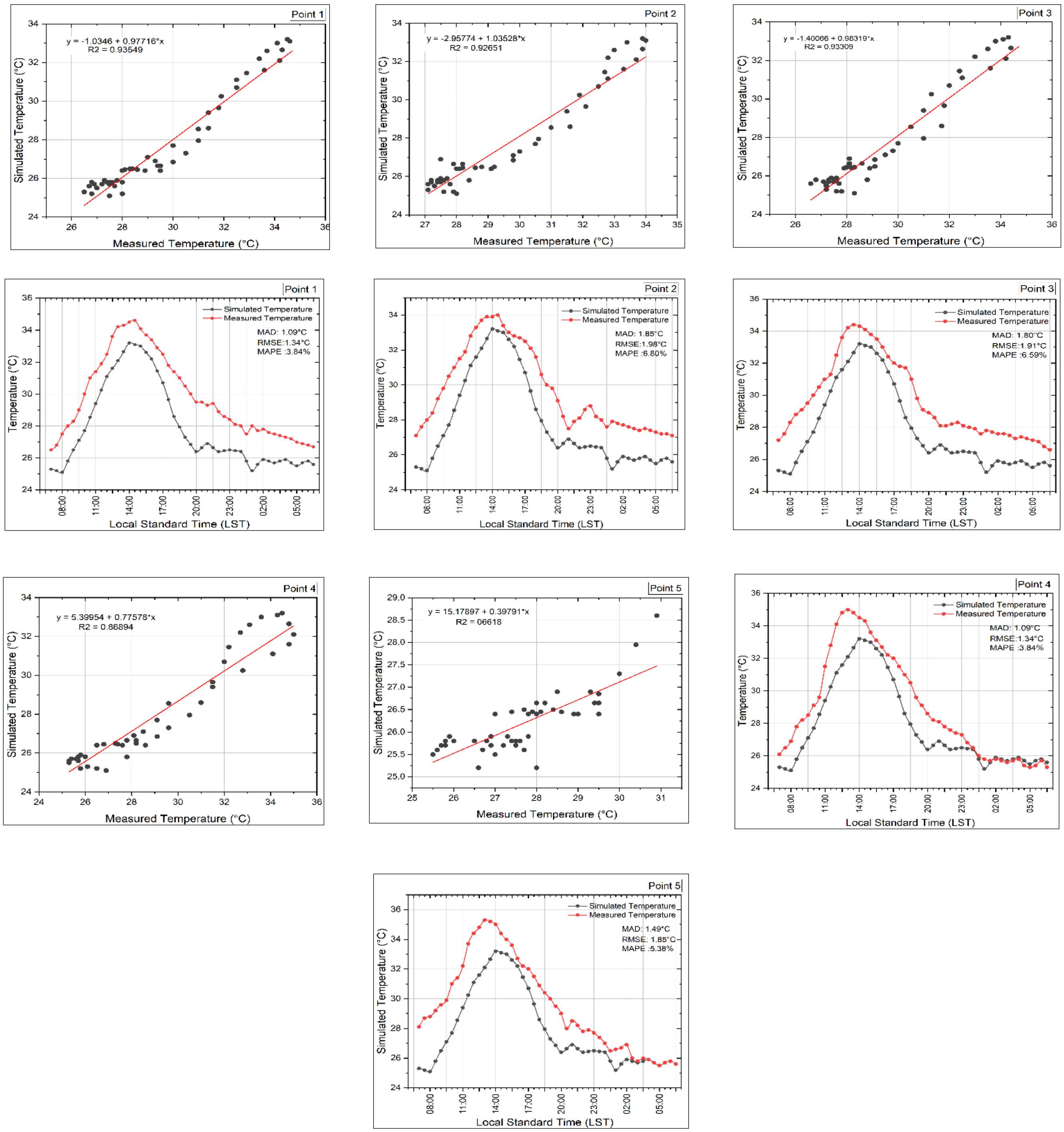

Figure 6. Validation of the microclimate (air temperature) was conducted by comparing measured and simulated data over a 24-hour period during the wet season.

