Jurnal Kejuruteraan 37(6) 2025: 3009-3021
https://doi.org/10.17576/jkukm-2025-37(6)-35

A Comprehensive Investigation of Thermal Comfort and Heat Island Phenomena in High-Risk Regions of Putrajaya

Mohd Anas Mohd Sabri[a,b*], Wan Aizon Wan Ghopa[a,b], Meor Iqram Meor Ahmad[a,b], Mohd Sabirin Rahmat[a,b] & Hawa Hishamuddin[a,b]

[a]Department of Mechanical & Manufacturing Engineering,
Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia

[b]Centre for Automotive Research (CAR),
Faculty of Engineering & Built Environment,Universiti Kebangsaan Malaysia

[*]Corresponding author: anasms@ukm.edu.my

Received 17 October 2024, Received in revised form 17 April 2025
Accepted 18 May 2025, Available online 30 September 2025

ABSTRACT

Urban heat islands (UHIs) are localized areas within cities that exhibit significantly higher temperatures than surrounding rural regions, primarily because of anthropogenic activities and urban infrastructure. Understanding thermal comfort (TC) is essential, as it directly influences the well-being and quality of life of urban populations. This study investigates the presence of UHIs in Putrajaya and evaluates the TC levels experienced by its residents. TC is assessed using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices, following internationally recognized standards ISO 7730 and ASHRAE 55-1992. Field measurements were conducted with the EK-H4 data logger as well as Thermal Comfort Station (TCS), which records key environmental parameters including air temperature, mean radiant temperature, relative humidity, and air velocity. Data collected were retrieved using EK-H4 V1.0 software and analysed with Microsoft Excel. A psychrometric chart was employed to visualize environmental conditions and identify TC zones. The results indicate that PMV values ranged from -1.0 to +1.4, reflecting considerable variability in thermal conditions across different locations and times. Recorded air temperatures ranged from 28.4°C to 36.9°C, relative humidity varied between 48.1% and 72%, and air velocity ranged from 0 to 2.32 m/s. These findings confirm the presence of localized UHIs in Putrajaya and reveal varying levels of thermal discomfort, highlighting the need for urban planning interventions aimed at mitigating heat stress and enhancing urban liveability.

Keywords: Heat island; thermal comfort; temperature; relative humidity

INTRODUCTION

Urban heat islands (UHIs) refer to localized areas that exhibit significantly higher temperatures than their surrounding regions (Vujovic et al. 2021). This phenomenon is commonly observed in densely developed urban environments, where closely spaced concrete buildings, expansive road networks, highways, and large asphalt-covered parking areas collectively contribute to increased heat absorption and retention. As noted by Hanafiah (2019), concrete structures not only absorb and store thermal energy but also obstruct natural airflow, thereby reducing wind circulation within the built environment. The UHI effect has detrimental implications for human thermal comfort (TC), often impeding individuals' ability to perform daily activities—particularly during periods of extreme heat.

The presence of UHIs significantly impacts human TC, particularly in densely populated metropolitan areas (Elkhazindar et al. 2022). TC refers to a psychological state in which individuals express satisfaction with the surrounding thermal environment and is closely influenced by both indoor and outdoor climatic conditions (de Dear et al. 2020). In regions affected by UHI—especially in developing countries with limited access to cooling infrastructure—achieving adequate TC poses increasing challenges. Goggins et al. (2012) observed that even a 1 °C increase above 29 °C can significantly elevate mortality rates, underscoring the serious health risks associated with thermally stressful environments. A variety of mitigation strategies have been explored to address these challenges, including the enhancement of urban greenery, the application of reflective and permeable pavement materials, and the optimization of urban geometry. Research by Santamouris (2015) and others has demonstrated that interventions such as green roofs, increased vegetation, and the use of high-albedo materials can effectively lower ambient air and surface temperatures, thereby improving outdoor TC in urban settings. Maghrabi et al. (2022) reviewed how UHI impacts building energy consumption. They identified contributing factors such as building orientation, surface albedo, land use, and anthropogenic heat. The authors suggested a positive relationship between urban greening and reduced energy use, pointing to research gaps in tropical UHI.

Given that individuals spend a significant portion of their time indoors, regulating indoor thermal conditions is crucial—particularly in urban environments where ambient temperatures are elevated due to the UHI effect. Enescu et al. (2020) emphasize that TC in residential buildings is influenced by multiple factors, including air temperature, relative humidity, air movement, and thermal radiation from surrounding surfaces. Their study underscores the critical role of architectural design, choice of building materials, and effective ventilation in mitigating thermal discomfort. By optimizing these variables, it is possible to enhance occupant comfort and overall well-being, even in thermally stressed urban settings. Moreover, several anthropogenic and environmental factors intensify the UHI effect and further compromise TC in urban areas. According to Lai et al. (2019), key contributors include increased urban density, widespread use of private motor vehicles, frequent open burning activities, and the rapid proliferation of high-rise developments. These conditions collectively exacerbate thermal stress and highlight the necessity for comprehensive urban planning strategies aimed at enhancing microclimatic conditions and indoor environmental quality.

UHI phenomenon has been the subject of numerous case studies across the globe. Imran et al. (2019) examined the spatial and temporal evolution of UHI in Melbourne, Australia, highlighting the significant impact of rapid urban expansion on the surface energy balance. Their findings indicated that the proliferation of impervious surfaces and alterations in land cover contributed to measurable increases in land surface temperature (LST), thereby intensifying the UHI effect over time. In the African context, a regional study by Doreen et al. (2021) encompassing Dar es Salaam, Nairobi, and Addis Ababa revealed that informal settlements exhibit higher maximum UHI intensities compared to formal urban zones. The study attributes this disparity to the prevalence of low-quality housing materials, the lack of vegetation cover, and high population densities, all of which exacerbate elevated urban temperatures and associated thermal discomfort. In Southeast Asia, cities such as Bangkok and Bandung, Arifwidodo and Chandrasiri (2020) reported that UHI effects significantly increased household electricity use and perceived heat stress. The study highlights that energy demand, public health, and urban inequality are intricately linked through UHI dynamics. In Indonesia, Pramudya et al. (2021) used the Universal Thermal Climate Index (UTCI) to reveal very strong thermal stress across urban zones, with future projections indicating increases of over 3 °C in perceived temperature

Previous studies have confirmed the presence of the UHI phenomenon in several regions across Malaysia, including Kuala Lumpur, Cyberjaya, Selangor, Johor Bahru, Kota Kinabalu, and George Town (Hashim et al. 2010). These urban centers have experienced elevated temperatures as a result of rapid urbanization and intensive infrastructural development. Kuala Lumpur serves as a prominent case study. Using the ADMS-Urban model, Yahya et al. (2022) reported UHI intensities ranging from 4.2 °C to 9.5 °C, primarily attributed to reduced vegetation cover and anthropogenic heat emissions from transportation and air conditioning systems. In a related study, Zaki et al. (2023) investigated microclimatic conditions in central Kuala Lumpur and found a direct impact on outdoor TC, with more than half of the surveyed participants reporting thermal discomfort.

