

Influence of Environmental Factors and Heat Island Intensity on Outdoor Thermal Comfort Among Residents in Section 7, Shah Alam, Selangor, Malaysia

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ARTICLE INFO

Received: 12 Jun 2025
Received in revised: 16 Feb 2026
Accepted: 24 Feb 2026
Published online: 29 May 2026
DOI: 10.32526/ennrj/24/20250150

Keywords:

Urban microclimate/ Urban heat island intensity/ Outdoor thermal comfort/ Physiological equivalent temperature/ Heat stress

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ABSTRACT

The aim of this study was to investigate the influence of meteorological factors and urban heat island intensity (UHII) on outdoor thermal stress among residents in Section 7, Shah Alam, Selangor. Meteorological data, including temperature, relative humidity, and wind speed, were collected for Shah Alam from April to September 2024. The UHII was determined by subtracting the surrounding rural temperature from the urban temperature. The physiological equivalent temperature (PET) was calculated using RayMan software, and statistical analyses were conducted using the Statistical Package for the Social Sciences version 28. The UHII in Shah Alam ranged from 0°C to 3.7°C, with a mean of $0.743 \pm 0.687^\circ\text{C}$. The PET analysis indicated that 57.9% of the respondents reported warm perception of their environment (moderate heat stress), with PET values among respondents ranging from 25.90 to 32.00 and a mean of 29.121 ± 1.235 . A strong positive correlation was observed between temperature and PET ($r=0.835$, $p<0.001$), as well as a moderate positive correlation between UHII and PET ($r=0.404$, $p<0.001$), while a negative relationship was found between relative humidity and PET ($r=-0.579$, $p<0.001$). Temperature ($B=1.160$, $p<0.001$) and wind speed ($B=-0.911$, $p<0.001$) were significant predictors of PET among residents in Shah Alam. In conclusion, temperature and wind speed significantly influence outdoor thermal comfort in Section 7, Shah Alam. Local authorities should implement mitigation measures such as integrated urban planning, expanded green spaces and infrastructure, and sustainable land use, which can be effective solutions to reduce UHII and air temperature while enhancing wind flow and outdoor thermal comfort in urban areas.

HIGHLIGHTS

- The study found that Shah Alam exhibited a UHII between 0°C and 3.7°C.
- 57.9% of the respondents in Shah Alam experienced moderate heat stress.
- There were significant relationships among temperature, relative humidity, and UHII with PET ($p<0.001$).
- An increase in temperature in Shah Alam would lead to an increase in the PET value ($B=1.160$, $p<0.001$).
- An increase in wind speed in Shah Alam would lead to a decrease in the PET value ($B=-0.911$, $p<0.001$).

1. INTRODUCTION

Rapid urbanization has significantly altered local microclimates, particularly in urban areas where air temperature has risen dramatically. This increase has raised concerns about urban heat islands (UHIs) and the thermal performance of open spaces within

city areas (Ishak et al., 2023). Thermal comfort and air temperature levels are influenced by factors such as building mass, canopy height, and spatial arrangement, which are closely related to the built-up areas in urban settings (Eslamirad et al., 2023).

The intensification of UHI effects poses

Citation: Mohamed N, Zeini NFAM, Anwar NIHK, Aminuddin MAM. Influence of environmental factors and heat island intensity on outdoor thermal comfort among residents in Section 7, Shah Alam, Selangor, Malaysia. Environ. Nat. Resour. J. 2026;24(4):459–468. (<https://doi.org/10.32526/ennrj/24/20250150>)

additional challenges to outdoor thermal comfort, primarily due to rising air temperature and heatwaves in urban areas (Eslamirad et al., 2023; Ren et al., 2023). Compared to suburban and rural regions, urban areas experience significantly warmer conditions, which can compromise the health and safety of city dwellers due to poor thermal comfort (Kalogeropoulos et al., 2022). This decline in comfort negatively affects the quality of life in urban space, residents' satisfaction, and overall urban thermal performance (Aghamolaei et al., 2023; Kalogeropoulos et al., 2022). Prolonged exposure to a poor thermal comfort environment may increase the risk of heat-related illnesses, such as heat exhaustion and heat stroke, among the urban population (Abdel-Ghany et al., 2013; Kurazumi et al., 2019). Therefore, understanding the relationship between environmental factors and UHI effects on thermal comfort is essential. Such understanding can enable authorities to develop effective mitigation strategies to address outdoor thermal stress, ultimately protecting residents from adverse health outcomes.