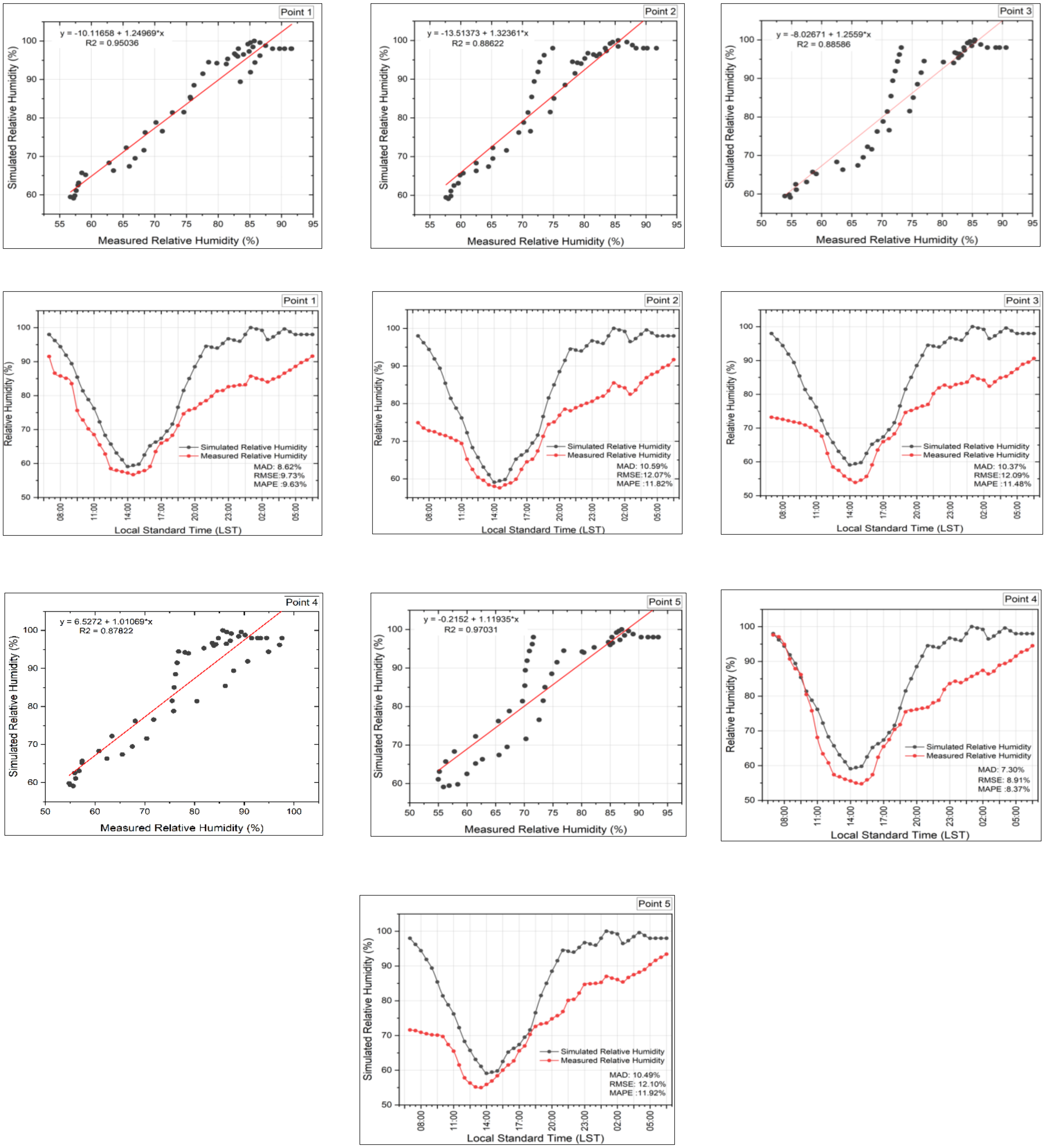

Figure 7. Validation of microclimate (Relative Humidity) measurements compared to simulations over a 24-hour period during the wet season.

