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Evaluating urban microclimate temperature using Envi-Met Simulation Model: A case study conducted in two city areas, Pudu and Wangsa Maju

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Abstract

Urban areas usually experience the urban heat island effect, where the area is significantly warmer than surrounding rural areas. This is due to the urban character and microclimate change. This study assesses the temperature of urban microclimate characteristics that influence typical urban commercial. The method study uses the ENVI-met numerical simulation software to compare differences in temperature of two urban commercial districts in Pudu and Wangsa Maju. A similar scale was used to simulate these sites with the same climatic conditions. Urban layout, building heights and densities, human movement, landcover, greening, and pavements were discovered to impact temperature change significantly. The variations of simulated and measured temperatures were parabolic in shape, and the variation trends of both were similar. The relative humidity in a residential district declined with increased temperature. The highest temperature is 32.5°C during peak time at 14.00 pm in Pudu, while at Wangsa Maju, peak time is at 13.00 pm with 31.2°C. The results were significantly influenced by the landcover (building, vegetation, and pavement), human movement and urban layout. The height of taller high-rise buildings contributed to the increase in temperature, and densely vegetated areas proved to reduce the temperature in urban areas. The findings of this study will contribute to the future microclimate planning of the cities as well as retrofitting landscaping programs and urban settings, especially in the city's area of Kuala Lumpur.

Keywords: ENVI-met, human movement, landcover, temperature, urban layout, urban microclimate

Introduction

Environmental protection has become increasingly important due to growing environmental concerns and awareness of human activity-related pollution, such as air pollution, global warming, and the urban heat island effect (Brahimi et al., 2023). Concern about microclimate in urban studies has increased due to its negative impact. Urban microclimate refers to atmospheric conditions within a specific urban area, including temperature, humidity, wind speed, and other climatic factors (Misni, 2024; Chatzinikolaou et al., 2018). It is a microclimate type influenced by a city's built environment and human activities within a city or town (Cortes et al., 2022). Several factors contribute to urban microclimates, such as Urban Heat Island (Misni, 2024; Misni, 2015). An urban heat island is a phenomenon where cities or areas experience higher temperatures than surrounding areas. It is primarily due to the absorption and retention of heat by buildings, roads, and other urban surfaces, leading to increased temperatures in urban areas (International Cartographic Association, 2003).

All data related to microclimate, including temperature, wind, and humidity, were gathered to help analyse the factors of urban heat islands and increasing temperature. ENVI-met software, developed by M. Bruse of the University of Mainz, Germany, in 2004, is the tool used in analysing and simulating the urban area to come out with solutions to problems related to the urban heat island (Huttner et al., 2008). The essence of modelling is found in approaches to understanding environmental behaviour that use systems thinking (International Cartographic Association, 2003). Urban microclimatic models can assess the interactions between green space and the development regions, which help estimate the urban microclimate pattern (Brahimi et al., 2023). Thus, this paper aims to study the factors contributing to the increase in temperature by comparing the characteristics of two urban areas using ENVI-met.

Climate change in Malaysia

According to the IPCC (2007) and Bernstein et al. (2008), climate change is the state of a climate that has changed over a long period, usually decades or longer, and may be detected using statistical tests by changes in the mean or variability of its attributes. Numerous sources worldwide have projected a steady earth warming over the next century, with an average global temperature of 3°C (1.8°C- 4°C). According to the Intergovernmental Panel on Climate Change (IPCC), there was about a 0.85°C increase in global average surface temperature between 1880 and 2012 (Bernstein et al., 2008). Additionally, a further warming of roughly 10°C each decade would anticipate an average global surface temperature increase. The annual mean temperature in the majority of southern Asia has been rising steadily over the past century, in contrast to the global mean temperature, which shows notable increases in the early and late 20th century and a slight cooling in the middle of the century (Misni, 2024; Misni, 2015; Folland et al., 2001). Malaysia experiences relatively constant temperatures year-round, with lowland mean temperatures ranging from 26 to 28 degrees Celsius. The diurnal variance can reach up to 12°C, even if the annual variation of the daily mean temperature may only be 2 to 3°C. Malaysia is expected to experience a 1.5°C temperature increase by 2050. Temperature comparison was made using a long-term means for 1961–1990 and 1998–2007. It is shown that Peninsular Malaysia records higher temperature rises than East Malaysia. In Peninsular Malaysia, an average temperature increases of 0.5°C to 1.5°C has been observed. Compared to other parts of Malaysia, the temperature rises more noticeably in Western Peninsular Malaysia (Malaysian Meteorological Department, 2009). On the microclimate scale, Kuala Lumpur has recorded higher temperatures between 1.64 and 6.75° C over the last few decades due to development and changing urban trends (Think City, 2021).

Literature review

Urban microclimate

Microclimate refers to small-scale climate patterns over a small area linked to meteorological variables (Mohammad & Hamdan, 2011). The urban microclimate refers to the condition of the atmosphere as specified by temperature, humidity, wind speed, and other climatic factors in a particular urban area. The urban microclimate is one example of a microclimate created by various elements of the built environment of a city. A microclimate is a region where the climate differs compared to surrounding regions. It is affected by urban morphology parameters involving building infrastructures, vegetation, and surface materials (Burdett, 2019). These have been the key factors over the last decades where high temperatures with frequent heat waves, such as urban sprawl from the human population's rapid expansion, affect the urban microclimate and outdoor conditions of human comfort (Chatzinikolaou et al., 2018). One example of a high-temperature area in an urban microclimate is an urban heat island, where the city is warmer than the surrounding rural areas (Misni, 2024). It is primarily due to the heat absorption and retention by buildings, roads, and other urban surfaces that cause the increased temperature in the cities (International Cartographic Association, 2003). Buildings and Infrastructure patterns, density, and height of various buildings determine the circulation of wind and sunlight penetration within the city. Tall structures might permit wind passage along the corridors, while narrow streets create smaller currents (Tsiros & Mavrogianni, 2022). This paper analysed the building height and street width of an urban morphology that causes an airflow decrease due to its narrow condition. Different materials used in the construction of buildings, such as asphalt, concrete, and green roofs, have different heat absorption and retention capacities.