In addition, outdoor thermal comfort can be evaluated using the physiological equivalent temperature (PET), a thermal index that estimates the thermal component within a given environment (Deb and Alur, 2010). Physiological equivalent temperature reflects the relationship between the atmospheric environment and human thermal perception by integrating various meteorological factors, such as air temperature, relative humidity, and wind speed (Matzarakis and Mayer, 1996). Among various thermal indices, PET is the most widely used for assessing outdoor thermal comfort and has proven effective in evaluating thermal exposure in urban settings (Gomaa et al., 2024; Ren et al., 2023).

This study aims to investigate the influence of meteorological factors and urban heat island intensity (UHII) on outdoor thermal stress, as measured by the PET among residents in Section 7, Shah Alam, Selangor. The research focuses on analyzing the relationship among UHII, key meteorological factors, and PET values. The PET values can be translated into thermal sensation and physiological stress levels, representing outdoor thermal comfort among residents in Shah Alam, Selangor. Additionally, this study seeks to determine the predictive factors for PET, which may support the development of targeted mitigation measures to address the thermal impacts of urbanization in Shah Alam.

2. METHODOLOGY

2.1 Study area

This study was conducted in Section 7, which is located within Shah Alam, the state capital of Selangor, Malaysia, specifically in the commercial and recreational areas of Shah Alam, where the population is frequently exposed to outdoor environments. Shah Alam is an urban area under the jurisdiction of Shah Alam City Council. Section 7, Shah Alam, is a rapidly urbanizing area in Selangor, Malaysia, featuring dense development, educational hubs like Universiti Teknologi MARA (UiTM), and a tropical rainforest climate (Shah Alam City Council, 2025). Its mix of infrastructure, green spaces, and strategic locations makes it a key site for studying UHIs, land use changes, and sustainable city planning (Department of Statistics Malaysia, 2023). Figure 1 shows the location of the study in Shah Alam.

2.2 Data collection

This study involved the collection of six months of meteorological data (April-September 2024), including temperature, relative humidity, and wind speed for Shah Alam, Selangor. Since Shah Alam does not have its own meteorological station, data from the nearest available station, Subang Jaya Meteorological Station, located approximately 7 km away, was used to represent the meteorological conditions in Shah Alam. A limitation of using meteorological data from Subang Jaya is that the data may not entirely represent local microclimates, such as wind and rainfall in Shah Alam. The use of meteorological data from Subang Jaya Meteorological Station was considered due to several factors: Both areas are classified as urban areas, the distance between the two locations is less than 10 km, and both areas are exposed to Malaysia's similar tropical climate, which is unlikely to vary greatly between them. Additionally, temperature data from a reference rural station, Pusat Pertanian Kalimpan in Hulu Selangor, were obtained to calculate the UHII for Shah Alam. The UHII was determined by subtracting the surrounding rural/suburban temperature from the urban temperature, as shown in Equation 1 (Ramakreshnan et al., 2019).

$$UHII = T_{\text{urban}} - T_{\text{rural}} \quad (1)$$

Where; UHII=Urban heat island intensity;
 T_{urban} =Average air temperature in the urban area;
 T_{rural} =Average air temperature in the nearby rural area