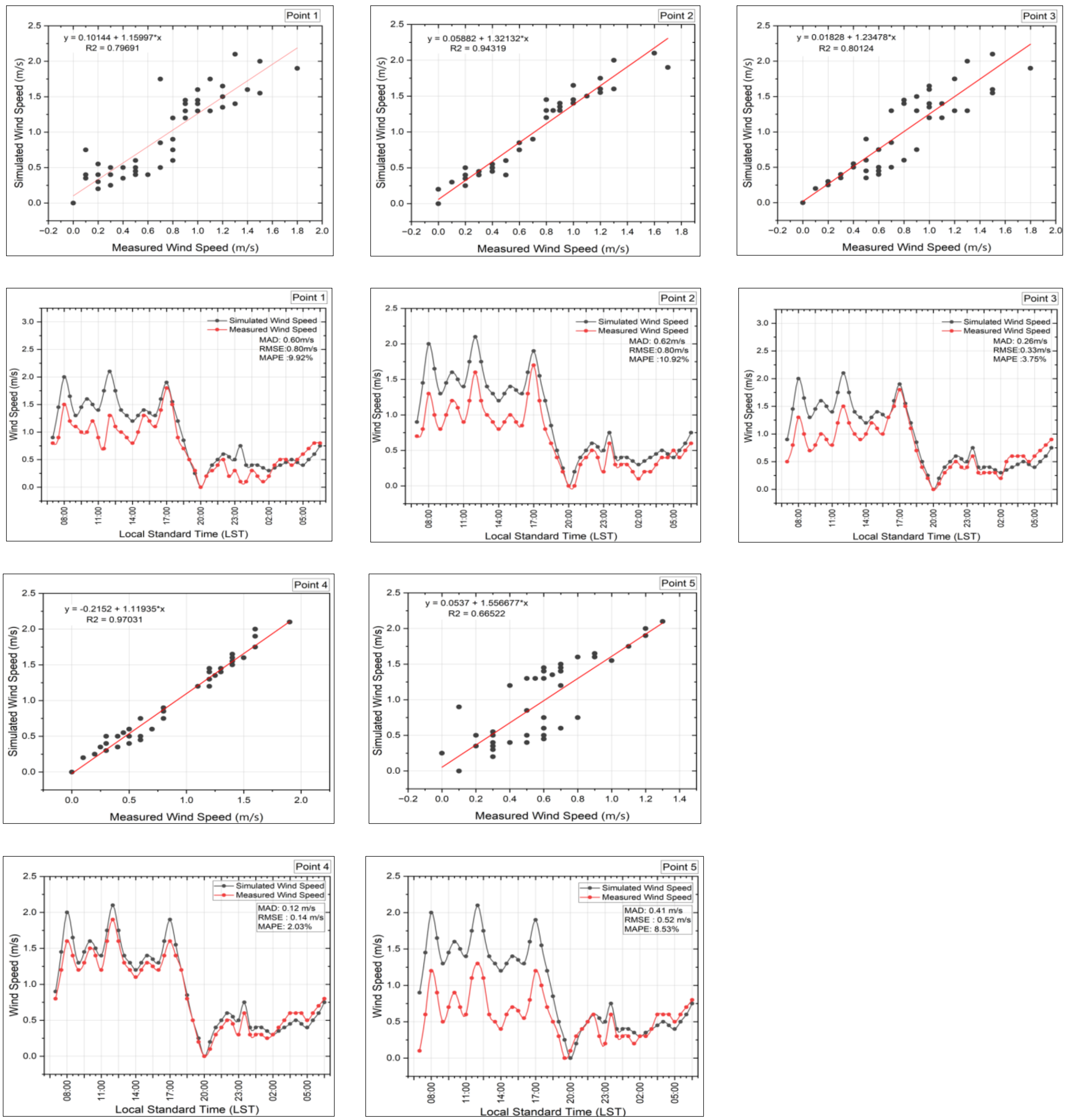

Figure 8. Validation of the microclimate (Wind Speed) based on measurements and simulations over a 24-hour period during the wet season.

Figures 6, 7, and 8 shown the validation of ENVI-met model through in site measurement. A comparison of numerical results with measured air temperatures, relative humidity, and wind speed in five selected representative points from the survey area (from 07:00 to 06:00 hours): (a) Correlation between simulated and measured air temperatures, and (b) Calibration of ENVI-met model. MAD, RMSE, and MAPE. To further ensure the accuracy of the ENVI-met simulation model, we conduct a calibration by calculating key metrics including correlation coefficient (R^2), Mean Absolute Deviation (MAD), Root Mean Squared Error (RSME) and Mean Absolute Percentage Error (MAPE). These metrics are widely used to quantify the agreement between simulated and observed values. The calibration of ENVI-met model with MAD, RMSE and MAPE for climate parameters are as follow:

$$MAD = \frac{1}{n}\sum_{k=1}^{n} |Tmes - Tsim| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=1}^{n}(Tmes - Tsim)^2} \quad (3)$$

$$MAPE = \frac{1}{n}\sum_{k=1}^{n}\left(\frac{1\,Tmes - Tsim}{Tmes}\right) \times 100\% \quad (4)$$

Where:

$Tmes$ = is the measured dependent variable

$Tsim$ = is the simulated dependent variable

n = is the total number of data points being considered

In validating the air temperature data, as shown in Table 4, the MAD values ranged from 1.09 to 1.90°C. The RMSE varied between 1.34 and 2.00°C, while the MAPE was found to be between 3.84% and 6.94%. These results indicate that the numerical model is accurate and successful. For relative humidity (RH), as shown in Table 5, the MAD values ranged from 7.30% to 10.59%. The RMSE ranged from 5.91% to 12.10%, and the MAPE ranged from 8.37% to 11.92%. These findings also affirm that the numerical model's accuracy is satisfactory and that it is successful. As shown in Table 6, the MAD values for wind speed data ranged from 0.12 to 0.62 m/s. The RMSE ranged from 0.14 to 0.80 m/s, and the MAPE varied from 2.03% to 10.9%. These results further confirm that the numerical model's accuracy is satisfactory and has been successful.

Table 4. Calibration of the ENVI-met model and the analysis of MAD, RMSE, and MAPE for the temperature parameter.

Location	dx	dy	k	MAD (°C)	RMSE (°C)	MAPE (%)
Point 1	12	32	1	1.90	2.00	6.94
Point 2	18	26	1	1.89	1.99	6.90
Point 3	24	21	1	1.85	1.94	6.75
Point 4	32	15	1	1.09	1.34	6.84
Point 5	37	31	1	1.49	1.85	5.38

Table 5. Calibration of the ENVI-met model and the analysis of MAD, RMSE, and MAPE for the relative humidity parameter.

Location	dx	dy	k	MAD (°C)	RMSE (°C)	MAPE (%)
Point 1	12	32	1	8.62	9.73	9.63
Point 2	18	26	1	10.59	12.07	11.82
Point 3	24	21	1	10.37	12.09	11.48
Point 4	31	15	1	7.30	5.91	8.37
Point 5	37	31	1	10.49	12.10	11.92

Table 6. Calibration of the ENVI-met model and the analysis of MAD, RMSE, and MAPE for the wind speed parameter.