Temperature

Temperature is the degree or intensity of heat in a substance or object. Temperature for the urban scale is defined as the degree of urban heat island due to urbanization, which results in increasing temperatures (Mukherjee, 2022). Urban heat islands can warm cities' temperatures by 0.14–0.25 °C per decade from 1970 to 2013 (WBG, 2021). By 2090, they are projected to rise between an additional 0.8 °C and 3.11 °C depending on global emissions, especially considering global warming trends drive overall raised environmental temperatures in cityscapes globally. Generally, cities with the most significant and densest populations experience the most remarkable temperature differences. Highly developed urban areas are estimated to experience mid-afternoon temperatures higher than surrounding vegetated areas. Even within a city, some areas are hotter than others. Neighbourhoods with more heat-absorbing buildings and pavement and fewer cooling green spaces have the most elevated temperatures (Alsaad et al., 2022; Yang et al., 2021). According to Misni (2024), downtown and industrial areas are hotter than urban parks and less densely populated residential areas.

ENVI-met software

ENVI-met is a three-dimensional non-hydrostatic microclimate model that includes a simple dimensional soil model, a radiative transfer model, and a vegetation model (Bruse & Fleer, 1998). ENVI-met software can calculate and simulate climate in urban areas with a typical grid resolution of 0.5 to 10 meters in space and 10 seconds in time. It calculates microclimate dynamics during a diurnal cycle [24 to 48 hours] using fundamental laws of fluid dynamics and thermodynamics (International Cartographic Association, 2003). The main prognostic variables of the program are wind speed and direction, air temperature and humidity, turbulence, radiative fluxes, bioclimatology, and gas and particle dispersion. ENVI-met software data are commonly used and associated with high spatial resolution satellite imagery, such as commercial satellites like

WorldView, QuickBird, GeoEye, or Sentinel2. These satellites' comprehensive photographs of the Earth's surface are essential for various ENVI-met environmental modelling and simulation applications. The following variables affect how accurate ENVI-met data is then used to investigate temperature and relative humidity, including spatial resolution. In general, results from higher-resolution satellite images yield more accurate data, particularly in localized investigations (Huttner, 2012). The size of the satellite imaging pixels utilized in the simulation can impact accuracy.

Moreover, model calibration will depict accuracy, depending on whether the ENVI-met model is properly calibrated using ground truth data. The simulated microclimate is calibrated to verify that it agrees with actual measurements. Reliable simulation results depend on accurate input parameters, which include land cover, surface attributes, and meteorological data.

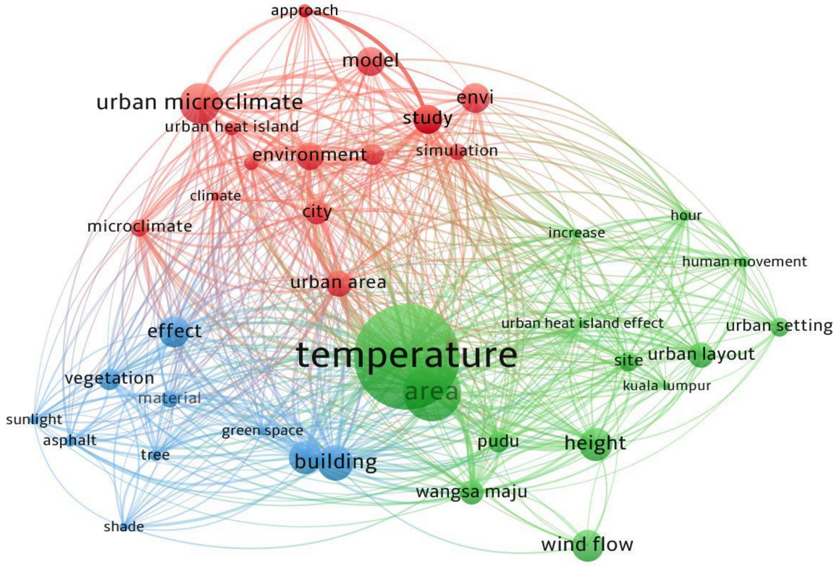


Figure 1. Urban temperature in microclimate

VOSviewer is commonly used for analysing scientific literature, allowing the visualisation of relationships between various entities, such as keywords, authors, or publications (Li et al., 2022). Each node represents a keyword and concept related to the research topic. The colours indicate different clusters or themes within the network (Figure 1). The keyword "temperature" is the main finding, indicating its significance in the network and its connection to various other concepts. Red Cluster represented the second finding, which focuses on urban microclimate and environmental studies, with keywords like "urban microclimate," "environment," and "city." This cluster emphasises the impact of urban settings on microclimatic conditions. Finally, Blue Cluster contains keywords like "wind flow," "height," and "site," which relate to the physical dynamics of urban environments and their effects on temperature regulation. Overall, the diagram reveals a complex interplay between environmental factors, urban design, and temperature, highlighting the multifaceted nature of urban microclimate research.

Table 1. Urban microclimate study and methods applied

No	Author	Study contents	Method	Objective/Findings	Software
1.	Alsaad et al. (2022)	ENVI-met simulation on the impact of facade greening on the urban microclimate	Quantitative Method	Numerical simulations to assess the facade greening in reducing the effects of heatwaves in Central cities	ENVI-met
2.	Chatzinikolaou et al. (2018)	Urban microclimate improvement using ENVI-MET climate model	Quantitative Method	Modelling of urban microclimate, by the complexity of the three dimensional space of cities	ENVI-met
3.	Huttner et al. (2008)	Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities	Quantitative Method	To evaluate possible countermeasures proposed by urban planners	ENVI-met
4.	Bande et al. (2019)	Validation of UWG and ENVI-met models in an Abu Dhabi District, based on site measurements	Quantitative Method	A comparison analysis (in the different seasons) between the rural data, the simulation output	(UWG) and ENVI-met
5.	Huttner (2012)	The development and application of the 3D microclimate simulation ENVI-met	Quantitative Method	ENVI-met can help solve typical microclimatic questions within an urban environment	ENVI-met
6.	Cortes et al. (2022)	Evaluating mitigation strategies for urban heat island in Mandaue City using ENVI-met	Quantitative Method	UHI in Mandaue could be improved by increasing vegetation, open spaces, and employing green roofs	ENVI-met
7.	Misni et al. (2019)	Microclimate Environmental Model for Built Environment and Design Complex UiTM Puncak Alam	Quantitative Method	Measure the microclimate that has been received within the area, by generating the microclimate environmental model	ENVI-met
8.	Brahimi et al. (2023)	Enhancing Urban Microclimates: Benefits of Greenery Strategies in a Semi-Arid Environment	Quantitative Method	The benefits of green cover in the urban environment, impact on microclimate and outdoor comfort, particularly during hot periods	ENVI-met
9.	Li et al. (2022)	A Review of Urban Microclimate Research Based on CiteSpace and VOSviewer Analysis	Quantitative Method	CiteSpace and VOSviewer software were utilised to analyse the urban microclimate research from 1980 to 2020	CiteSpace and VOSviewer
10.	Yang et al. (2021)	Verifying an ENVI-met simulation of the thermal environment in Shanghai	Quantitative Method	Simulate the thermal environment of a complex urban green space accurately using ENVI-met	ENVI-met

Table 1 summarizes previous research on urban microclimate studies and techniques used, demonstrating the different methods adopted by researchers. The number of articles published on urban microclimate has progressed through three distinct stages: initial, slow, and rapid growth (Li et al., 2022). This evolution reflects a growing acknowledgement of the influence of urban microclimate on environmental planning and public health, making clear its importance in our present investigations concerning sustainable development strategies to face climate change.

