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BUILDING PHYSICAL CHARACTERISTICS AND MICROCLIMATIC CONDITIONS INFLUENCE OUTDOOR THERMAL COMFORT: CASE OF KUALA LUMPUR

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Abstract: *Rapid urbanization in tropical cities like Kuala Lumpur has exaggerated outdoor thermal discomfort, primarily due to the urban heat island (UHI) effect. This has led to growing concern over public health and urban livability. This study investigates how building physical characteristics and microclimate conditions influence outdoor thermal comfort in six locations, including residential, commercial, and green spaces, which were selected to examine variations in thermal comfort across different urban forms. Data on air temperature, relative humidity, wind speed and heat index were collected at a height of 1.5 meters over seven consecutive days in March 2024 using handheld environmental meters. The findings revealed a mean temperature range of 29.1°C to 30.0°C, with standard deviations as high as 5.7°C, indicating significant temperature fluctuation. There is a strong negative correlation between wind speed and air temperature ($r = -0.913$, $p = 0.011$) and heat index ($r = -0.952$, $p = 0.003$), highlighting that higher wind speeds considerably lower perceived heat and enhance thermal comfort. Conversely, higher air temperature was associated with higher heat index values, indicating higher thermal discomfort, particularly in dense urban areas with limited ventilation. The study also highlights the effect of building height towards microclimatic conditions, with low-rise buildings (<4 storeys) contributing to higher heat retention than mid-rise buildings. These findings provide valuable insight into how urban planning can mitigate*

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thermal discomfort through strategic building designs and ventilation improvements, contributing to sustainable urban development.

Keywords: *Building physical characteristics; Microclimatic conditions: Outdoor thermal comfort; Kuala Lumpur; Building heat indicators*

Introduction

Nowadays, the consideration of thermal comfort has gained priority as it directly affects human well-being, safety and health, particularly for urban dwellers. As urbanisation increases, cities are experiencing significant challenges related to outdoor thermal comfort due to the rapid expansion of the built environment and increasing anthropogenic heat emissions. This is primarily contributing to the development of urban heat island (UHI) phenomena, which influences the urban climate. UHI has been determined as a difference in the mean and maximum temperature between urban and surrounding rural areas (Zaki et al., 2020). The implication of UHI is not only in terms of temperature differences but also in influencing energy consumption, public health, and environmental sustainability. The relationship between UHI and thermal comfort is particularly critical as the higher urban temperatures, the higher potential health risk and the poorer thermal comfort. Studies have shown that mortality risk increases by about 7.9% for every 1°C rise, particularly during heat waves (Zhao et al., 2018) Moreover, a recent study has demonstrated that humid heat is increasingly a global trend (Raymond et al., 2020), highlighting urban temperature and humidity as aggravators of heat island impact (Doan et al., 2016). This interplay between UHI and thermal comfort aggravates the overall urban experience, emphasising the need for sustainable urban planning.

The building physical characteristics and urban setting are key drivers of the UHI effect and outdoor thermal comfort. The building height, design, materials used, condition and human activity pattern contribute to different microclimatic conditions within urban areas (Ghaffarianhoseini et al., 2019; Ibrahim et al., 2021; Ronalmanto et al., 2021). Research indicates that the geometry of urban settlements, including building height, has significantly affected pedestrian-level thermal comfort. Specifically, the height-to-width (H/W) ratio influences wind speed and solar radiation exposure. A study by Ronalmanto et al., (2021 indicates that a higher H/W ratio can lower street-level wind speeds, may hinder natural ventilation and increase the impression of heat. Contrariwise, optimal building heights with better vegetation and materials can enhance airflow and reduce the accumulation of heat (Baca and Tsai, 2015). In tropical climates, building materials face unique climatic challenges posed by high temperature and humidity. Materials with high thermal mass, such as concrete and brick, are the most prevalent materials in tropical urban settings due to their durability. Yet, this conventional concrete can absorb heat during the day and release it at night. Thus, innovations in reflective concrete formation have widely been explored by many researchers.