Location	dx	dy	k	MAD (°C)	RMSE (°C)	MAPE (%)
Point 1	12	32	1	0.60	0.80	9.92
Point 2	18	26	1	0.62	0.80	10.9
Point 3	24	21	1	0.26	0.33	3.75
Point 4	31	15	1	0.12	0.14	2.03
Point 5	37	31	1	0.41	0.52	8.53

4.2 Evaluating the Impact of Vegetation on Microclimate on Site

Air Temperature

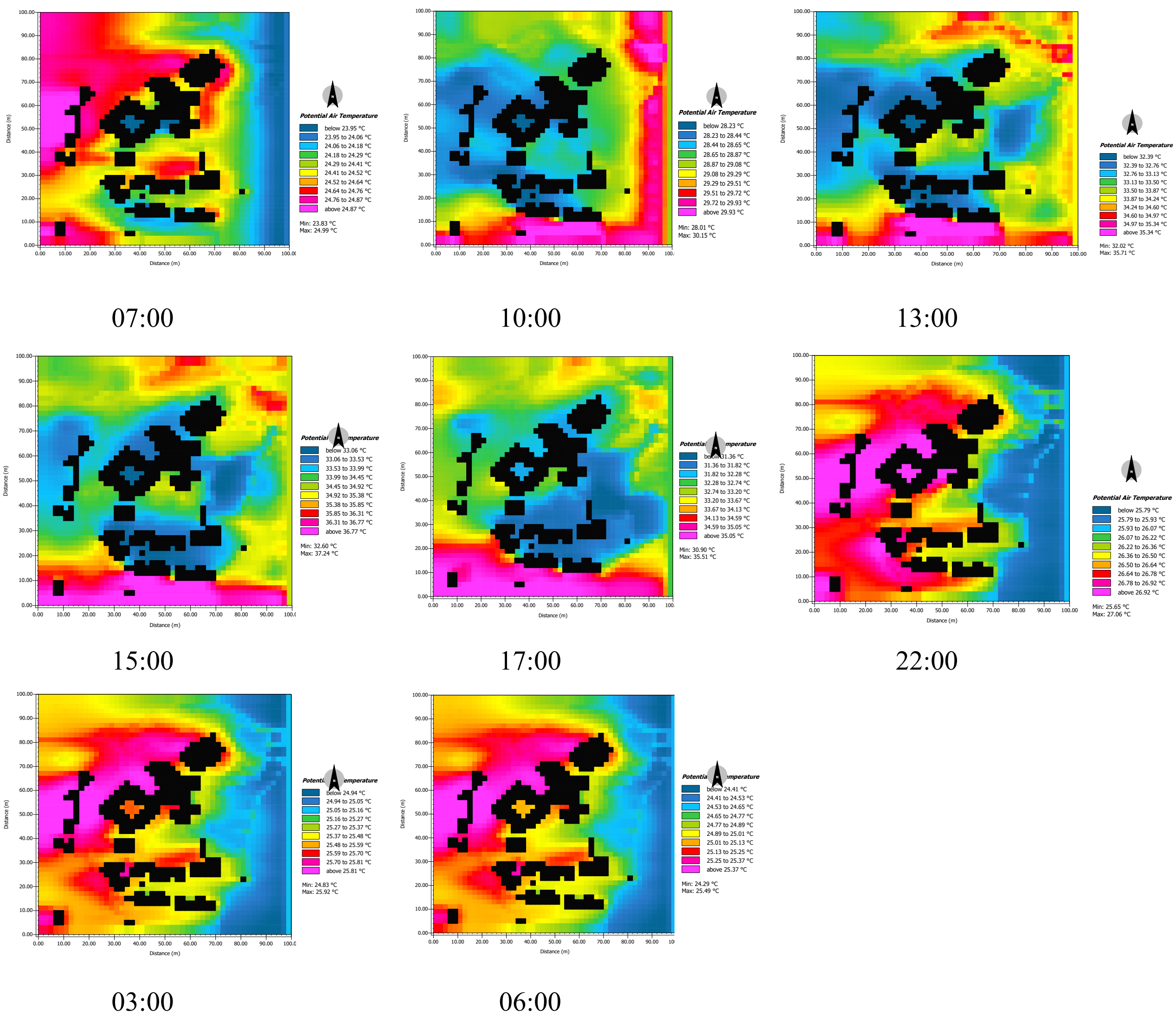

Figure 9. Temperature map of FBE and FAD over a 24-hour period.

Figure 9 presents a detailed temperature map showing how temperatures varied across the site over 24 hours on 7 December 2024. The lowest temperature recorded was 23.5°C, measured at 03:00 hours early in the morning. As the day progressed, temperatures began to rise, particularly after 07:00 hours. By 10:00 hours, the temperature was noticeably increasing, and it continued to climb steadily throughout the morning and early afternoon. The highest temperature of 32.8°C was reached at 15:00 hours, despite relatively high relative humidity. The study highlights the crucial role of vegetation in moderating temperatures.