Method and study area

This study aims to examine the factors contributing to the rise in temperature. The study figured out how the air temperature and thermal conditions vary based on land cover and the urban layout in urban commercial areas. Therefore, a site in Pudu and Wangsa Maju was selected as a site study for this investigation. Its specific urban structure is the main reason for introducing it as a case study area.

ENVI-met and Leonardo: Basic aspects of the environmental model

This study uses Envi-met as a three-dimensional non-hydrostatic microclimate model that can calculate and simulate climate in a grid resolution. The grid resolutions of 0.5 to 10 meters in space and 10 seconds in time are typical for urban regions. It computes the dynamics of microclimate temperature for 24 hours. The program's main prognostic factors are wind speed, direction, temperature, and humidity. The ENVI-met's core data structure is below (Chatzinikolaou et al., 2018). Figure 2 justifies the method data structure of the ENVI-met model.

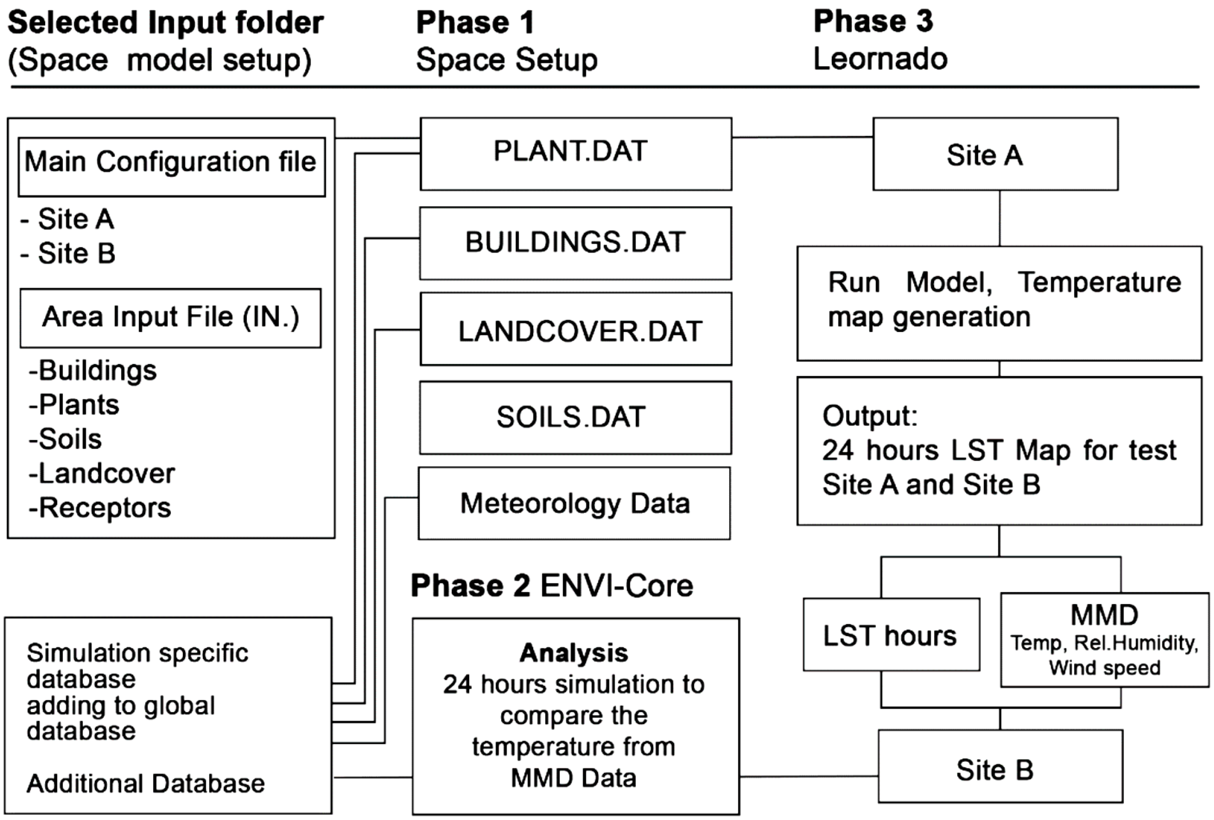


Figure 2. Method data structure of ENVI-met

Site study area

Two sites are selected to compare the impact of the commercial characteristics of each site on temperature.

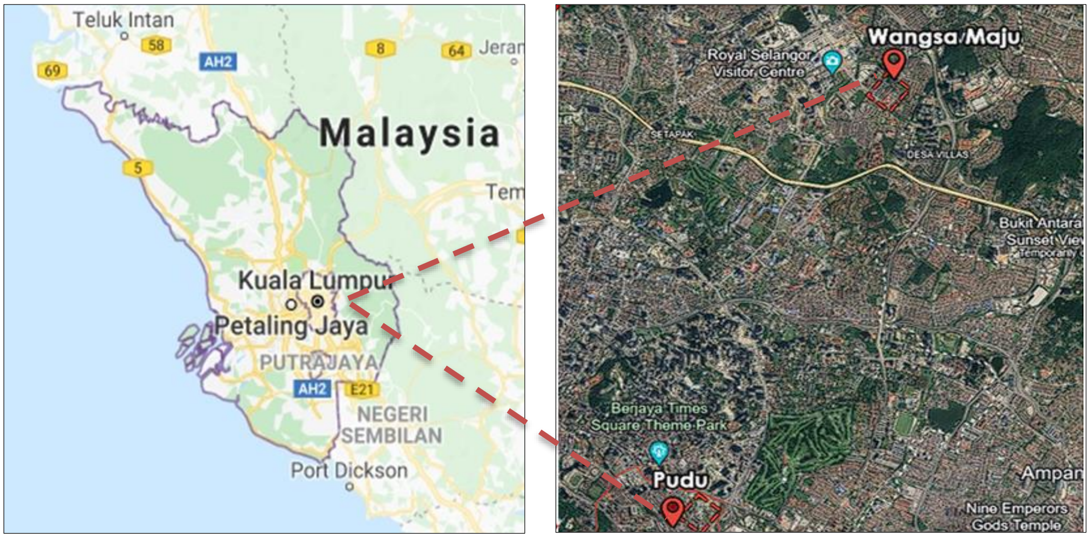


Figure 3 (i). Site study location Wangsa Maju and Pudu, Kuala Lumpur

Figure 3 (ii). Site study location; Pudu (left) and Wangsa Maju (right), Kuala Lumpur

The study sites are shown in Figure 3 above in the city centre, Pudu, and Wangsa Maju, Kuala Lumpur, Malaysia.