The present study aims to address a significant gap in the existing literature by examining the impact of UHIs on TC, with a particular focus on Putrajaya—Malaysia's rapidly developing administrative capital experiencing substantial urban expansion. The primary objective is to identify high-risk zones within Putrajaya that are most vulnerable to excessive heat accumulation. Utilizing analytical tools alongside field-based assessments, the study will evaluate TC levels in relation to spatially localized UHI patterns. Comprehensive analyses of TC and UHI intensity will be conducted to characterize environmental conditions across multiple urban sites.

METHODOLOGY

Figure 1 illustrates the flow diagram outlining the methodology adopted in this study. The first step involved identifying a suitable study location that meets two criteria: proximity to Universiti Kebangsaan Malaysia (UKM) and the presence of notable thermal stress due to high ambient temperatures. Putrajaya was selected as the study area, as it not only attracts a significant number of tourists but is also recognized as one of the hottest urban regions in Malaysia. Recent records indicate that Putrajaya has experienced peak temperatures of up to 38.5 °C, largely attributed to the UHI effect (Harun et al. 2024). Following the site selection, the study was designed to investigate both the UHI phenomenon and its implications for TC, thereby allowing for a more comprehensive analysis. The next phase involved determining the necessary environmental parameters for data collection, which included ambient temperature, relative humidity, wet bulb globe temperature (WBGT), and air velocity. Data were then collected and subjected to analysis. If the initial dataset was deemed insufficient or inconclusive, additional rounds of data collection were conducted to ensure accuracy and reliability. Once the data quality was confirmed to be satisfactory, the collection phase was concluded.

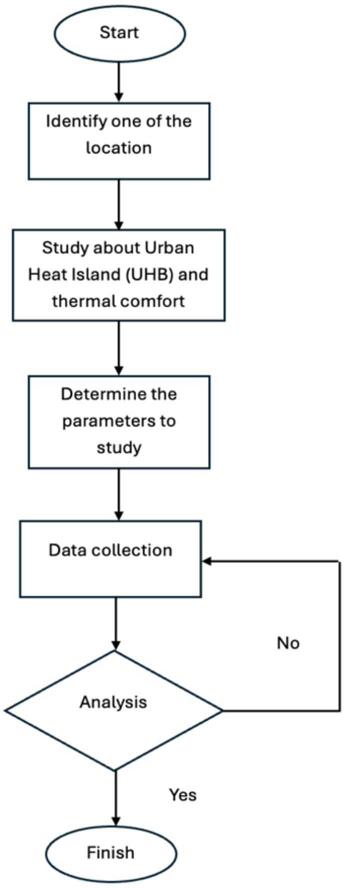
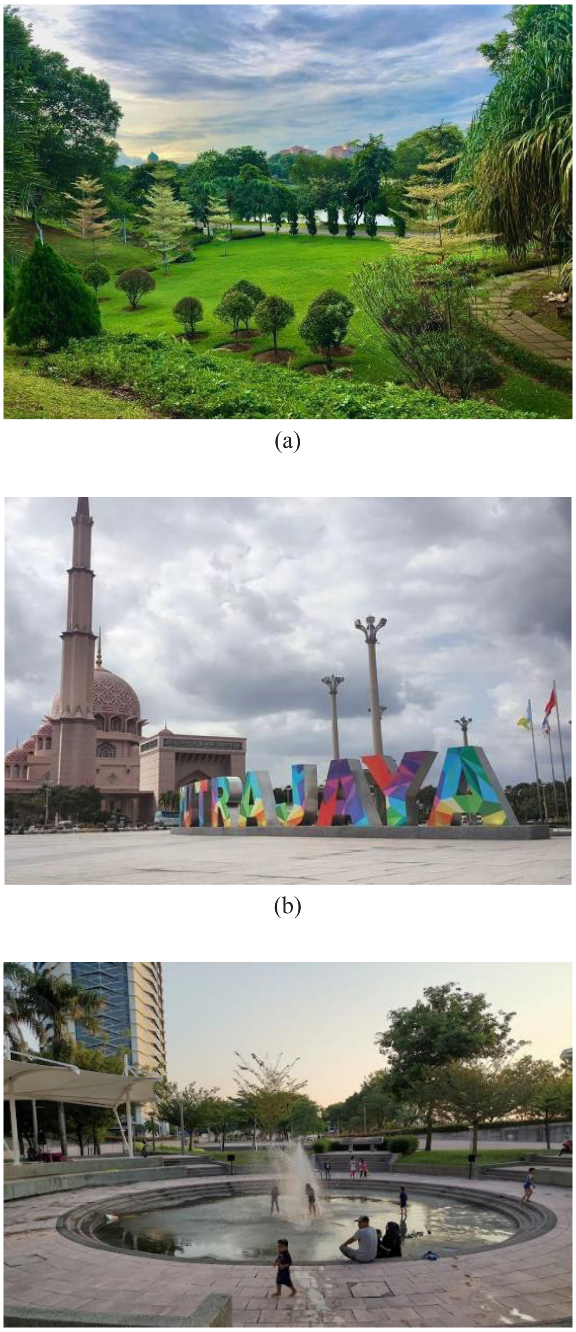


FIGURE 1. Flow chart of the study

The selected measurement locations include Dataran Gemilang, Dataran Putra, and Taman Wawasan Halaman—three prominent urban public spaces in Putrajaya that are subject to varying levels of solar radiation and diverse built environment configurations, as illustrated in Figure 2 a), b) and c). Data collection was conducted in situ across these locations, with measurements taken during three distinct time intervals: morning (8:00 a.m. to 10:00 a.m.), noon (11:00 a.m. to 1:00 p.m.), and afternoon(2:00 p.m. to 4:00 p.m.). These time intervals were chosen to capture the diurnal variation in thermal conditions and to reflect periods of peak public space usage. The experimental setup was configured to simulate naturally ventilated environments, thereby enabling an accurate evaluation of both outdoor and semi-outdoor TC conditions.