In areas with dense tree cover, temperatures were 1°C to 2°C cooler compared to other parts of the site. This cooling effect was primarily due to shading and evapotranspiration. Water bodies situated near greenery enhanced this cooling effect, working together to mitigate the surrounding heat. The ENVI-met simulation clearly demonstrated how natural elements, such as trees and water, can effectively combat the urban heat island effect, making them essential for creating comfortable and sustainable campus environments (Hasan et al., 2023; Xu et al., 2022).

Relative Humidity

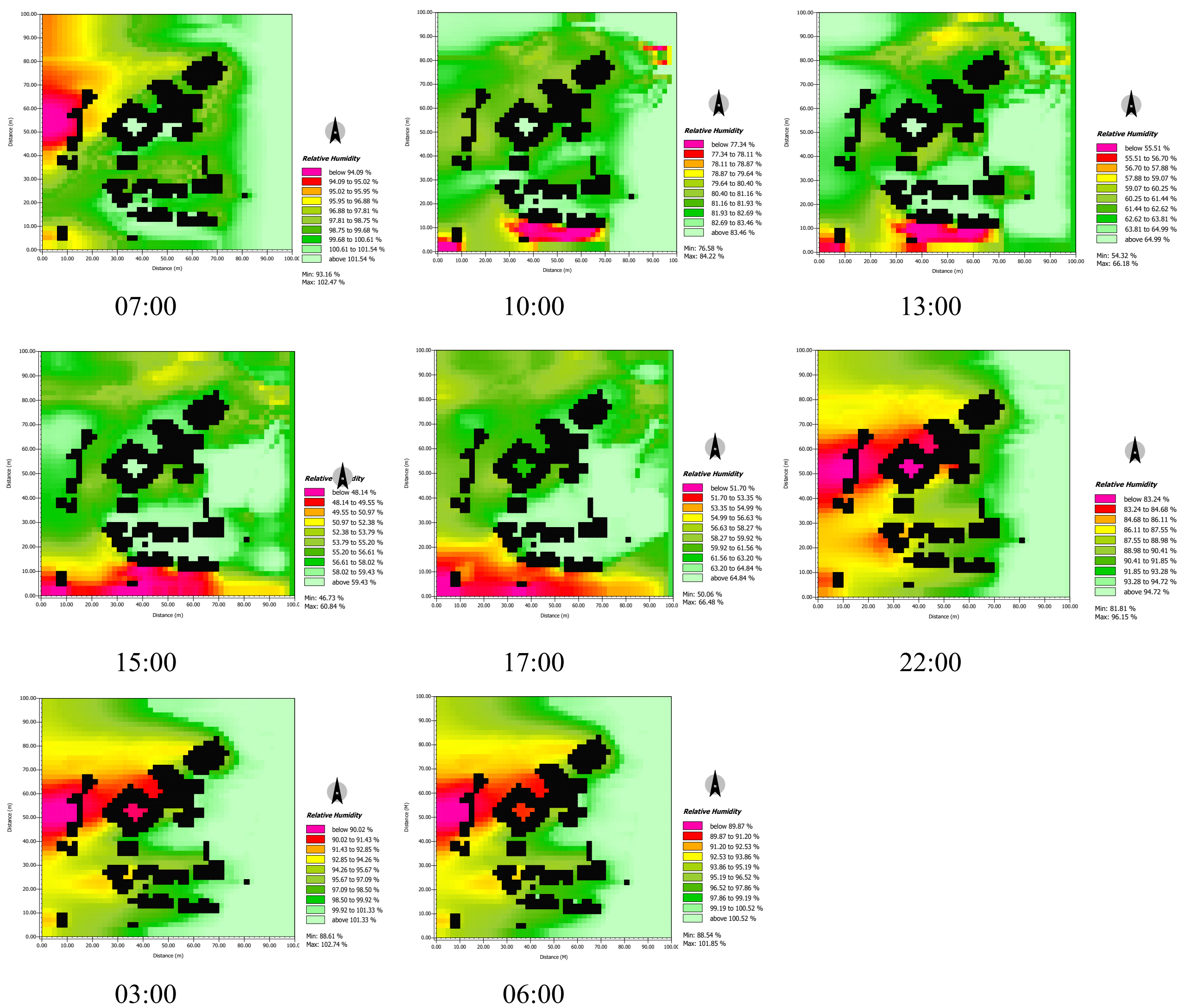

Figure 10. The RH map in FBE and FAD over a 24-hour period.

Figure 10 shows the distribution of relative humidity (RH) across the site over 24 hours on 7 December 2024. Throughout the day, the humidity levels fluctuated significantly. The highest recorded RH was 98%, recorded early in the morning at 03:00 hours, coinciding with lower temperatures. As the day progressed, the RH levels gradually decreased, reaching a low of 62% around 15:00 hours, when temperatures were at their peak. Green spaces played a crucial role in stabilizing humidity levels, making outdoor areas more comfortable in tropical climates. Vegetated areas retained more moisture in the air, effectively mitigating discomfort associated with high heat and humidity. These findings support prior research highlighting greenery's ability to create balanced, favourable microclimates (Wong et al., 2007). The data highlighted the importance of green infrastructure in enhancing the campus's overall liveability.