Similar to many Southeast Asian megacities, Kuala Lumpur city has not been exempted from experiencing the UHI effect. Many studies have been conducted to evaluate UHI around Kuala Lumpur, including a study by (Ahmad et al., 2009) that identified many areas in Kuala Lumpur, such as Jinjang – Kepong, Segambut – Sentul, and slightly south of the study area, exhibit pronounced UHI patterns. These regions are most affected by increasing temperatures due to urban development. On the other hand, Ramakreshnan et al., (2019) revealed that UHI events occur mainly during the nights in magnitude ranges of 0–2 °C. This clearly shows that the built

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environment retains more heat during the night, expanding temperature differences between urban and surrounding regions. Zaki et al. (2020) further quantifies this effect, highlighting average and maximum UHI intensity values in Kampung Baru are 4.4°C and 6.0°C respectively, while the results from mobile measurement recorded the highest temperatures in Kampung Baru rather than in the surrounding areas, signifying heat collected within this urban layout. Moreover, previous studies on UHI in Kuala Lumpur have reported that UHI has significant effects on thermal comfort, human health, pollution, societal economy, and meteorology and climate. The unique climatic condition of tropical cities often experiences higher humidity levels with higher temperature fluctuations due to seasonal variations. Thus, understanding the temperature dynamic in the Kuala Lumpur city area in different seasonal periods with different land-used and local urban layouts is crucial to developing sustainable strategies to mitigate these impacts.

Despite the growing number of studies on UHI, there is still a gap in understanding the specific interplay between building characteristics, microclimatic conditions, and outdoor thermal comfort in different land-use areas, especially tropical urban areas. This study aimed to investigate the influence of building physical characteristics and microclimatic conditions on outdoor thermal comfort in urban Kuala Lumpur.

Methodology

Study Area

The research was conducted at six distinct locations around Kuala Lumpur city: Jalan Parlimen (1), Jalan Raja Laut (2), Jalan Kinabalu (3), Jalan Sultan Ismail (4), Jalan Dewan Sultan Sulaiman (5), and Jalan Raja Abdullah (6) as shown in Figure 1. These locations represent a range of urban contexts that reflect the diversity of land use in Kuala Lumpur, including rivers, parks, highways, urban residential, office and commercial buildings. The selection of these locations considers all the elements that could influence the local microclimate during the site investigation.

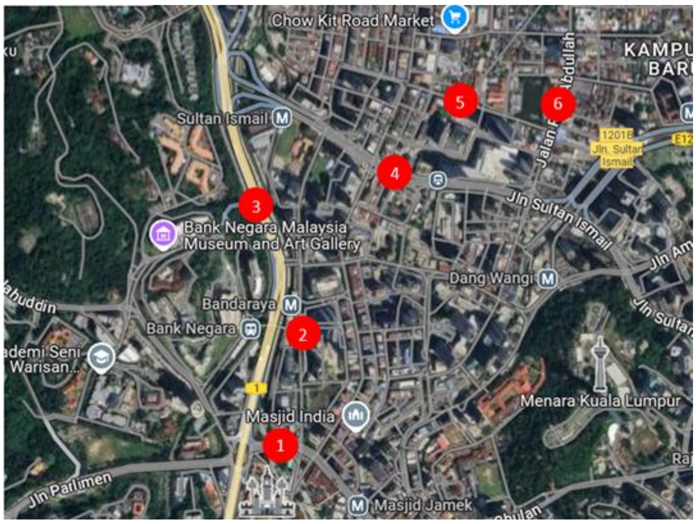

Figure 1: Location of the study area in Kuala Lumpur city centre
Source: Google Map

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Table 1: Details of study area location