(a)

(b)

(c)

FIGURE 2. Place chosen for data collection a)Dataran Gemilang b)Dataran Putrajaya c) Taman Wawasan

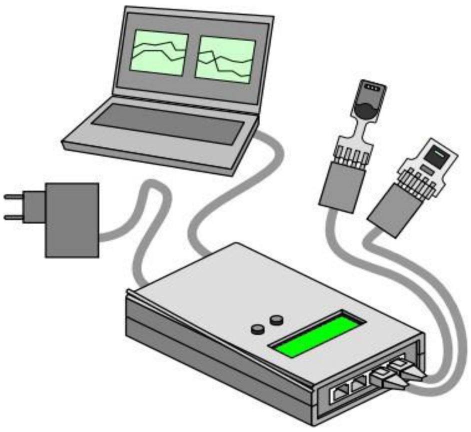


FIGURE 3. EK-H4 data logger

FIGURE 4. Thermal Comfort Station (TCS) to assess UHI and TC

In this study, the EK-H4 data logger, as illustrated in Figure 3, is employed as the main instrument for collecting environmental data relevant to TC assessment and UHIs analysis. The EK-H4 data logger is utilized to measure key microclimatic parameters including air temperature and relative humidity. Additional parameters such as mean radiant temperature and air velocity are obtained using a Wet Bulb Globe Temperature (WBGT) sensor and an anemometer, integrated within the Thermal Comfort Station (TCS), as shown in Figure 4. These environmental variables are essential for evaluating TC using standardized indices. All measurements are conducted under naturally ventilated conditions to ensure an accurate representation of the outdoor environmental context.

Following the field data collection phase, the recorded environmental parameters are transferred to a computer for subsequent analysis. This is accomplished by connecting the EK-H4 data logger to the computer's central processing unit via a dedicated data cable. The EK-H4 V1.0 software is then used to facilitate the data transfer process. Upon launching the software, the connected device is automatically detected, and the relevant datasets are opened for visualization. This interface allows for a preliminary review and verification of the collected data before proceeding to detailed analysis. The processed data will be used to assess spatial and temporal variations in TC across the study sites and to compute TC indices such as the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD).

To calculate the PMV index—an essential metric for evaluating TC—the measured environmental parameters, including air temperature, mean radiant temperature, relative humidity, and air velocity, are imported into Microsoft Excel. Once these parameters are entered, Equation (1), representing the PMV calculation in accordance with ISO 7730 and ASHRAE Standard 55-1992, is applied. Following the PMV computation, the PPD index is derived using Equation (2), also implemented within the Excel spreadsheet. A PMV versus PPD graph is subsequently generated to visualize the distribution of TC responses across the collected data points, thereby enabling a clearer interpretation of comfort conditions in the study area.

$$PMV = (0.303 \times e^{-0.036M} + 0.028)$$

$$\begin{bmatrix} (M-W) - 3.05x10^{-3}[5733 - 6.99(M-W) - p_a] - 0.42[(M-W) - 58.15] - 1.7x10^{-5}M \\ (5867 - p_a) - 0.0014(34 - t_a) - 0.0014M(34 - t_a) - 3.96\times10^{-8} f_{cl}\,[(t_{cl} + 273)^4 - (t_r - \\ 273)^4] - f_{cl} h_c (t_{cl} - t_a) \end{bmatrix} \quad (1)$$

Where,
$I_{cl.}$ = thermal insulation of clothes (1Clo 0.155 m^2K/W)
fcl = Clothing surface area factor
t_a = Temperatures (°C)
t_r = Average radian temperature (°C)
v_{ar} = Relative air velocity (m/s)
p_a = steam pressure on ambient air (kPa)
p_s = water saturated steam pressure (Pa)
h_c = Convection heat transfer coefficient (W/m^2K)
t_{cl} = surface temperature of clothing (°C)

The PPD value is represented as a function of PMV based on the equation below:

$$PPD = 100 - 95exp - (0.3353PMV^4 + 0.2719PMV^2) \quad (2)$$

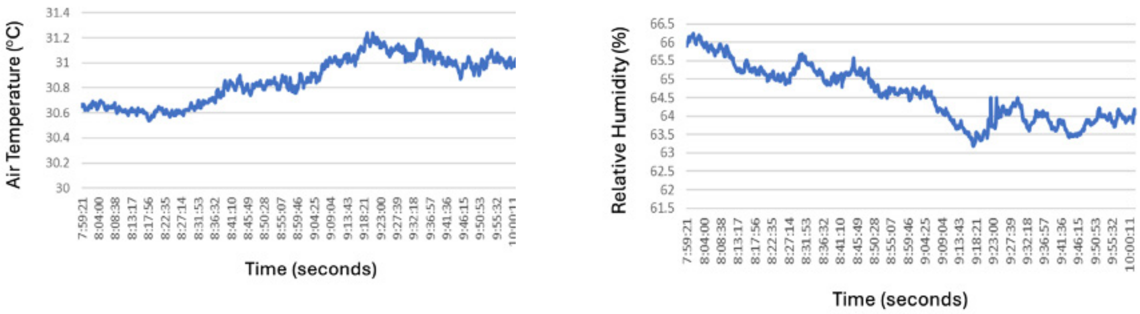
Moreover, the dataset is further analyzed by plotting the measured parameters onto a psychrometric chart to identify zones that fall within the established TC range. This graphical representation facilitates the evaluation of environmental conditions in relation to the comfort zones defined by ASHRAE Standard 55-1992. By visualizing the data in this manner, the analysis provides additional insight into the thermal environment experienced at the study locations, enabling the identification of specific periods and areas that align with or deviate from optimal comfort conditions.

RESULTS AND DISCUSSION

Environmental parameters such as relative humidity, dew point temperature, air temperature, mean radiant temperature, and air velocity were measured in advance as part of the data collection process. These parameters were subsequently used to calculate the PMV and PPD values. Data were recorded at 10-second intervals to ensure high temporal resolution. Measurements were conducted during three distinct time periods to capture diurnal variations: morning (8:00 a.m. to 10:00 a.m.), noon (11:00 a.m. to 1:00 p.m.), and afternoon (2:00 p.m. to 4:00 p.m.).