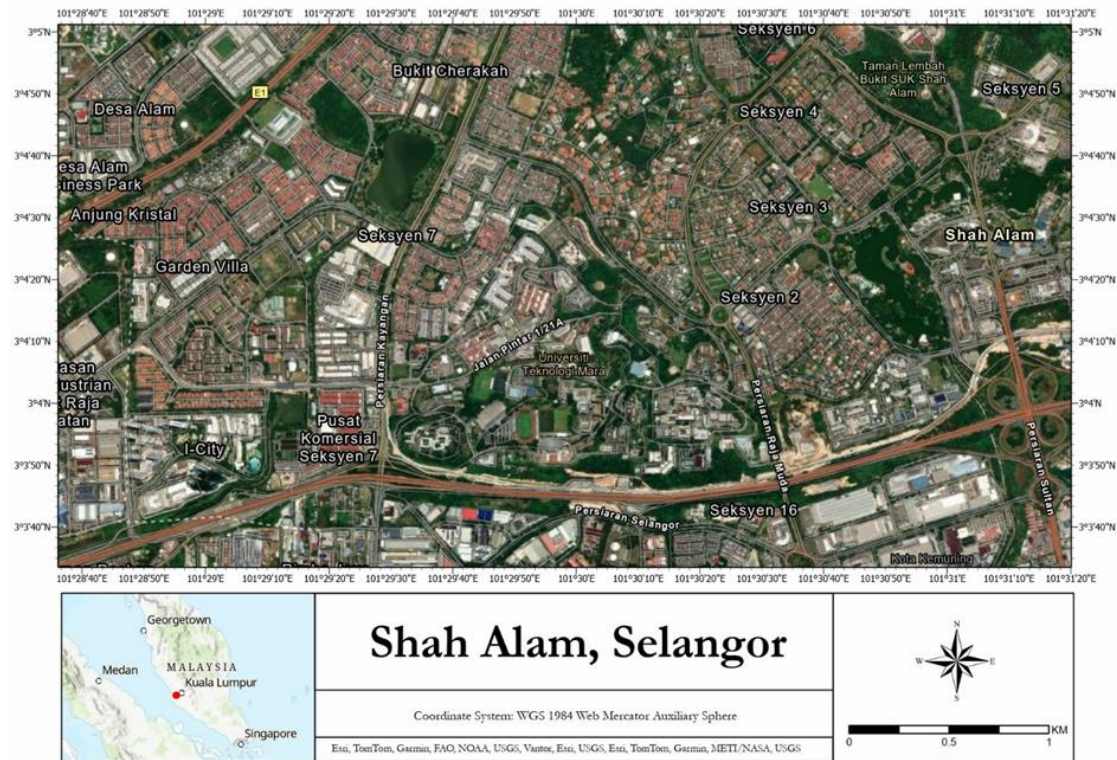


Figure 1. Study location in Shah Alam (Source: WGS 1984 Web Mercator Auxiliary Sphere)

Physiological equivalent temperature was calculated using RayMan software, which simulates the human thermal environment based on temperature, relative humidity, and wind speed from meteorological data and residents' information (height, weight, age, gender, clothing factors, and activity) collected using questionnaires distributed to 183 residents in Section 7, Shah Alam. The inclusion criteria for respondents were residents aged more than 20 years old to 50 years old; permanent residents of Section 7, Shah Alam, for at least one year; Malaysian citizens; and individuals who frequently engage in outdoor activities in the area. The inclusion criteria of the respondents allow the study to obtain PET values that represent the human thermal environment among residents in Shah Alam. However, individuals under 20 and above 50 years were removed due to potential differences in thermal homeostasis responses. Therefore, the findings of this study may not represent those under 20 and above 50 years old and may not be generalizable to the entire population of Shah Alam. After obtaining the meteorological data for Shah Alam, including temperature from the reference meteorological station and PET values, all data were sorted and cleaned using Microsoft Excel 2019 before

being imported into the Statistical Package for the Social Sciences (SPSS) version 28.

2.3 Data analysis

Using SPSS version 28, descriptive analyses were conducted on temperature (Shah Alam and the reference station), relative humidity, wind speed, PET, and UHII. To obtain PET data for each respondent, meteorological data (temperature, relative humidity, and wind speed) and residents' height, weight, age, gender, clothing factors, and activity information were entered into the RayMan software before the PET values could be generated. All data were tabulated as means, standard deviations, minimums, and maximums, while thermal perception was presented in terms of frequency and percentage. This was done to provide an overview of the obtained data prior to further statistical analyses. Thermal sensation and physiological stress levels were determined based on PET values to describe the outdoor thermal comfort experienced by residents in Shah Alam during the study period. Table 1 shows the categorization of thermal sensation and grade of physiological stress levels based on PET values.