Wind Speed

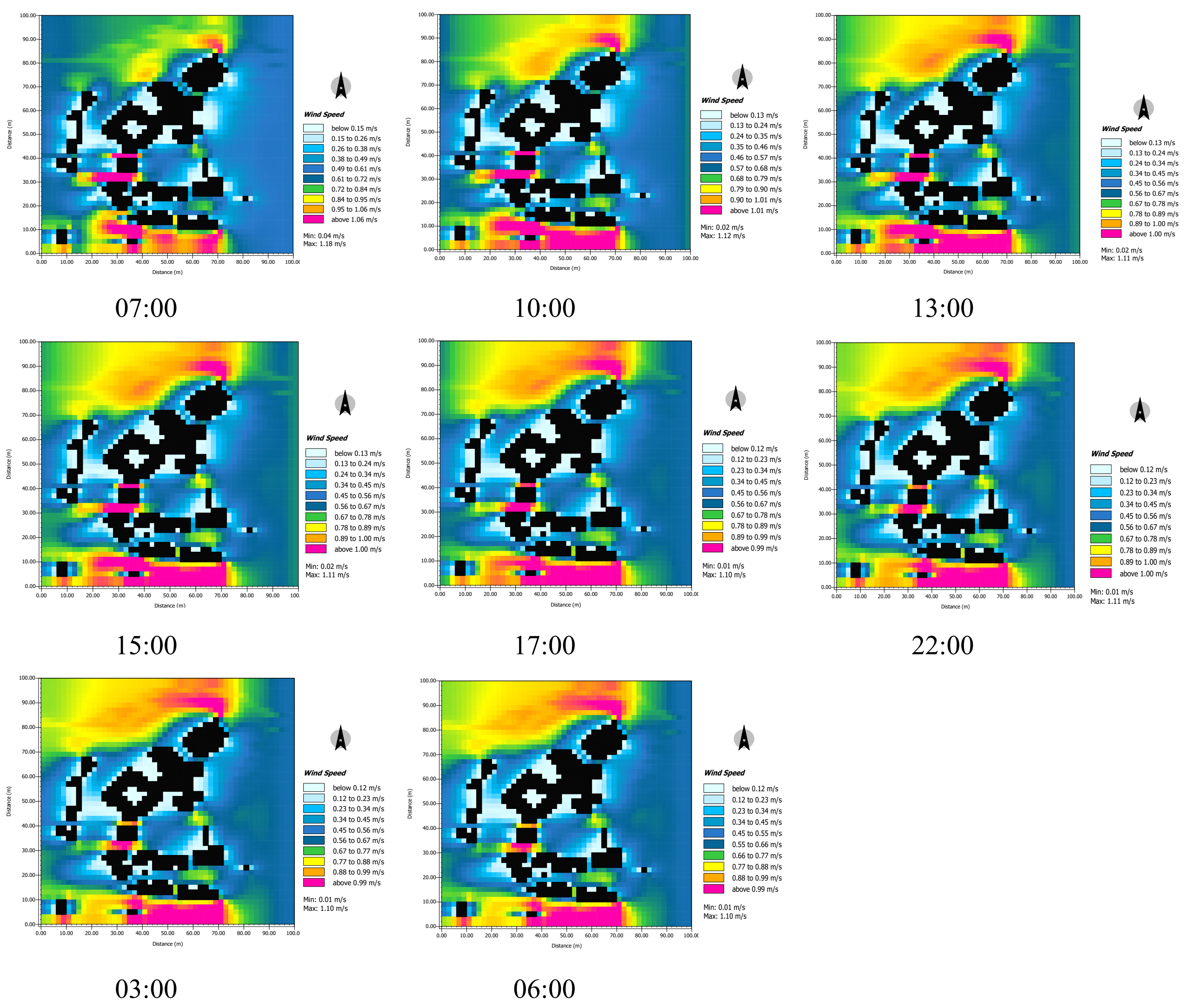

Figure 11. Wind Speed map for FBE and FAD over a 24-hour period.

Figure 11 illustrates the wind speed distribution across the campus site over 24 hours on 7 December 2024. Wind speeds ranged from 0.01 m/s to 1.6 m/s, with the highest recorded at 07:00 hours, when ventilation across the site was most effective. As the day progressed, wind speeds gradually decreased, reaching their lowest levels between 13:00 and 15:00 hours, coinciding with peak temperatures and reduced air movement. The strategic placement of vegetation enhanced wind flow and mitigated stagnant air zones. Trees positioned along wind corridors facilitated air movement, contributing to natural cooling. ENVI-met simulations supported these findings, emphasizing the importance of incorporating vegetation into urban design as a key strategy for creating thermally comfortable outdoor spaces (Ouyang et al., 2022).

Microclimate Change Around Campus Area

Open spaces in densely built areas can help lower the surrounding temperature. This emphasizes the importance of open spaces in mitigating the urban microclimate. In the FBE and FAD regions, green spaces cover a large area and feature mature trees that are approximately 10 years old. These areas also include several shrubs, water bodies, and grasses that cover the ground surface. However, the mature trees have not reached their full potential, resulting in minimal shading and limited evaporation. As a consequence, the surrounding temperatures in the FBE and FAD areas are negatively impacted.