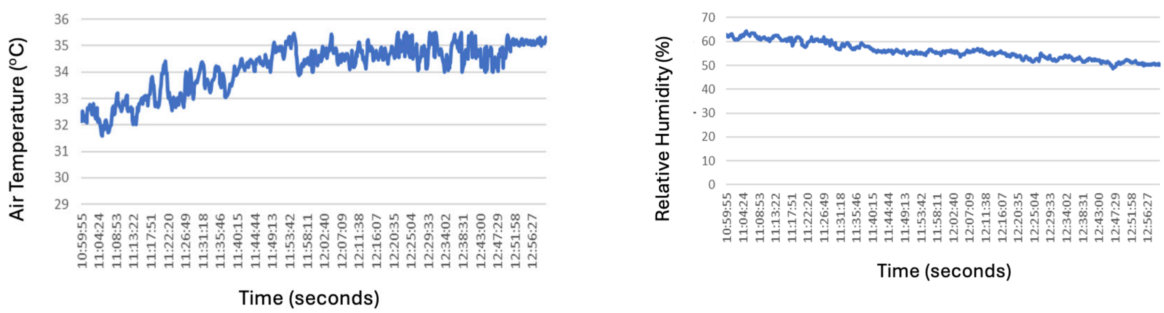
HEAT ISLAND ANALYSIS

1. Dataran Gemilang



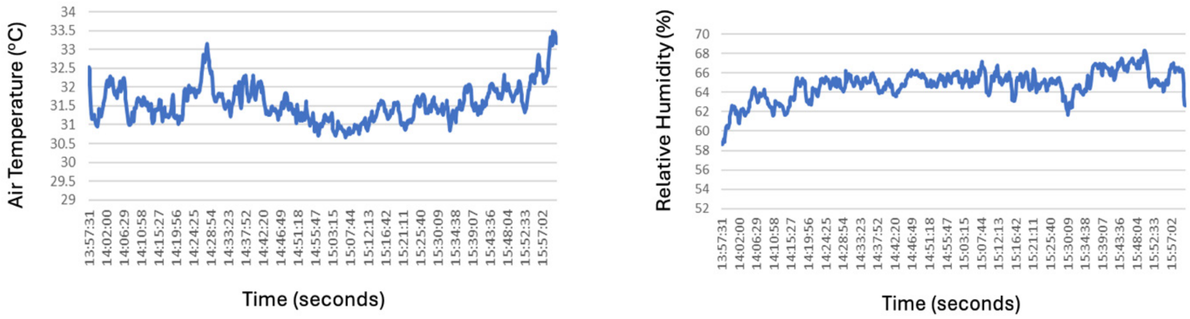
(a) (b)

FIGURE 5. Morning distribution of data in Dataran Gemilang for a) temperature and b) relative humidity



(a) (b)

FIGURE 6. Noon distribution of data in Dataran Gemilang for a) temperature and b) relative humidity

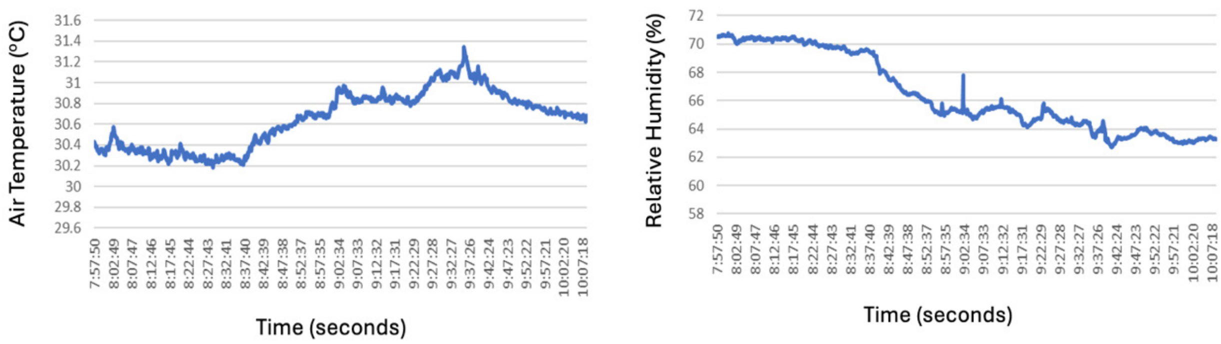


(a) (b)

FIGURE 7. Afternoon distribution of data in Dataran Gemilang for a) temperature and b) relative humidity

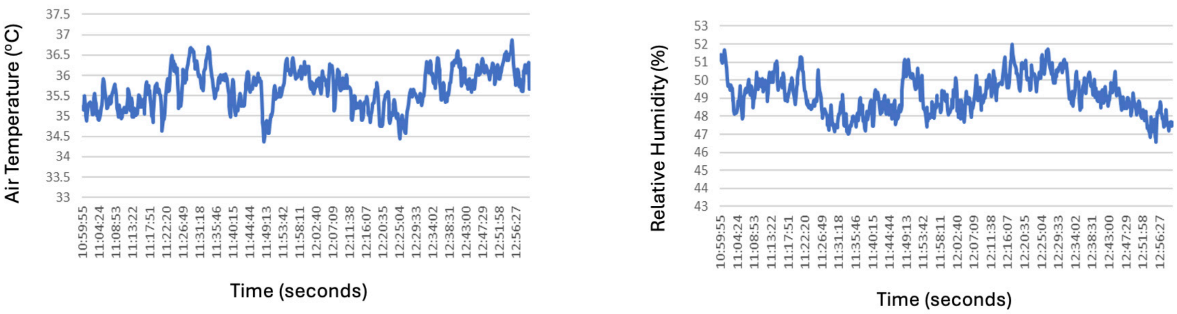
As illustrated in Figure 5a), the highest recorded air temperature between 8:00 a.m. and 10:00 a.m. was 31.2 °C, while the peak relative humidity during this period was 66.3%, as shown in Figure 5b). From 11:00 a.m. to 1:00 p.m., the temperature reached a maximum of 35.2 °C (Figure 6a)), with a corresponding highest relative humidity of 64% (Figure 6b)). Later in the afternoon, as depicted in Figure 7a), the maximum temperature was 33.5 °C, and the highest relative humidity recorded was 68.3% (Figure 7b)). These results indicate that Dataran Gemilang experienced its peak temperature during noon hours and humidity levels predominantly during late afternoon.

