IC-57

# BUILDING PHYSICAL CHARACTERISTICS AND MICROCLIMATIC CONDITIONS INFLUENCE OF 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 liveability. 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 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 both 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 is 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 compared to mid-rise buildings. These findings provide valuable insight into how urban planning can mitigate 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

## 1. 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, city areas experience

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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 influence the urban climate. UHI has been determined as a difference of 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 about 7.9% for every 1°C rise in temperatures 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) and highlighted 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, emphasizing 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 activities pattern contribute to different microclimatic conditions within urban areas (Ghaffarianhoseini et al., 2019; Ibrahim, Kershaw, Shepherd, & Coley, 2021; Ibrahim, Kershaw, Shepherd, & Elwy, 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) indicated that a higher H/W ratio can lower the wind speeds at street level, 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 & Tsai, 2015). In tropical climate, 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 south-east 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) which 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. Meanwhile, Ramakreshnan et al. (2019) revealed UHI events occur mainly during the nights in magnitude ranges of 0–2 °C. This clearly shows that the built 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 as 4.4°C and 6.0°C respectively, while the result from mobile measurement recorded highest temperatures in Kampung Baru rather that in the surrounding areas, signifying heat collected within this urban layout. Moreover, previous studies on UHI in Kuala Lumpur have reported that UHI has major 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 temperature dynamics in Kuala Lumpur city area in different seasonal periods with different land-used and local urban layout are crucial to develop sustainable strategies in mitigating these impacts.

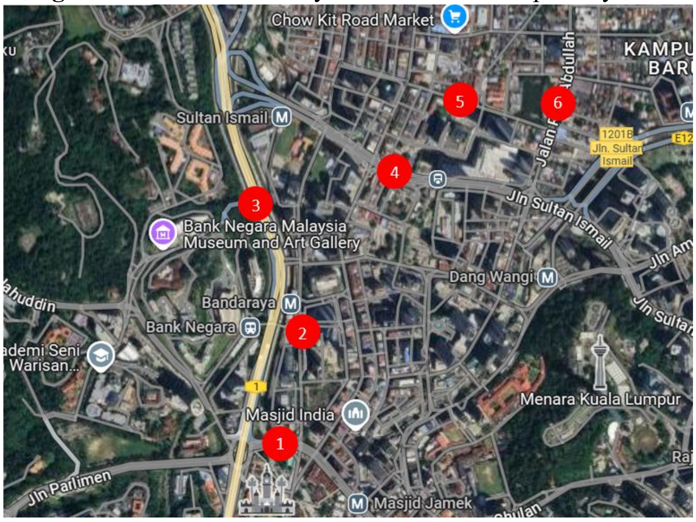
Despite the growing number of research on UHI, there is still a gap in understanding specific interplay between building characteristics, microclimatic conditions, and outdoor thermal comfort in different land-use areas, especially tropical urban areas. This study aims to investigate the influence of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

## 2. Methodology

### *2.1 Study Area*

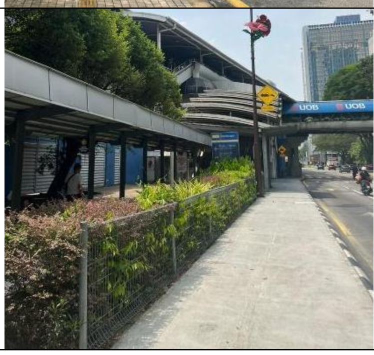
The research was conducted at six distinct locations around Kuala Lumpur city: Jalan Parlimen (1), Jalan Raja Laut (2), Jalan Kinabalu (3), Jalan Sultan Ismail (4), Jalan Dewan Sultan Sulaiman (5), and Jalan Raja Abdullah (6) as shown in Figure 1. These locations represent a range of urban contexts that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

**Figure 1:** Location of study area in Kuala Lumpur city center




***Source:*** *Google Map*

**Table 1:** Details of study area location.

| Location Name | Location Picture | Location Description |
|---|---|---|
| Jalan Parlimen |  | Main road to city centre with greenery and sidewalk. It is situated near major landmarks including Dataran Merdeka, Gombak River and government offices. Heavy traffic and vibrant activity during weekdays. |
| Jalan Raja Laut |  | Highly active pedestrian area close to public transport infrastructure. The location is likely busy during weekdays (office hours). There are several shopping centres nearby. |

| | | |
|---|---|---|
| Jalan Kinabalu |  | Main road to city centre, connecting to several important roads such as Jalan Sultan Hishamuddin and Jalan Kuching. It is also located close to Perdana Botanical Gardens. |
| Jalan Sultan Ismail |  | Main road to city center with monorail track overhead. It is surrounded by medium and tall buildings including offices, educational institutions and commercial business. It experiences heavy traffic and vibrant activity throughout the day. |
| Jalan Dewan Sultan Sulaiman |  | Located between 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 |  | It passes through Kampung Baru area. Surrounded by low rise building and modern offices building, hotels and commercial spaces rising in the area. |

### *2.2 Field Measurement*

In this study, a cross-sectional research design was employed to assess microclimatic conditions across different land-use areas as shown in Figure 2. The handheld measuring technique was carried out using 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 of 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 the 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.

**Figure 2:** Research Design

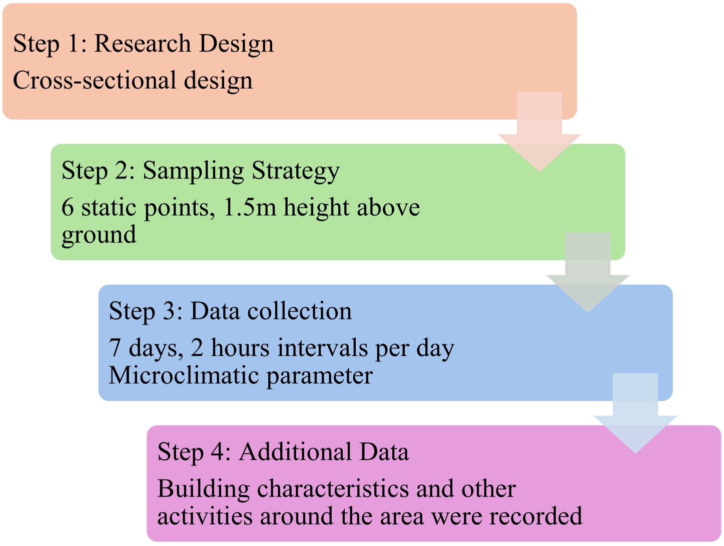



**Table 2:** Details of the handheld measurement

| 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 |

## 3. Result

Table 3 shows the mean and standard deviation of microclimatic conditions for the 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 is stable in all sites with slight variation. However, the mean air temperature recorded more variables with values ranging from 29.1°C to 30.0°C, and standard deviation as high as 5.4°C, especially at Jalan Dewan Sultan Sulaiman and Jalan Sultan Ismail, which indicate 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. 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 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 |
| **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 can 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 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, it compounds to create a cooling effect (Makvandi et al., 2019). 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 | | | |

## 4. 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 emphasizes 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 environment conditions. Heat index, the combination of air temperature and relative humidity provide 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 buildings (fewer than 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 settings such as density, layout and material used are 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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