Site A - Pudu, Kuala Lumpur

Pudu is the first selected site located at the longitude and latitude of 3.1348° N, 101.7136° E. It is known for its heavy and compact commercial characteristics, composed mainly of commercial buildings, urban plazas, and a few institutional land uses. Moreover, the site has a mix of grid and angular patterns of urban form with building heights ranging from 3m (minimum height) to 40m (max height). Pudu's total site study area is around 174,540 square meters (87,270m x 87,270m).

Site B - Wangsa Maju, Kuala Lumpur

Wangsa Maju is the second selected site at the longitude, latitude of 3.2038° N, 101.7367° E. It is known as one of the central suburbs of Kuala Lumpur. DBKL recently announced plans to transform Wangsa Maju's Section 1 into Kuala Lumpur's first zero-carbon township, focusing on green technologies. This research helps investigate the temperature in Wangsa Maju in relation to the existing low-vegetated area. The site has an angular pattern of urban form with building heights ranging from 3m (minimum height) to 40m (max height). Wangsa Maju's total site study area is around 176,700 square meters (88,350 m x 88,350m).

The meticulous morphological analysis enables the collection of essential input data, covering building patterns and materials, vegetation softscape, and road networks. These data will form an essential foundation for analysing the temperature in Pudu and Wangsa Maju. The microclimate data was gathered from the Malaysian Meteorological Department on 20th November 2023 to help further analyse site temperature.

Building the ENVI-met model

ENVI-met model is among the standard tools used in simulating the microclimate model using the system founded on the fundamental laws of fluid and thermal dynamics. The software was designed to analyse the microscale thermal interactions within the urban environment (Huttner et al., 2008). The simulation of the Pudu area was performed with the help of the ENVI-met simulation. To create the three-dimensional models, the Suite Program and Spaces were utilised to digitize the foundation of Pudu to reflect the actual condition of the study area (Table 2).

Table 2. Input data and initial settings for the ENVI-Met model

Model location	**Site A**	**Site B**
Name of location	Pudu, Kuala Lumpur	Wangsa Maju, Kuala Lumpur
Position (Latitude)	3.13°	3.26°
Position (Longitude)	101.7°	101.73°
Model geometry		
Domaine size	87,270m x 87,270m	88,350 m x 88,350m
Model dimension	X-Grid =60 Y-Grid=60 Z Grid=30	X-Grid =60 Y-Grid=60 Z Grid=30
Size of grid cell	dx = 2m dy = 2m dz = 1m	dx = 2m dy = 2m dz = 1m
Model rotation out of grid from north	20°	20°
Height of 3D model TOP	46m	30m
Difference model top to highest point	30m	30m

Simulation setting

Using the ENVI-Guide, the simulation was conducted over 24 hours, beginning at 7:00 AM on Sunday, November 20, and ending at 7:00 AM on Monday, November 21, 2023 (Table 3). This period aligned with the times when people were too busy to go to work in the morning and were most likely to engage in outdoor activities. The meteorological data used to include the temperature, wind, and humidity was obtained from the Malaysia Meteorological Department Centre in Petaling Jaya.

Table 3. Settings of the ENVI-met simulation

Simulation setting	
Start date	21 November 2023
Start time	07.00 am
Total simulation	24h
Air temperature	24h cycle
Relative humidity	24h cycle
Wind speed	1.46

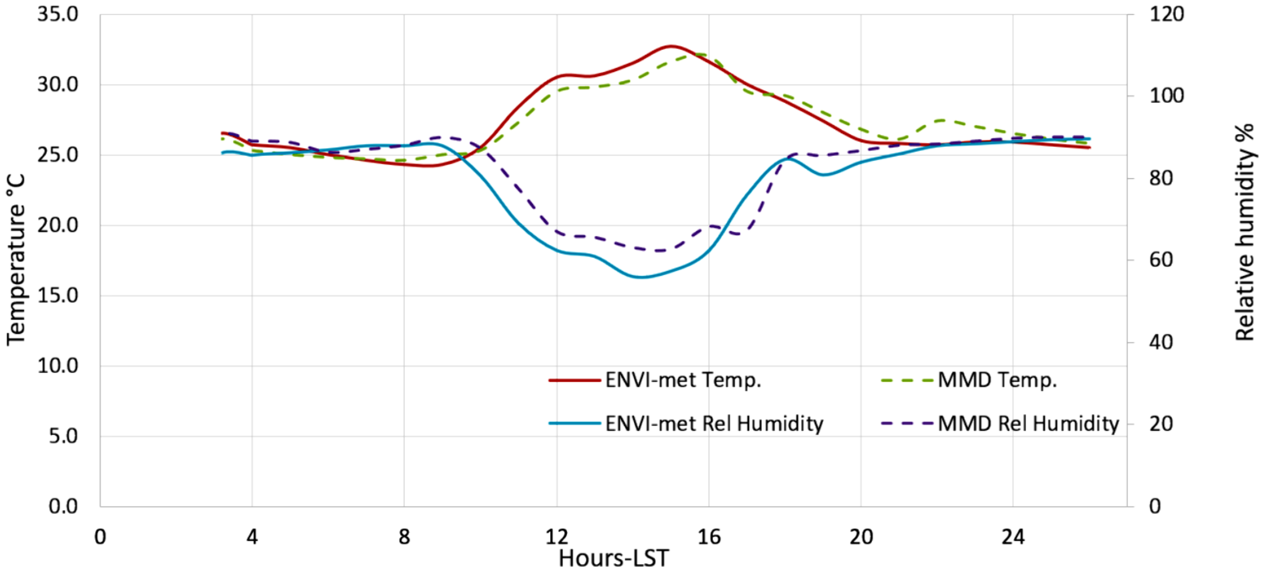


Figure 4. Microclimate data from MMD and ENVI-met for 24 hours during wet seasons around both cities in Kuala Lumpur

Figure 4 above is the graph of microclimate data gathered from the Malaysian Meteorological Department on 20th November 2023 to help analyze the temperature on the selected sites in Pudu and Wangsa Maju. This data can be used to correspond to the study area by providing actual meteorological parameters such as temperature, wind speed, and humidity, which are essential for calibrating the ENVI-Met model. By comparing the simulated data from ENVI-Met with the actual measurements obtained from the MMD, these can validate the accuracy of the simulation. The simulated results closely match the observed data, indicating that the model is reliable and can be used to assess the microclimate characteristics of the studied urban areas.