2. Dataran Putrajaya



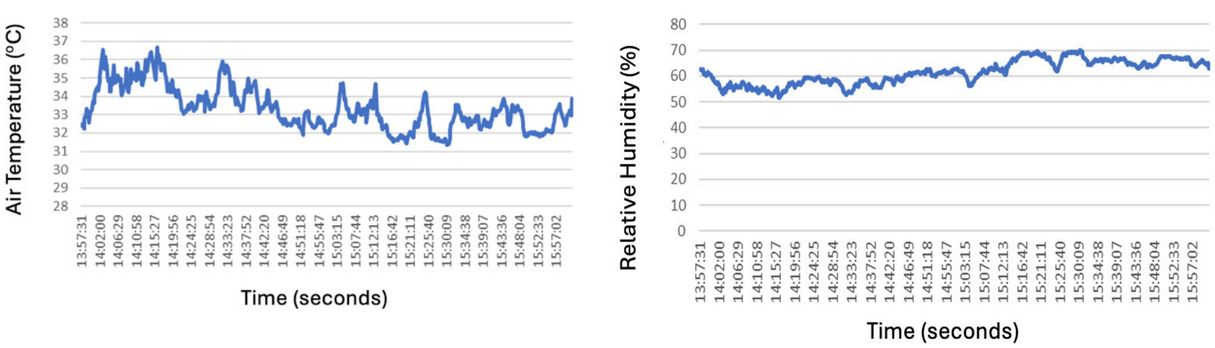
(a) (b)

FIGURE 8. Morning distribution of data in Dataran Putrajaya for a) temperature and b) relative humidity



(a) (b)

FIGURE 9. Noon distribution of data in Dataran Putrajaya for a) temperature and b) relative humidity

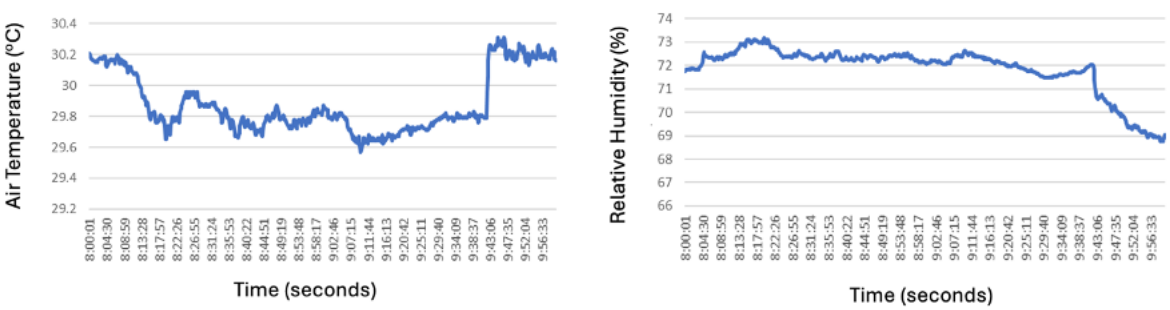


(a) (b)

FIGURE 10. Afternoon distribution of data in Dataran Putrajaya for a) temperature and b) relative humidity

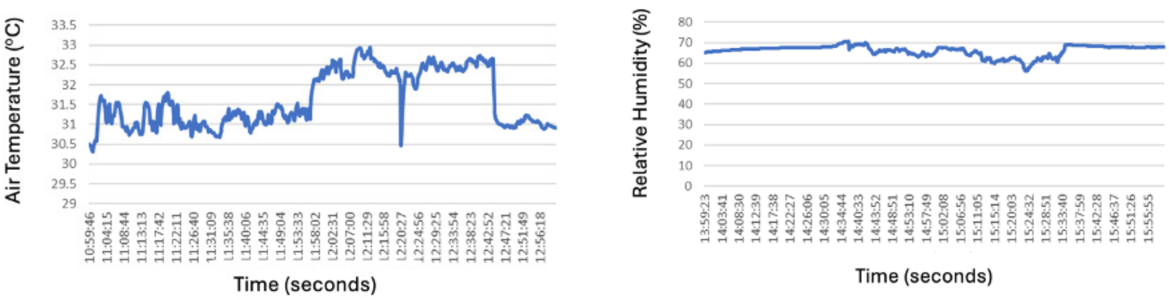
Figure 8a) displays the morning temperature profile, where the highest temperature recorded between 8:00 a.m. and 10:00 a.m. was 31.3 °C, with the relative humidity peaking at 70.5%, as seen in Figure 8b). During the midday period (11:00 a.m. to 1:00 p.m.), temperatures rose significantly, reaching a maximum of 36.9 °C (Figure 9a)), while relative humidity decreased to 52%, as shown in Figure 9b). In the subsequent period (2:00 p.m. to 4:00 p.m.), the highest temperature recorded was 36.7 °C (Figure 10a)), and the peak relative humidity was 70% (Figure 10b)). These data suggest that Dataran Putra experienced its highest temperatures during the midday period, with relative humidity highest in the early morning.

3. Taman Wawasan



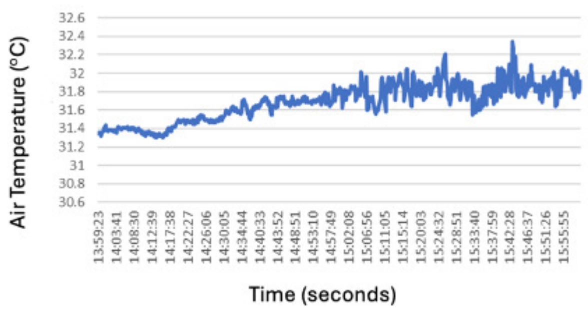
(a) (b)

FIGURE 11. Morning distribution of data in Taman Wawasan for a) temperature and b) relative humidity

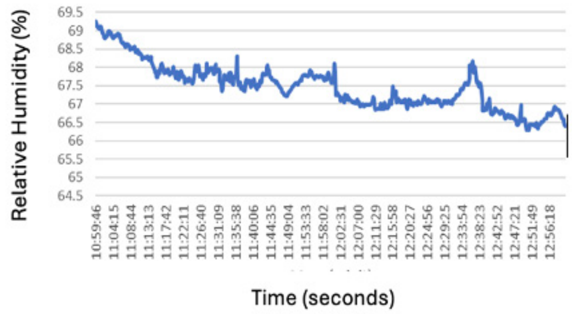


(a) (b)

FIGURE 12. Noon distribution of data in Taman Wawasan for a) temperature and b) relative humidity



(a)



(b)

FIGURE 13. Afternoon distribution of data in Taman Wawasan for a) temperature and b) relative humidity

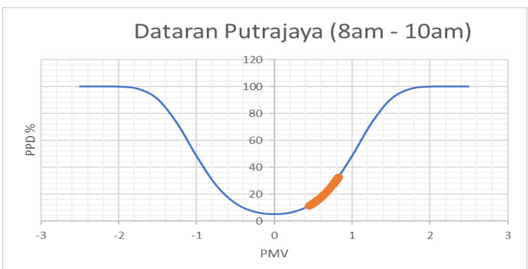
According to Figure 11a), the maximum air temperature recorded between 8:00 a.m. and 10:00 a.m. was 30.3 °C, with relative humidity reaching 73.2%, as shown in Figure 11b). By midday (11:00 a.m. to 1:00 p.m.), the temperature rose to a high of 33.0 °C (Figure 12a)), accompanied by a peak relative humidity of 69.3% (Figure 12b)). In the late afternoon (2:00 p.m. to 4:00 p.m.), Figure 13a) shows a slightly lower maximum temperature of 32.3 °C, while relative humidity increased to 70.1% (Figure 13b)). These observations indicate that Taman Wawasan experienced its highest thermal load during noon, with notable humidity levels persisting throughout the day, particularly in the early morning.