Location Name	Location Picture	Location Description
Jalan Parlimen		The main road to the city centre has greenery and sidewalks. It's situated near major landmarks, including Dataran Merdeka, Gombak River, and government offices. During weekdays, there is heavy traffic and vibrant activity.
Jalan Raja Laut		Highly active pedestrian area closes to public transport infrastructure. The location is likely frequently busy during weekdays (office hours). There are several shopping centres nearby.
Jalan Kinabalu		The main road to the city centre connects to several important roads, such as Jalan Sultan Hishamuddin and Jalan Kuching. It is also located close to Perdana Botanical Gardens.
Jalan Sultan Ismail		The main road to the city center has a monorail track overhead. It is surrounded by medium and tall buildings, including offices, educational institutions, and commercial businesses. It experiences heavy traffic and vibrant activity throughout the day.
Jalan Dewan Sultan Sulaiman		It is located between the Chow Kit area and Kampung Baru. The road is lined with several small restaurants and has a steady flow of traffic and foot activity.

Jalan Raja Abdullah		The passes through the Kampung Baru area, which is surrounded by low-rise buildings, modern offices, hotels, and commercial spaces.

Field Measurement

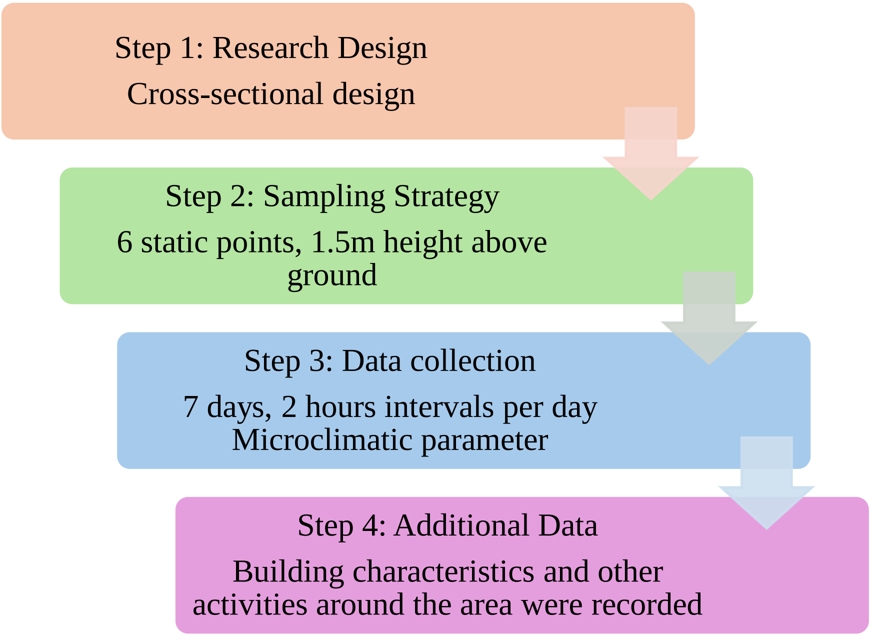

Figure 2: Research Design

This study employed a cross-sectional research design to assess microclimatic conditions across different land-use areas, as shown in Figure 2. The handheld measuring technique used an environmental meter sensor to measure variations in environmental parameters, including air temperature, relative humidity, heat index, and air velocity, to identify patterns that reflect the microclimatic differences between land-use types. The data were collected manually within different land-use areas with the sensor positioned at a height approximately 1.5 m above the ground level, considering the height of the average breathing zone of a standing adult. This height was chosen as it reflects the microclimatic conditions experienced by people in outdoor areas. The field measurements were conducted for seven (7) consecutive days in March 2024, and measurements were recorded every two (2) hours per day at six static points. The data of building characteristics and activities around each study area were also recorded to account for the influence of these factors on the microclimate. Table 1 summarises the details of the handheld measurement, while Table 2 shows the environmental meter specifications, including type, setting, and accuracy.