Table 1. Categorization of thermal sensation and grade of physiological stress levels based on PET values

PET value (°C)	Thermal sensation	Grade of physiological stress
<4	Very cold	Extreme cold stress
4-8	Cold	Strong cold stress
8-13	Cool	Moderate cold stress
13-18	Slightly cool	Slight cold stress
18-23	Comfortable	No thermal stress
23-29	Slightly warm	Slight heat stress
29-35	Warm	Moderate heat stress
35-41	Hot	Strong heat stress
>41	Very hot	Extreme heat stress

Source: [Matzarakis and Mayer \(1996\)](#); [Stojićević et al. \(2016\)](#)

Additionally, SPSS version 28 was also used to examine the relationship between meteorological factors and UHII with PET. Pearson correlation analysis and stepwise linear regression were employed as part of the statistical analysis. Pearson correlation identifies the strength and direction of the linear relationship between meteorological factors and UHII with PET, while linear regression assesses the relationship between the tested variables, indicating how changes in meteorological factors and UHII affect PET among residents in Shah Alam, Selangor. This approach allows for the identification of significant predictors influencing PET values in urban areas. For the regression model, the stepwise method was used instead of the enter method because the former adds or removes variables based on their statistical significance, rather than forcefully adding all variables into a regression model. All collected data were processed and tested to meet the assumptions of Pearson correlation (e.g., normality of data, absence of outliers, and linear relationship between variables) and stepwise linear regression (e.g., linearity,

homoscedasticity, normality of residuals, and independence of errors) prior to the analysis. This ensures that the selected statistical analysis provides validity and reliability of the findings, preventing inaccurate interpretations and predictions of the data.

3. RESULTS

3.1 Meteorological factors in Shah Alam

A descriptive analysis of the meteorological factors in Shah Alam is presented in [Table 2](#). The minimum and maximum temperatures recorded in Shah Alam, Selangor were 25.9°C and 31.1°C, respectively, with the mean and standard deviation (SD) for the temperature of 28.784±1.038°C. These values were higher than those recorded at the control station, where the minimum and maximum temperatures were 24.0°C and 29.4°C, respectively, with a mean of 27.040±0.827°C. The relative humidity recorded a minimum value of 61.7% and a maximum value of 88.8%, with a mean of 76.435±5.956%. The wind speed in Shah Alam ranged from 0.60 m/s to 3.70 m/s, with a mean of 1.701±0.481 m/s.

Table 2. Descriptive analysis of meteorological factors

Meteorological parameters	N	Min	Max	Mean	SD
Temperature (°C)	183	25.90	31.10	28.784	1.038
Temperature (reference station) (°C)	183	24.00	29.40	27.040	0.827
Relative humidity (%)	183	61.70	88.80	76.435	5.956
Wind speed (m/s)	183	0.60	3.70	1.701	0.481

3.2 Urban heat island intensity in Shah Alam

Urban heat island intensity was derived from the temperature difference between Shah Alam and a reference station located in a rural area. [Figure 2](#) shows the temperature difference between these two locations. It was found that, during the period from 1st April until 30th September 2024 (183 days),

temperatures in Shah Alam were generally slightly higher than those at the reference station in the rural area, indicating the presence of a UHI effect in Shah Alam. These temperature differences correspond to the UHII, where the intensity in Shah Alam ranged between 0.0°C and 3.7°C, with a mean of 1.743±0.687°C ([Table 3](#)).