Based on the graphical distribution of temperature and relative humidity data, it is evident that ambient temperatures are lower during the morning hours, while relative humidity is comparatively higher. As the day progresses toward noon and afternoon, the temperature increases, accompanied by a corresponding decrease in relative humidity. This inverse relationship occurs because rising air temperatures enhance the atmosphere's capacity to hold moisture, thereby reducing the relative humidity percentage even if the absolute moisture content remains unchanged.

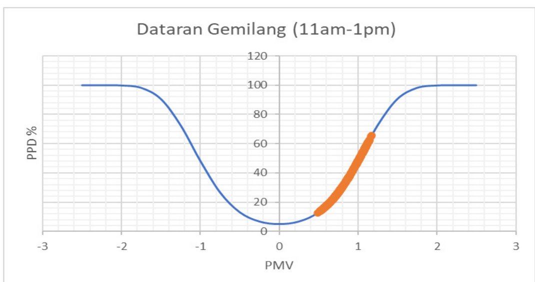
PMV AND PPD ANALYSIS

The PMV and PPD analysis was carried out using the Equation 1 and 2. These values are calculated using Microsoft Excel software which is then analyzed in the form of PMV graph against PPD.

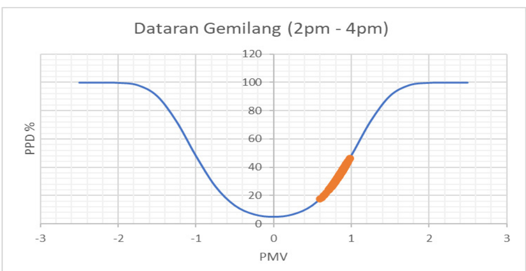
1. Dataran Gemilang



(a)



(b)



(c)

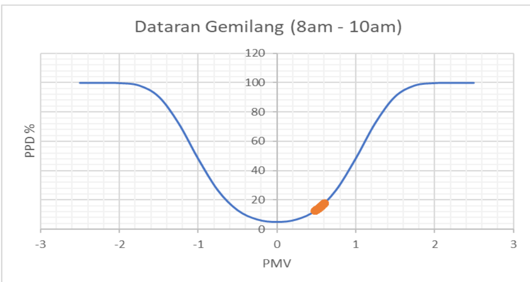
FIGURE 14. PMV and PPD values for Dataran Gemilang in a) the morning, b) noon and c) afternoon.

A person is generally considered to be in a thermally comfortable state when the PMV value falls within the range of -1 to +1, commonly referred to as the TC range. As we can see in Figure 14 a), during the morning period, aided by natural ventilation, the PMV values recorded were within this comfort range, and the corresponding PPD values were below 40%. This can be attributed to lower ambient temperatures and a cooler overall environment during the early hours.

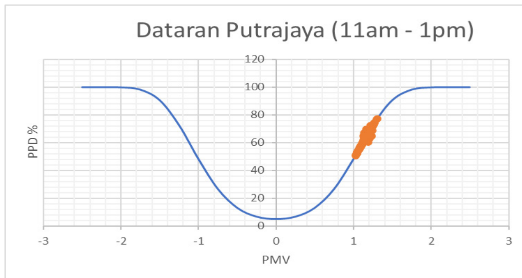
In contrast, the midday period exhibited PMV values outside the comfort range. PPD values during this time approached 70%, indicating significant thermal discomfort among occupants (Figure 14 b)). This outcome is largely due to the high average temperature recorded at Dataran Gemilang, reaching up to 34 °C, coupled with a relatively low average humidity level of 56%.

During the afternoon as displayed in Figure 14 c), the PMV values returned to within the comfort range, while the PPD values indicated less than 50% dissatisfaction. Although initial temperatures remained relatively high, a gradual decrease in temperature and a concurrent increase in relative humidity contributed to improved thermal conditions, thus bringing the PMV values back within acceptable tolerance limits.

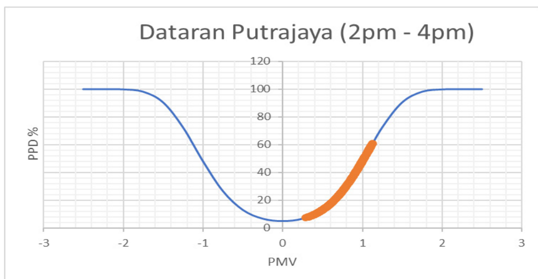
2. Dataran Putrajaya



(a)



(b)



(c)

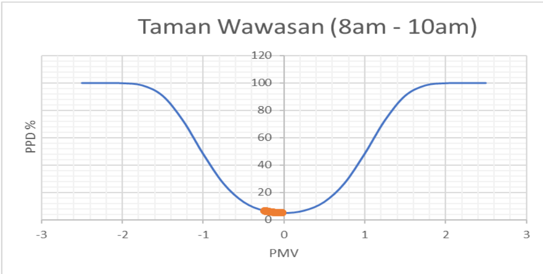
FIGURE 15. PMV and PPD values for Dataran Putrajaya in a) the morning, b) noon and c) afternoon.

Figure 15 a) presents the graphical distribution of TC data collected at Dataran Putrajaya across three time intervals: morning, noon, and afternoon. During the morning period, the PMV values largely fell within the TC range, and the corresponding PPD values indicated less than 20% dissatisfaction, suggesting a generally comfortable thermal environment.

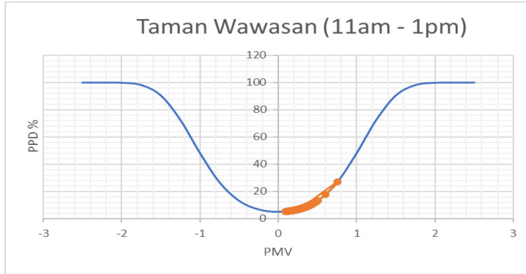
However, at noon, a significant portion of the data points fell outside the comfort range as shown in Figure 15 b). The PPD readings approached 80%, reflecting widespread thermal discomfort. This elevated discomfort level is likely attributable to increased vehicular activity in the area during midday, which contributes to higher carbon dioxide emissions and a corresponding rise in ambient temperature.

In the afternoon (Figure 15 c)), the most of PMV data predominantly inside the comfort range, and PPD values were recorded at below 70%. Although a slight decrease in temperature was observed during this period, the overall distribution of PMV and PPD values indicates that thermal conditions remained relatively warm, contributing to continued discomfort in the area during the late afternoon.