Simulating scenarios

Two scenarios simulated using ENVI-Met software are shown in Figure 5. The simulation and comparison of sites A and B enable the evaluation of the impact of vegetation and softscape on urban microclimate and outdoor thermal comfort.

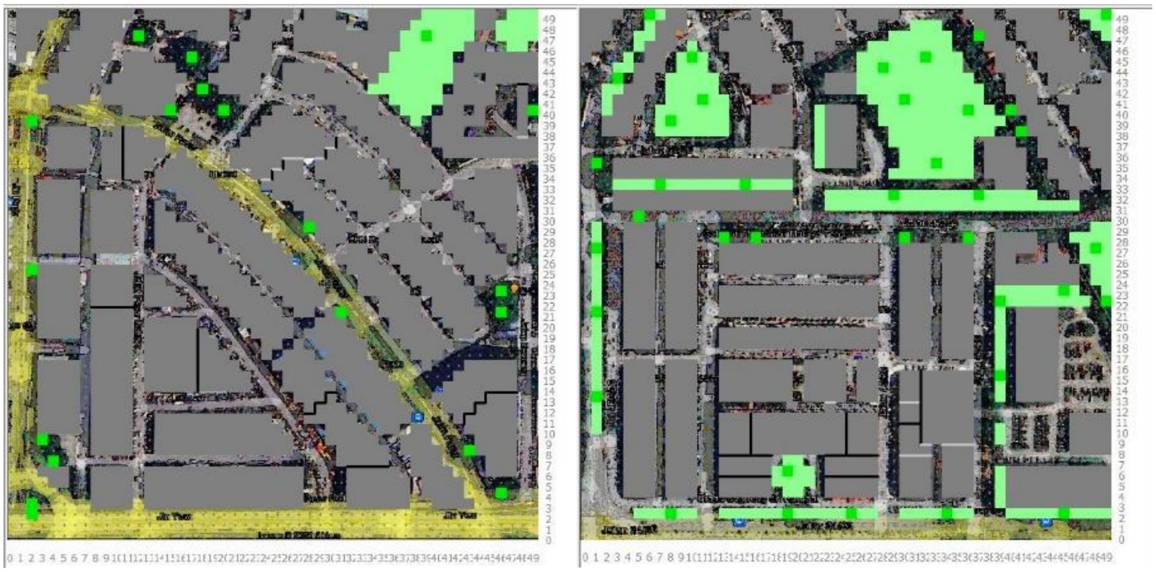


Figure 5. Site simulation using ENVI-met for Site A- Pudu (left), and Site B- Wangsa Maju (right)

The simulation started with a building and layout arrangement specific to the building height and material used, followed by adding vegetation such as trees and ground covers and base on-site materials such as asphalt, concrete, soil type, and others.

Landuse

From the land use characteristics of both study sites, Pudu and Wangsa Maju, significant differences in urban development and coverage in green spaces are realized. Pudu is predominantly an urban commercial area with most land use characterized by highly dense commercial buildings, urban plazas, and limited land use for institutions. The compact nature of this area results in less than 10% of the total land being covered by vegetation, which contributes to the urban heat island effect. With the predominance of impervious features like asphalt and concrete, temperatures are exacerbated in the daytime due to increased heat retention.

On the other hand, in the case of the Wangsa Maju site, the urban characteristic was observed to have more balanced urban features. Green space is estimated to comprise around 35% of the area. The presence of parks, landscaped places, and streets moderately lowers the local temperatures. Vegetation provides cooling by shading and evaporating water from plants, improving microclimate. The grid layout in Wangsa Maju, whereby streets are more spaced and there is adequate ventilation, reduces heat retention as opposed to the compact and angular Pudu layout.

Soil type

The soil type in both Pudu and Wangsa Maju is predominantly characterized by laterite soil, known for its distinctive reddish colour and high iron and aluminium oxide content. This soil type is typically porous and well-draining, allowing for efficient water movement. However, it is essential to note that laterite soil generally lacks fertility, which can limit vegetation growth in these urban areas (Weil & Brady, 2017). In Pudu, the limited vegetation cover exacerbates the effects of the urban heat island phenomenon, as the lack of plant life reduces the cooling effects that soil and vegetation can provide. The compact urban layout and high density of impervious surfaces further contribute to heat retention, making the area more susceptible to elevated temperatures.

Conversely, with its more significant proportion of green spaces, Wangsa Maju benefits from the presence of vegetation that can help mitigate temperature increases. The combination of laterite soil and vegetation in Wangsa Maju allows for better moisture retention and supports a more diverse plant community, contributing to localized cooling through shade and evapotranspiration. Understanding the soil type and its characteristics is crucial for evaluating the microclimate in these urban areas, as it directly influences vegetation growth and, consequently, the overall thermal dynamics of the environment.

Building arrangement

The building pattern in towns and cities is very significant to the microclimate conditions, mainly those affecting temperature. This angular/radial urban pattern in Pudu enables partial wind flow; however, variations in building height, whose maximum is 42 meters, result in a closely compacted setting. Such a setting may produce heat-trapping canyons that impede airflow and worsen the UHI situation. (Liang & Wu, 2020).

In contrast, although the Wangsa Maju grid iron urban pattern may impede the passage of wind due to the taller and closer structure of the buildings, comparatively, its structures are lower and more uniform. This environment may allow for excellent circulation of air, which enhances heat dispersion and keeps the temperature lower. (Liang & Wu, 2020) Due to the low building height, Wangsa Maju allows for the easy flow of wind, creating better thermal comfort and reducing the possibility of temperature accumulation, which is typical of higher-built-up and denser urban configurations (Sobstyl et al., 2018)

It is indicated that building arrangement has some implications concerning temperature because urban morphology, influenced by building density and height, plays a decisive role in determining local thermal conditions. It has also been established that urban areas with higher building density and heights record higher positive temperature increases due to reduced airflow and increased heat retention. Generally, the design of buildings in Pudu and Wangsa Maju shows that urban design significantly impacts conditions within the microclimate. In conclusion, good urban planning will create better thermal comfort and decrease city heat problems.