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Table 2: Details of the handheld measurement

Item	Description
Date	25 March – 3 April 2024
Time	Every 2 Hour
Instruments	Environmental meter
Instrument's height	1.5 m

Table 3: Instrument specifications of the KESTREL 3000 environmental meter

Data logger	Model	Climatic Variables	Instruments Accuracy	Measurement Range
Environmental Meter	Kestrel 3000	Wind Speed	±3% FS	0.4 – 40 m/s
		Heat Index	±3%	-29 to + 70°C
		Humidity	±3%	5 – 95%
		Temperature	±2°C	-29 to + 70°C

Result

Table 3 shows the mean and standard deviation of microclimatic conditions for variables of wind speed, air temperature, relative humidity, and heat index across six (6) locations in Kuala Lumpur. The average wind speed across the location was relatively consistent at about 1.6 to 1.7 mph with a standard deviation of 0.8 mph. This indicates that wind speed was stable in all sites with slight variation. However, the mean air temperature has recorded more variable with values ranging from 29.1°C to 30.0°C and a standard deviation as high as 5.4°C, especially at Jalan Dewan Sultan Sulaiman and Jalan Sultan Ismail, which indicates more temperature fluctuations. The relative humidity was consistently high, with mean values ranging from 73.5% to 74.9%. Yet, the standard deviation shows more variability, especially at Jalan Kinabalu (15.4%) and Jalan Sultan Ismail (16.0%), where there are fluctuations in humidity levels. With ranging from 35.9°C to 37.0°C, the mean heat index was recorded high across all locations, and Jalan Raja Abdullah mainly had the highest variability with a standard deviation of 7.8°C.

Table 3: Summary of microclimatic measurements across different locations in Kuala Lumpur

Location		Wind speed (mph)	Air Temperature (°C)	Relative humidity (%)	Heat Index (°C)
Jalan Parlimen	Mean	1.7	30.0	74.9	37.0
	Std Dev	0.8	3.7	14.1	6.0
Jalan Raja Laut	Mean	1.6	29.8	74.4	36.8
	Std Dev	0.8	4.2	14.8	6.4
Jalan Kinabalu	Mean	1.6	29.7	73.9	36.6
	Std Dev	0.8	4.7	**15.4**	6.8
Jalan Sultan Ismail	Mean	1.6	29.5	73.8	36.4
	Std Dev	0.8	5.0	**16.0**	7.2

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Jalan Dewan Sultan Sulaiman	Mean	1.6	29.3	73.6	36.2
	Std Dev	0.8	**5.4**	16.5	7.6
Jalan Raja Abdullah	Mean	1.6	29.1	73.5	**35.9**
	Std Dev	0.8	5.7	17.0	**7.8**

Besides, the key relationships between these variables are further highlighted through correlation analysis. There is a strong negative correlation between air temperature and wind speed (r = -0.913, p = 0.011), which indicates that higher wind speeds are correlated with lower air temperature. This relationship can be attributed to the cooling effect of wind. Likewise, wind speed also has a strong negative correlation with the heat index (r = -0.952, p = 0.003), showing that higher wind speeds contribute significantly to reducing perceived heat, indirectly improving thermal comfort. Conversely, there is a strong and positive correlation between air temperature and heat index (r = 0.923, p = 0.009), highlighting that higher air temperature leads to higher perceived heat. However, relative humidity did not significantly correlate with other variables, implying that humidity had a minimal effect on temperature and heat index.