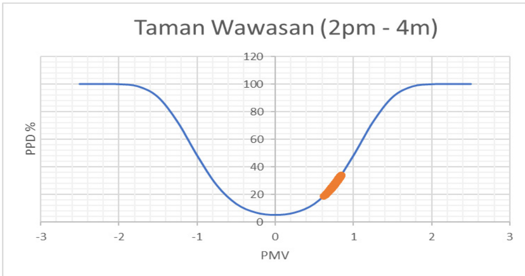
3. Taman Wawasan



(a)



(b)



(c)

FIGURE 16. PMV and PPD values for Taman Wawasan in a) the morning, b) noon and c) afternoon.

Figure 16a), b) and c) illustrates the graphical distribution of TC data recorded at Taman Wawasan during the morning, noon, and afternoon periods. The PMV readings throughout the day remained within the established TC range, and the PPD values indicated less than 40% dissatisfaction. These favorable results can be attributed to the extensive presence of vegetation, particularly mature trees, which dominate the landscape in Taman Wawasan. Trees play a critical role in regulating microclimates by absorbing excess carbon dioxide (CO_2) from the atmosphere and providing shade. Notably, it has been reported that trees occupying an area of approximately 0.4 hectares can absorb an amount of CO_2 equivalent to the emissions produced by approximately 26,000 train miles. Additionally, studies conducted by urban climatologists have shown that daytime temperatures beneath tree canopies are typically 2°C to 3°C lower compared to adjacent open spaces. These factors collectively contribute to improved thermal conditions and enhanced comfort levels in Taman Wawasan.

COMFORT ANALYSIS ON PSYCHROMETRIC CHARTS

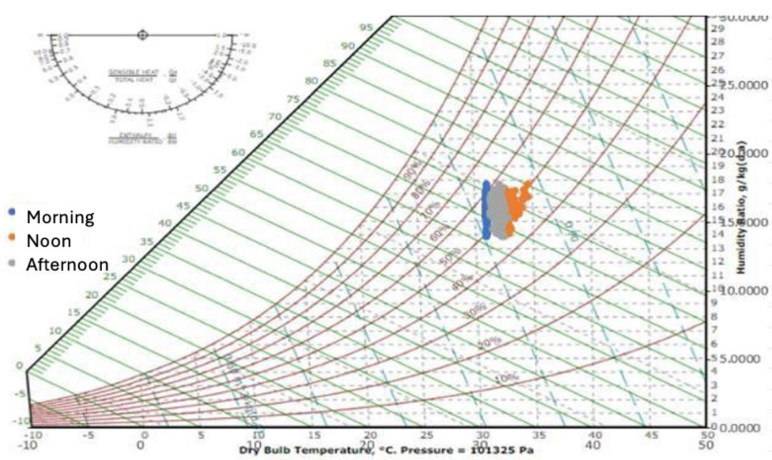


FIGURE 17. Distribution of TC on the Psychrometric Chart of Dataran Gemilang

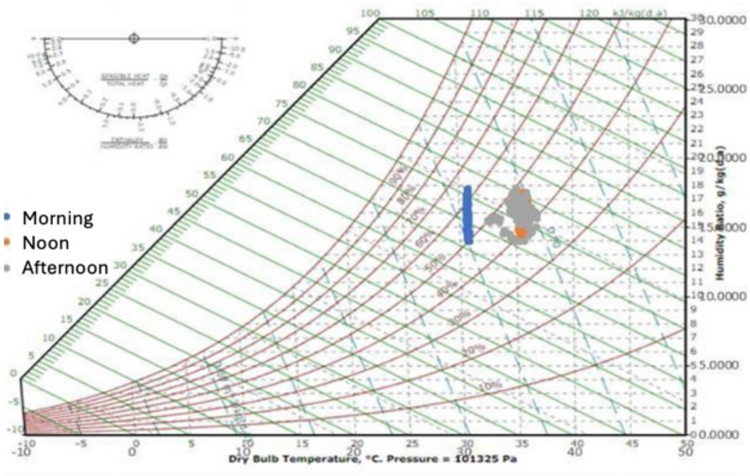


FIGURE 18. Distribution of TC on the Psychrometric Chart for Dataran Putrajaya

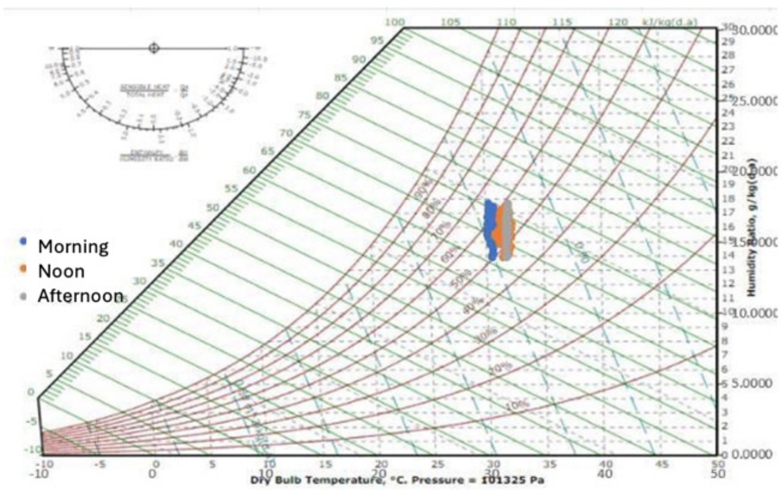


FIGURE 19. Distribution of TC on the Psychrometric Chart for the Taman Wawasan.

The data for each location represent a combination of measurements taken during the morning, noon, and afternoon periods. It is assumed that all measurements were conducted at standard atmospheric pressure (1 atm = 101.325 kPa), which serves as the basis for plotting the psychrometric chart.

Based on Figure 17, the average temperature at Dataran Gemilang was approximately 32 °C, with an average relative humidity of 61%. The recorded temperature ranged from 31 °C to 35 °C, while relative humidity varied between 40% and 70%.

At Dataran Putrajaya, as shown in Figure 18, the average temperature was 33 °C, with an average relative humidity of 59%. The observed temperature ranged from 30 °C to 36.5 °C, and relative humidity values spanned from 38% to 52%.

In contrast, Taman Wawasan, as illustrated in Figure 19, recorded a lower average temperature of 31 °C and a higher average relative humidity of 68%. Temperature readings ranged from 29 °C to 32.5 °C, while relative humidity varied between 45% and 70%. These findings suggest that, despite elevated temperatures in certain locations, TC remains achievable—particularly in areas with higher humidity and shading, such as Taman Wawasan.