Results and discussion

Evaluation of the impact of vegetation on microclimate and outdoor comfort on Site A

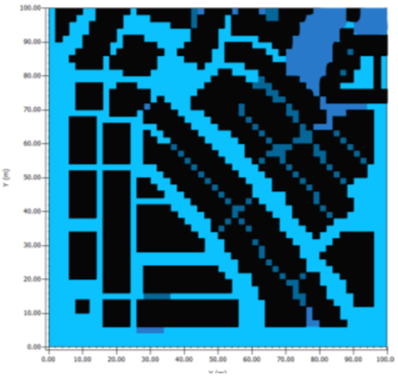
Based on the ENVI-met simulation results for Site A, air temperatures exhibited a range between 24.09°C and 32.0°C from 0800 to 1200 am, with the highest recorded temperature occurring at 13.00.

The figures below illustrate the simulation outputs of the day selected for the study. Figure 6 illustrates the significant temperature fluctuations throughout the day. The temperature value reaches more than 30°C at noon and can rise above 32°C, registering as the maximum value during the whole day. The 'heat stress zone' was consistently observed to occur in the most densely urbanized areas and those exposed to intense direct sunlight.

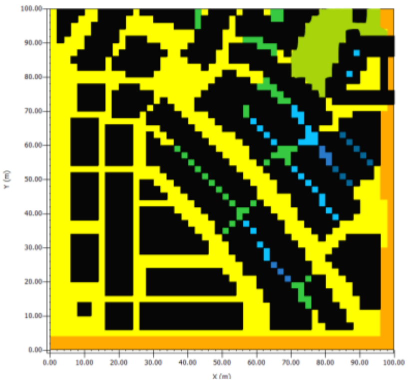
Comparison between Site A (Pudu) and Site B (Wangsa Maju)

Several factors affect the thermal environment of urban areas, including plants, building materials, and urban morphology, making it difficult to determine the effect of plants on thermal conditions. Therefore, an alternative simulation was studied by comparing two sites in Kuala Lumpur, which is Pudu and Wangsa Maju. Based on the percentage, the Pudu site has the most minor vegetation cover compared to Wangsa Maju. Comparing these two sites on the same day allows for assessing the impact of vegetation. The presence or absence of the vegetation element mainly causes variation in the PET index and meteorological parameters.

Temperature change pattern in Site A - Pudu



07.00 AM



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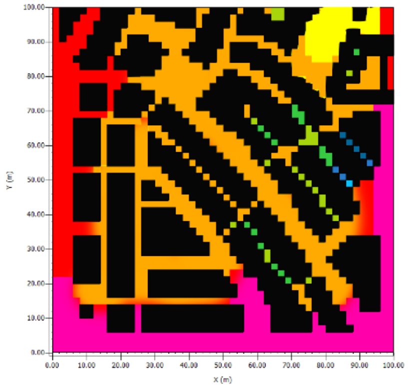

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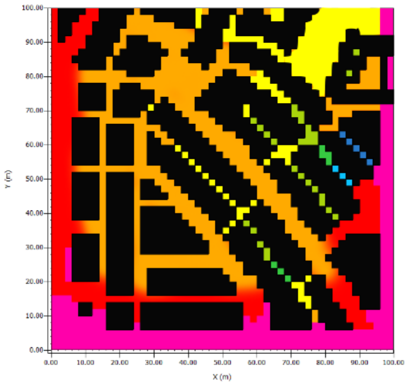
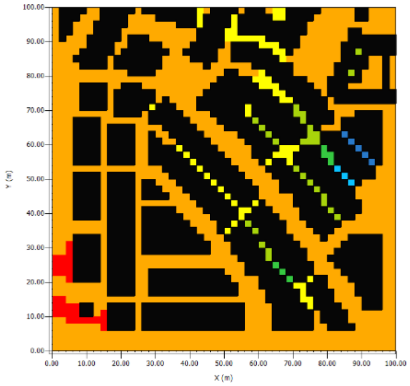


15.00 AM



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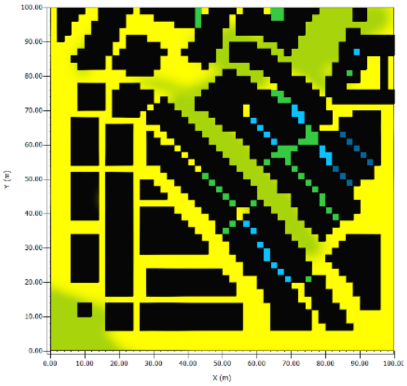

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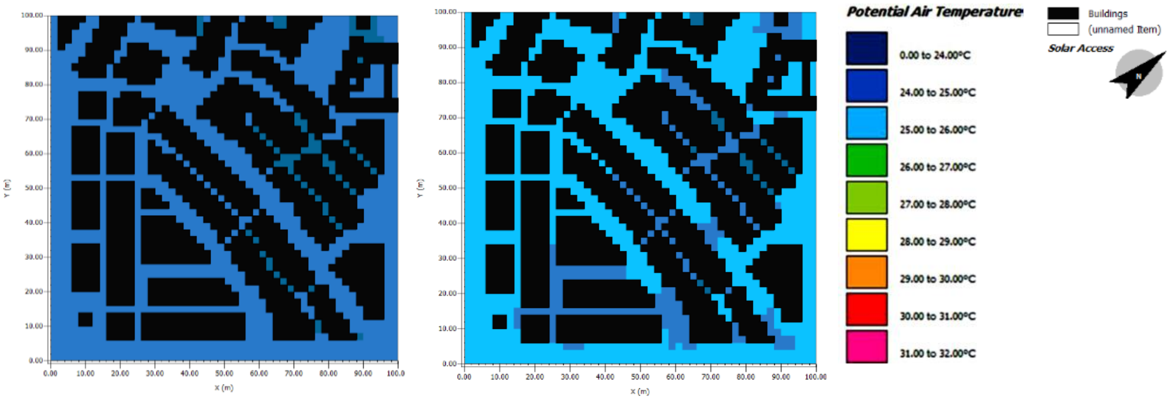
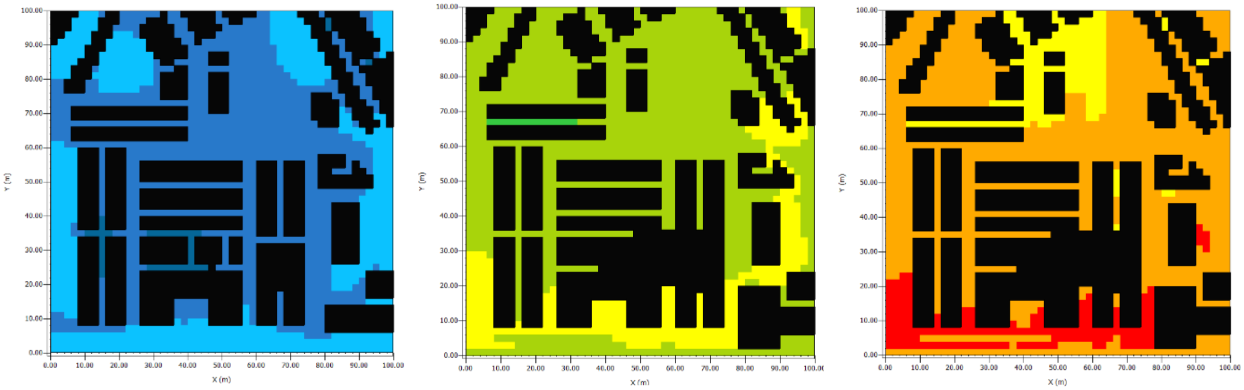