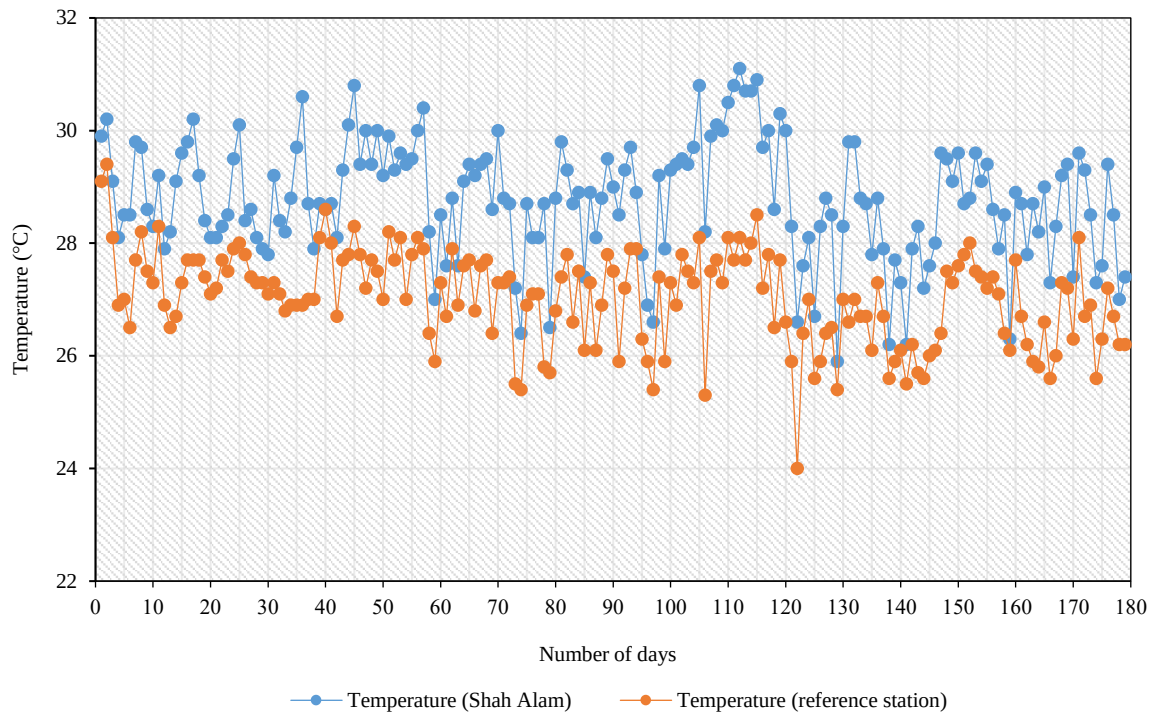


Figure 2. Temperature differences between Shah Alam and the reference station

3.3 Physiological equivalent temperature

Regarding the PET, the values among residents in Section 7, Shah Alam ranged from 25.9 to 32.0, with a mean of 29.121 ± 1.235 (Table 3).

The PET value can be translated into the thermal perception experienced by residents in Section 7, Shah Alam, allowing for the grading of the

physiological stress that they experience. This provides an indication of the outdoor thermal comfort experienced by the residents of Shah Alam. It was found that 42.1% of the residents felt slightly warm, which corresponds to slight heat stress, while 57.9% of the residents felt warm or experienced moderate heat stress (Table 4).

Table 3. Descriptive analysis of UHII and PET

	N	Minimum	Maximum	Mean	SD
UHII	183	0.00	3.70	1.743	0.687
PET	183	25.90	32.00	29.121	1.235

Table 4. Thermal perception and grade of physiological stress

Thermal perception	Frequency (n)	Percentage (%)	Grade of physiological stress
Slightly warm	77	42.1	Slight heat stress
Warm	106	57.9	Moderate heat stress

N=183

3.4 Correlation between meteorological factors and UHII with PET

This study found a trend of increasing PET values with increasing UHII and temperature, while PET values decreased with higher relative humidity. A slight increase in PET values was also observed with increasing wind speed. Figure 3 shows the trends of

PET values in relation to UHII, temperature, relative humidity, and wind speed.

The results for the Pearson correlation analysis between meteorological factors and UHII with PET are presented in Table 5. The results indicate that temperature ($r=0.835$, $p<0.001$) and UHII ($r=0.404$, $p<0.001$) have positive relationships with PET,

meaning that increases in temperature and UHII will increase PET values. On the other hand, relative humidity shows a negative relationship with PET ($r=-0.579$, $p<0.001$), indicating that increases in relative

humidity will reduce PET values. No relationship was found between wind speed and PET ($r=0.038$, $p=0.614$), suggesting that changes in wind speed do not affect the PET values experienced by residents.