Table 4: Correlations of microclimatic condition

		Wind Speed (mph)	Air Temperature (°C)	Relative Humidity (%)	Heat Index (°C)
Wind Speed (mph)	Pearson Correlation	1	-.913*	-.181	-.952**
	Sig. (2-tailed)		.011	.731	.003
	N	6	6	6	6
Air Temperature (°C)	Pearson Correlation	-.913*	1	-.187	.923**
	Sig. (2-tailed)	.011		.723	.009
	N	6	6	6	6
Relative Humidity (%)	Pearson Correlation	-.181	-.187	1	.107
	Sig. (2-tailed)	.731	.723		.841
	N	6	6	6	6
Heat Index (°C)	Pearson Correlation	-.952**	.923**	.107	1
	Sig. (2-tailed)	.003	.009	.841	
	N	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Two models have been developed to investigate the relationship between building height categories and their effect on the heat index through regression analysis. The first model uses building < 4 storeys as the predictor variable, while the second model includes 5 – 12 storeys as an additional predictor variable. As shown in Table 5, building height significantly influences the heat index, with R-squared value in Model 1 is 0.740, indicating that 74% of the variance in the heat index is justified by the height category < 4 storeys. In this model, the coefficient value is 2.123 (p = 0.028), meaning that buildings with fewer than four stories tend to increase the heat index. This positive relationship emphasised that low-rise buildings could exacerbate the heat index, likely due to the sky view factor and limited airflow (Luo et al., 2023; Srivastava et al., 2024). Low-rise structures in densely built areas tend to increase heat

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retention during the day and delay cooling at night, contributing to higher land surface temperature (Makvandi et al., 2019). This phenomenon is compounded by the limited shading provided by these structures, which allows for greater solar exposure, reducing outdoor thermal comfort.

When combining both predictors (< 4 storeys and 5 – 12 storeys) in Model 2, the R-squared value increases to 0.949 with a coefficient value of 1.166 (p = 0.039), indicating that mid-rise buildings might offer better ventilation and shading capabilities directly lower the heat index. These structures strike a balance between the compactness of high-rise buildings and the openness of low-rise buildings. With the combination of mid-rise buildings surrounded by high-rise buildings, compound to create a cooling effect (Makvandi et al., 2019). Toren and Sharmin (2023) added that strategically placement of mid-rise buildings can optimise the cooling performance of urban areas by creating wind corridors and reducing heat accumulation, which particularly beneficial during peak summer temperature. These findings strengthen the argument that height variability significantly influences outdoor thermal comfort.

Table 5: Regression analysis of building height categories and heat index

Model	Predictor Variable	Unstandardised Coefficient (B)	Standard Coefficient (Beta)	t-value	p-value	R^2	Adjusted R^2	Std. Error of Estimated
Model 1	constant	36.687	-	100.950	< 0.001	0.740	0.675	0.7268
	< 4 storeys	2.123	0.860	3.372	0.028			
Model 2	Constant	36.979	-	181.747	< 0.001	0.949	0.915	0.3714
	< 4 storeys	2.414	0.978	7.266	0.005			
	5 – 12 storeys	-1.166	-0.472	-3.509	0.039			

Conclusion

The study concludes that building physical characteristics and microclimatic conditions significantly determine outdoor thermal comfort in tropical urban areas like Kuala Lumpur. Through field measurement in six distinct locations of Kuala Lumpur, the result revealed that wind speed significantly enhances outdoor thermal comfort by reducing both air temperature and heat index. Regions with higher building density and lower wind speeds are more vulnerable to thermal discomfort due to limited airflow. This clearly emphasized the main role of wind in lessening thermal discomfort by facilitating heat dissipation from the human body and improving air quality through ventilation. In tropical climates of Malaysia, people experience hot and humid environmental conditions. Heat index, the combination of air temperature and relative humidity, provides a more accurate representation of perceived temperature in determining thermal comfort. Based on the findings, higher temperatures correlate with greater heat index, yet slight variation in relative humidity can lead to changes in the heat index. In this study, Jalan Raja Abdullah recorded the highest deviation of heat index. The finding also shows that there is a strong correlation between building height and heat index where low-rise building (fewer that four stories) particularly in dense urban areas tend to trap heat and elevated heat index. In contrast, mid-rise buildings provide balance by improving ventilation and shading, thereby mitigating heat island effect. Nevertheless, urban

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setting such as density, layout and material used also closely related to microclimatic conditions and thermal comfort. Thus, simulation of urban design is needed to identify the best urban design that focuses on energy efficiency and outdoor thermal comfort.

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