03.00 AM 06.00 AM

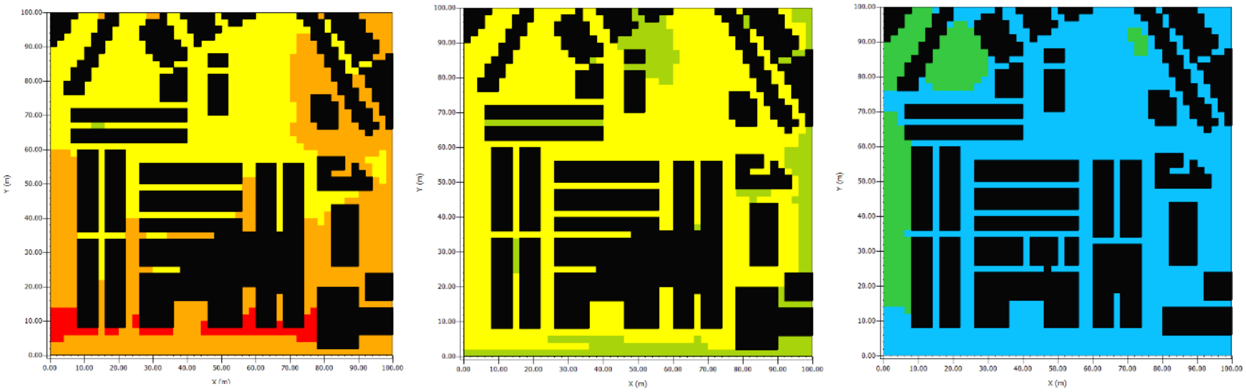
Figure 6. Temperature map in Pudu

Figure 6 shows the temperature result from the ENVI-met software for 24 hours on 21 November 2023 in Pudu. At 03.00 am, the temperature was recorded to be the lowest, slightly increasing at 10.00 am. The highest temperature was captured at 13.00 pm with 32.5°C. At 10.00 pm, the temperature in Pudu remained high at 29.3°C even though the relative humidity was high. Elevated relative humidity may restrict the night-time air cooling. Warmer evening temperatures can be caused by moisture in the air, which retains heat and slows its dissipation.

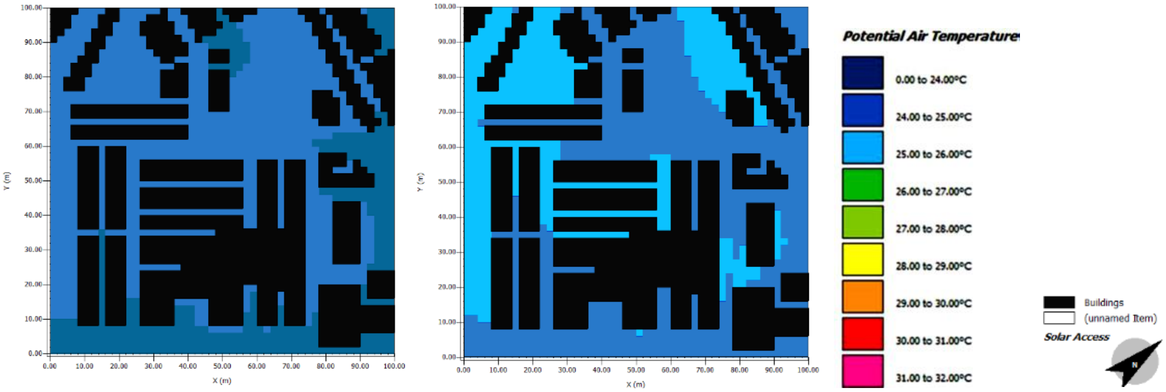
Temperature change pattern in Site B - Wangsa Maju



07.00 AM 10.00 AM 13.00 PM



15.00 AM 17.00 AM 22.00 PM



03.00 AM 06.00 AM

Figure 7. Temperature map in Wangsa Maju

Figure 7 shows the temperature result from the ENVI-met software for 24 hours on 21 November 2023 in Wangsa Maju. Similar to the temperature pattern in Pudu, at 03.00 am, the temperature in Wangsa Maju was recorded to be the lowest at 23.4°C and increased at 10.00 am. The highest temperature was captured at 13.00 pm with 31.2°C. At 10.00 pm, Wangsa Maju experienced a lower temperature than Pudu, at 28.6°C, due to the early daily closing business hours.