Land use

The key factor influencing the microclimate is the land use within the campus area. Paved surfaces, such as parking lots, roads, buildings, and plazas, tend to absorb significant heat during the day. In the evening, these surfaces release the absorbed heat, raising ambient temperatures, especially around building areas. The prevalence of paved areas and the low vegetation density contribute to heat retention, making the surrounding environment uncomfortable. In contrast, areas with green spaces and nearby water features tend to have lower ambient temperatures—approximately 1°C cooler than in the building areas. Heat retention from impervious surfaces exacerbates the urban heat island (UHI) effect, a common phenomenon on urban campuses. Additionally, the density of forests surrounding the campus affects the airflow and wind speed in open spaces.

Building Arrangement

The arrangement of buildings within the campus area affects both temperature and airflow. The simulation shows that during the day, surrounding buildings with moderate vegetation receive some sunlight, allowing heat to accumulate and raising the temperature around them. Additionally, these building blocks restrict airflow, leading to reduced wind speeds, especially during peak hours when temperatures are high. In contrast, wind speed around the building area is lower than in open spaces. This indicates that open areas with sufficient green space have more stable wind flow, which aids in natural cooling and creates a more comfortable environment.

Campus Open Space Characteristics

Campus open spaces play an important role in shaping microclimate conditions through their vegetation, soil, and land cover. Existing vegetation contributes to cooling through processes like evapotranspiration and shading. However, the current canopy coverage is still insufficient to provide continuous shade during peak hours, resulting in higher surface temperatures. To enhance the cooling effect during the hottest parts of the day, it is essential to increase the number of mature trees and diversify the range of vegetation species.

Additionally, much of the campus area is characterized by laterite soils, which offer good drainage but have limited fertility, affecting plant growth. Despite this limitation, these soils help retain moisture, contribute to environmental cooling, and improve humidity levels.

Furthermore, land cover materials such as concrete and asphalt significantly influence thermal conditions. These hard surfaces absorb heat during the day and gradually release it at night, raising surrounding temperatures. Simulations indicate that exposed areas, such as parking lots and roads, can reach temperatures of up to 33°C in the afternoon. In contrast, areas with vegetation and water features remain relatively cooler. This highlights the importance of balancing hard surfaces with blue-green infrastructure to improve the campus microclimate.

Scenario Comparison

To evaluate the effectiveness of the proposed landscape intervention, Scenario 01 was compared with Scenario 02. Key microclimate parameters—air temperature, relative humidity, and wind speed—were analysed during peak daytime periods to assess improvements in thermal comfort. The results indicate that Scenario 02 consistently improved microclimatic conditions compared to the baseline. Air temperature in exposed areas decreased by approximately 1–2°C, while relative humidity increased slightly, and wind speed improved in open spaces. These findings highlight the effectiveness of integrating green infrastructure elements, such as vegetation and water features, in mitigating urban heat and enhancing outdoor comfort within a tropical campus environment.

Enhancing Green around Campus Area

Figure 12 presents the model of FBE and FAD, surrounded by mature trees and water elements, projected to be achieved in the next 15 years based on Scenario 02 modeling. The introduction of vegetation and water features significantly improves the microclimate by providing shade and promoting evapotranspiration, which cools the environment. Additionally, the presence of water features enhances this effect and stabilizes the surrounding humidity. The strategic placement of trees improves airflow, reducing stagnant air and creating a more comfortable atmosphere. This combination of greenery and water mitigates the urban heat island (UHI) effect, resulting in a cooler environment, enhanced thermal comfort, and increased sustainability. Increasing vegetation coverage by 20% to 30% could further amplify the cooling effect, leading to an estimated temperature reduction of 1.5°C to 3°C, depending on the density of tree cover and green spaces. This change could equate to a 5% to 15% decrease in ambient temperature, significantly improving the study environment.