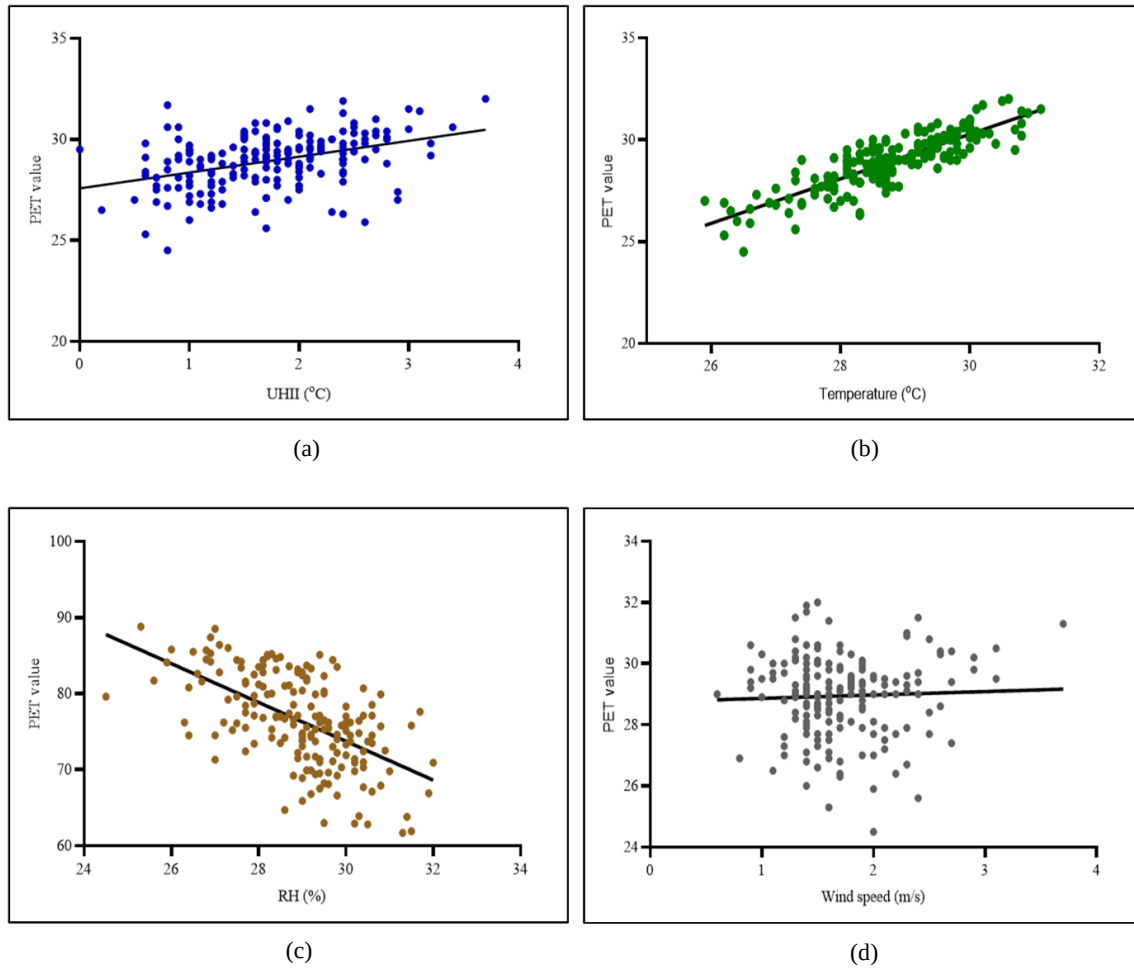


Figure 3. Trends of PET values with (a) UHII, (b) temperature, (c) relative humidity, and (d) wind speed

Table 5. Correlation between meteorological parameters and UHII with PET

Parameters	r	p
Temperature (°C)	0.835	<0.001
Relative humidity (%)	-0.579	<0.001
Wind speed (m/s)	0.038	0.614
UHII (°C)	0.404	<0.001

3.5 Predictors for PET

A stepwise regression analysis was performed to examine the relationship between meteorological factors and UHII with PET, as shown in Table 6. The stepwise regression finalized the model by including temperature and wind speed as predictors of PET

while removing relative humidity and UHII, as both factors did not significantly contribute to the model.