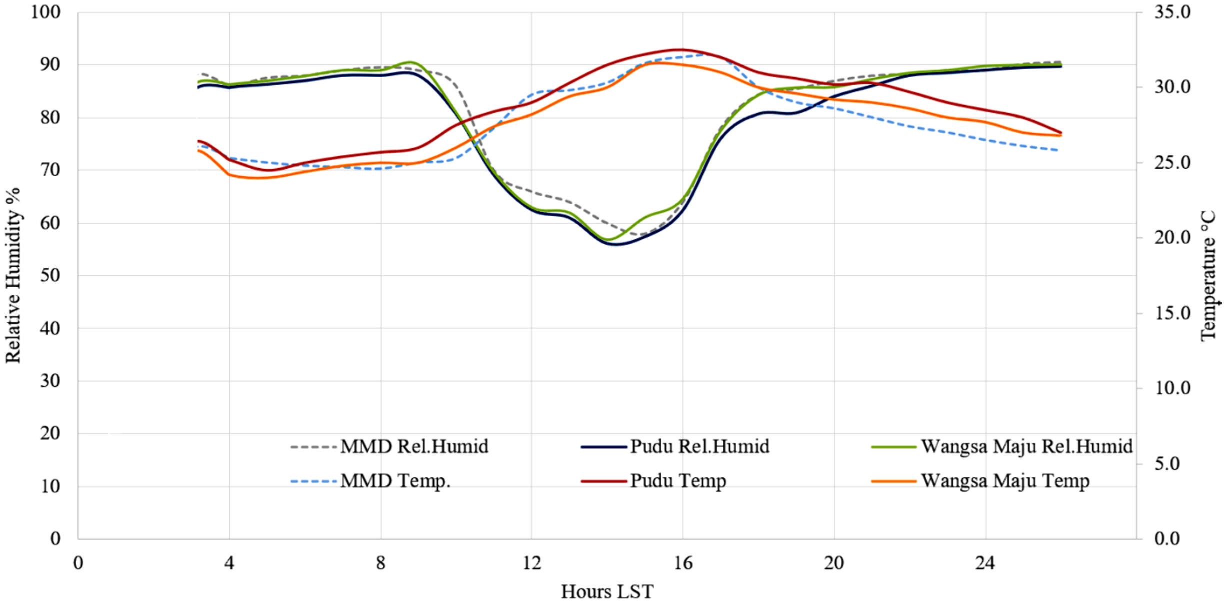


Figure 8. Microclimate data from MMD and ENVI-met data for Pudu and Wangsa Maju

The data from MMD was compared to Site A-Pudu and Site B Wangsa Maju for validation. Based on the graph Figure 8, ENVI-met data shows that the temperature in Pudu is much higher compared to Wangsa Maju. At the same time, relative humidity in Pudu is much lower than in Wangsa Maju. The highest difference is about 1.3°C in temperature.

Discussion on temperature change pattern in Site A - Pudu and Site B- Wangsa Maju

As a result, Site A Pudu has a higher temperature compared to Site B Wangsa Maju, with a 1.3°C difference in temperature from 13.00 pm until 15.00 pm. This is due to several factors contributing to the increase in temperature in Pudu, including landcover, urban layout, human movement, and business operating hours.

a. Landcover

Different land cover types have different albedo effects, determined by the amount of sunlight reflected or absorbed. The landcover in Pudu is mainly covered by impervious surfaces such as concrete and asphalt, which are common in urban areas with high pedestrian traffic. The absorption and retention of heat by these surfaces results in higher temperatures than Wangsa Maju. Compared to lighter surfaces like grass or open soil, darker surfaces like asphalt absorb more heat. The percentage of green land cover does not reach even 10%, which causes the Pudu area to experience hot temperatures and take time to cool down. Compared to lighter surfaces like grass or open soil, darker surfaces like asphalt absorb more heat.

Inversely, Site B, Wangsa Maju, has more than 10% green cover, which includes soil and vegetation. From the figure above, the temperature in the area covered with parks and vegetation is lower than in the area covered with road asphalt and concrete pavement. The shade trees and other vegetation reduce the direct sunlight that reaches the ground. Furthermore, they release water through evapotranspiration, which lowers the surrounding air temperature.

b. Urban layout and setting

The urban layout plays a vital role in controlling the temperature. Pudu area has an angular pattern of urban sprawl, which is suitable for wind flow. However, it has diverse building heights, mostly 14m high and above. The highest building in Pudu is 42m in height, and the building arrangements are compact and dense. An urban area's building density and arrangement affect the temperature. In contrast, tall buildings in high-density areas can form heat-trapping canyons that hinder airflow and exacerbate the urban heat island effect.

Wangsa Maju has a grid pattern of urban sprawl, which might block wind flow in some parts, but fortunately, the building is much lower and organized compared to Site A, Pudu. Lower buildings may experience less obstruction to wind flow, promoting better air circulation, which can help disperse heat and maintain lower temperatures in the urban environment. Moreover, the roads are complete with street plantation as streetscape, and the size of major and minor roads are more comprehensive, which helps in reducing traffic congestion, thus minimizing the production of carbon dioxide and reducing the temperature in Wangsa Maju.

c. Human movement and business operating hour

Business Operating Hours often operate in buildings requiring HVAC systems; these may emit heat into the surrounding environment, especially during peak operating hours. Besides, lighting, electrical appliances, and equipment employed in commercial buildings generate much heat, contributing to the urban heat island phenomenon. Many commercial and business buildings also operate for longer hours, a factor extending electricity usage and leading to rising temperatures. These extended hours of doing business often translate into more work from heating, ventilation, and air conditioning systems that eventually release waste heat to the environment, further raising local temperatures. It also states that the energy consumption of commercial buildings, particularly for cooling, significantly contributes to the UHI effect, especially in cities with high densities of commercial activity (Smith & Levermore, 2008).

Conclusion

Through the analysis and comparison of Pudu and Wangsa Maju's temperature trends, the findings confirmed that Pudu recorded an overall higher temperature than Wangsa Maju both day and night. The urban morphology of Pudu is compact and dense, allowing heat to accumulate on the buildings and exacerbate the urban heat island effect. The configuration of the buildings of Pudu, which tend to be close together with different building heights, led to increased temperatures, especially during the peak afternoon hours. Additionally, building materials with reflective surfaces increased the amount of heat absorbed, leading to a further temperature increase. In contrast, Wangsa Maju benefits from being more organized as it contains more green space that aids temperature mitigation. Vegetation provides shade and lowers temperature by evapotranspiration, which results in lower temperatures than Pudu.

The study's findings indicate that greater rigidity in urban planning and allocating plenty of green space within the city area are essential for managing temperature in densely populated areas. Moreover, human activities, including transportation and industrial processes, contribute to the thermal dynamics of urban environments. The continuous operation of businesses in Pudu leads to sustained heat generation, while Wangsa Maju experiences a reduction in temperature during non-business hours due to decreased human activity.

To conclude, enhancing vegetation cover and implementing green technologies, such as green roofs and walls, are recommended strategies to reduce urban temperatures. These measures can significantly improve the microclimate, promoting a more sustainable and comfortable urban environment. In future research, a 3D model will be developed to mitigate the high temperature via using more shade trees around urban development and on the building envelope, including roofs and walls.

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