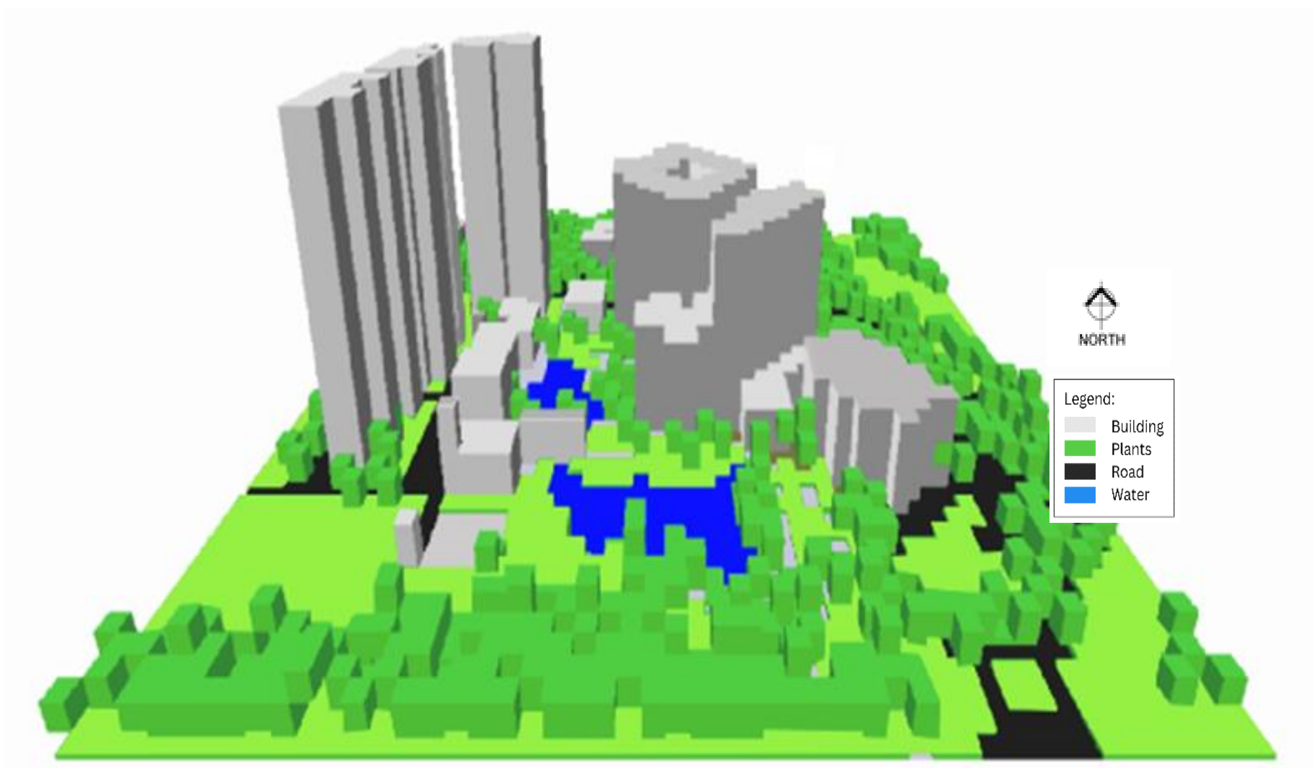

Figure 12. illustrates the origin 3D model of the FBE and FAD surrounded by mature trees and water elements, which are expected to be fully developed in 15 years (right).

5.0 CONCLUSION

This study investigated the environmental impact of the microclimate at the Faculty of Built Environment (FBE) and the Faculty of Art and Design (FAD) at UiTM Puncak Alam, addressing the urgent need for climate-responsive campus design in tropical environments. The campus experiences high temperatures, and the limited shading in certain areas can negatively affect comfort and outdoor activities. Through ENVI-met simulations, the study demonstrated that strategically integrating vegetation and water features could significantly improve thermal comfort, reduce air temperature by 1–2°C, stabilize humidity, and enhance natural airflow. Areas with abundant greenery were found to be cooler and more comfortable, while the thoughtful placement of trees and green spaces helped mitigate stagnant air and urban heat island effects. The results validate ENVI-met as an effective tool for assessing microclimate conditions and highlight the importance of incorporating sustainable landscape design into campus planning. Overall, this study provides actionable insights to enhance the microclimate and promote a more sustainable campus environment.

Novelty: This study lies in its quantitative evaluation of microclimate improvement strategies for a tropical campus. It integrates field measurements with ENVI-met simulation scenarios. Rather than merely assessing existing environmental conditions, the study develops and tests targeted landscape configurations of open spaces. It evaluates the impact of vegetation density, water elements, and the spatial configuration of open spaces on air temperature, humidity, and wind flow. By translating simulation outcomes into practical landscape design recommendations, the study establishes a framework linking microclimate modelling with campus landscape planning in hot, humid climates.

Recommendations: (i) Increasing the density and variety of vegetation across the campus is essential. Native and climate-resilient plant species should be prioritized for their low maintenance requirements and high cooling efficiency. Additional shaded areas created by tree canopies can reduce surface temperatures and promote outdoor activities. (ii) Strategically located water features, such as ponds, fountains, and rain gardens, can further regulate microclimatic conditions by lowering ambient temperatures and stabilizing humidity levels. These features will also enhance the aesthetic value of the campus environment. (iii) Collaborate with local authorities and urban planners to address the urban heat island (UHI) effects in the surrounding areas. Establish green corridors that connect the campus to nearby parks or natural reserves to enhance regional ecological connectivity.

Future Research Direction: Future research could explore how the size and layout of campuses, including older, well-planned ones, impact thermal comfort and sustainability. Comparing these different types of campuses can provide insights into how design and age influence the microclimate. Additionally, studies could examine how other universities, in similar or different climates, manage their environments to identify best practices for creating sustainable and comfortable spaces. Another area worth exploring is shading, particularly comparing the benefits of natural shade from trees with artificial options like pergolas or shaded walkways. These efforts would provide valuable guidance for designing adaptable, comfortable, and environmentally friendly campuses.

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