CONCLUSION

The existence of the UHI phenomenon in Putrajaya is evident based on the graphical trends of air temperature and relative humidity over time. Observations indicate that temperatures in Dataran Gemilang, Dataran Putrajaya, and Taman Wawasan increase markedly during the afternoon hours, while relative humidity concurrently declines. This inverse relationship highlights the influence of rising ambient temperatures on humidity levels, which is characteristic of UHI effects. Several adverse impacts of the UHI phenomenon have been identified:

1. A reduction in human comfort due to elevated temperatures, which interferes with daily activities.
2. Increased energy consumption for cooling purposes, contributing to higher greenhouse gas emissions.
3. A heightened risk of heat-related illnesses, including heat stroke.

The PMV analysis further reveals spatial and temporal variations in TC across the study sites. At Dataran Gemilang, PMV values remained within the comfort range (–1 to +1) during the morning. However, these values shifted to between +0.4 and +1.3 in the noon, and +0.4 to +1.2 in the noon, reflecting rising ambient temperatures during these periods. Similarly, at Dataran Putrajaya, the morning PMV values were within the comfort range (–1 to +1), while in the noon, they increased to between 0 and +1.4, and in the noon ranged from +0.2 to +1.2.

In contrast, Taman Wawasan consistently recorded PMV values within the TC range (+1 to –1) across all time intervals. This can be attributed to the site's environmental characteristics, including extensive vegetation and shading, which contribute to improved microclimatic conditions.

The findings suggest that optimal TC can be achieved when ambient temperatures are maintained between 25 °C and 29 °C, with relative humidity levels ranging from 70% to 80% and air velocity between 0.3 m/s and 1.0 m/s. Based on these thresholds, Taman Wawasan remains thermally comfortable throughout the day, while Dataran Gemilang and Dataran Putrajaya exhibit comfort primarily during the morning hours.

According to the psychrometric chart, a concentration of temperatures around 29 °C—particularly evident at Taman Wawasan—supports favorable comfort conditions. However, the distribution of thermal data varies significantly across locations, influenced by the unique physical and environmental features of each site. Based on the results, the study will present practical recommendations and sustainable urban design interventions aimed at reducing UHI effects and improving indoor thermal comfort. The findings are expected to provide valuable insights for urban planners, architects, and policymakers committed to enhancing liveability in Malaysia's rapidly urbanizing regions.

ACKNOWLEDGEMENT

The research has been funded by the Ministry of Higher Education (MOHE) Malaysia, Malaysia under the Fundamental Research Grant Scheme with grant number FRGS/1/2021/TK0/UKM/03/2. It is also partly funded by Universiti Kebangsaan Malaysia (UKM), Malaysia under the grant GGPM-2021-008.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Arifwidodo, S. D., Chandrasiri, O., Abdulharis, R., & Kubota, T. 2020. Exploring the effects of urban heat island: A case study of two cities in Thailand and Indonesia. *APN Science Bulletin* 9(1). https://doi.org/10.30852/sb.2019.539

de Dear, R., Xiong, J., Kim, J., & Cao, B. 2020. A review of adaptive thermal comfort research since 1998. *Energy and Buildings* 214: 109893. https://doi.org/10.1016/j.enbuild.2020.109893

Doreen, K., et al. 2021. Urban heat exposure and vulnerability in East African cities. *Climate* 9(4): 51. https://doi.org/10.3390/cli9040051

Elkhazindar, S., Abdelalim, A., Elmasry, S., Mohamed, A. A., & Fadli, F. 2022. The effect of urban form on the heat island phenomenon and human thermal comfort: A comparative study of UAE residential sites. *Energies* 15(15): 5471. https://doi.org/10.3390/en15155471

Enescu, D. 2017. A review of thermal comfort models and indicators for indoor environments. *Renewable and Sustainable Energy Reviews* 79: 1353–1379. https://doi.org/10.1016/j.rser.2017.05.175

Goggins, W. B., Chan, E. Y. Y., & Kim, J. J. 2012. Association between daily ambient temperature and hospital admissions in Hong Kong. *PLOS ONE* 7(3): e30559. https://doi.org/10.1371/journal.pone.0030559

Hanafiah, A. 2019. Urban heat island phenomenon in Penang Island, Malaysia (Master's thesis). *Universiti Utara Malaysia. Journal of Innovation and Applied Sciences*, 7, 1–13.

Harun, Z., Akkurt, N., & Lotfy, E. R. 2024. Urban heat island patterns in garden cities: Putrajaya as a case study. *Indoor and Built Environment*. https://doi.org/10.1177/1420326X24124445

Hashim, N. M. 2010. Analisis tren pemanasan global dan kesannya terhadap aspek dayahuni bandar di

Malaysia: The impact of global warming trends on urban livability in Malaysia—An analysis. *GEOGRAFIA Online Malaysia Journal of Society and Space* 2(2): 72–88. https://journalarticle.ukm.my/799/1/7.2010-2-Norazwan-melayu-1.pdf

Imran, H. M., Kala, J., Ng, A. W. M., & Ghafourian, A. 2019. Urban heat island intensity and its spatial variability in Melbourne, *Australia. Sustainable Cities and Society* 46: 101412. https://doi.org/10.1016/j.scs.2019.101412

Lai, D., Liu, W., Gan, T., Liu, K., & Chen, Q. 2019. A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of the Total Environment* 661: 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062

Maghrabi, A., Mohamed, M. F., Raman, S. N., Mat Sulaiman, M. K. A., Mohammad Yusoff, W. F., & Abuhussain, M. A. 2022. *A review: Urban heat island and its impact on building energy consumption*. *Jurnal Kejuruteraan* 34(4): 553–563.

Santamouris, M. 2015. Regulating the damaged thermostat of the cities—Status, impacts and mitigation challenges. *Energy and Buildings* 91: 43–56. https://doi.org/10.1016/j.enbuild.2015.01.027

Vujovic, S., Haddad, B., Karaky, H., Sebaibi, N., & Boutouil, M. 2021. Urban heat island: Causes, consequences, and mitigation measures with emphasis on reflective and permeable pavements. *CivilEng* 2(3): 459–484. https://doi.org/10.3390/civileng2020026

Yahya, M. S., et al. 2022. Modelling the spatial variation of urban heat island in Kuala Lumpur. *Sustainability* 14(13): 8182. https://doi.org/10.3390/su14138182

Zaki, S. A., et al. 2023. Outdoor thermal comfort and human perception in Kuala Lumpur. *Atmosphere* 14(5): 852. https://doi.org/10.3390/atmos14050852