Based on Table 6, the correlation coefficient (R) was 0.901, indicating a good level of prediction of PET values using temperature and wind speed. In addition, the coefficient of determination (R^2) was 0.812, which means that the temperature and wind speed explain 81.2% of the variation in PET values. After adjustment ($\Delta R^2=0.810$), the independent variable explains 81% of the variation in PET values in this model. The F-ratio for the regression model was $F(2, 182)=378.375$, $p<0.001$, indicating that the independent variables significantly predict the dependent variable. These results demonstrate that the regression model provides a good fit of the data.

Table 6. Stepwise regression analysis of predictors for PET

	B	SE	β	t	p	F	R	R ²	ΔR^2	Sig.
Model 1										
Temperature	0.988	0.048	0.840	20.738	<0.001	430.069	0.840	0.705	0.703	<0.001
Model 2										
Temperature	1.160	0.042	0.986	27.803	<0.001	378.375	0.901	0.812	0.810	<0.001
Wind speed	-0.911	0.090	-0.359	-10.119	<0.001					

Model 2 shows that for every 1.160°C increase in temperature, the PET value increases ($B=1.160$, $p<0.001$). Conversely, for every 0.911 m/s increase in wind speed, the PET value experienced by residents in Section 7, Shah Alam, decreases ($B=0.911$, $p<0.001$). This highlights that as temperature rises, the PET value also increases, which can affect thermal perception (slightly warm, warm, hot, and very hot perception) and physiological stress (slight, moderate, strong, and extreme heat stress) among residents. Meanwhile, the increase in wind speed results in a decrease in the PET value ($B=-0.911$, $p<0.001$), emphasizing the cooling effect provided by the wind speed, which may improve thermal perception and reduce physiological stress among the residents.

4. DISCUSSION

Urbanization and the expansion of urban areas have long been associated with the reduction of green cover and the concurrent increase in air temperature due to the UHI effect (Bian et al., 2025). Urban development often involves replacing vegetation with thermally conductive and heat-retaining materials, which leads to higher ambient temperatures in the affected areas (Asnawi et al., 2024; Cheela et al., 2021). The UHI phenomenon reflects environmental responses to land use and land cover changes in developed areas, contributing to a gradual increase in UHII over time (Rendana et al., 2023).

In this study, Shah Alam exhibited clear UHI characteristics, with a maximum recorded UHII of 3.7°C. This value is significantly higher than the UHII of 0.7°C reported in Hulu Langat, Selangor, in 2021. The elevated UHII in Shah Alam may be attributed to a pronounced trend in land cover transformation, characterized by expanding built-up areas and declining vegetation, particularly in the Klang Valley region where Shah Alam is located (Azari et al., 2022). This finding highlights the effect of urbanization and land use and land cover changes on urban areas, contributing to rising air temperatures and increasing UHII.

Moreover, land use and land cover changes have been associated with outdoor thermal comfort, as built-up areas in urban environments may promote heat stress among urban residents compared to those living in suburban or rural areas (Yeo et al., 2021). As urban heating driven by UHI, global warming, and extreme climate events becomes more pronounced, concerns about outdoor thermal comfort and public health risks have intensified (Dzyuban et al., 2022). Meteorological factors such as air temperature, wind speed, and relative humidity, along with personal activities (both static and dynamic), significantly influence thermal perception in open spaces (Bian et al., 2025; Yeo et al., 2021). On the other hand, PET has been frequently used as an evaluation indicator for different comfort levels in several studies focusing on outdoor thermal comfort (Bian et al., 2025; Qi et al., 2025). Therefore, examining temperature, relative humidity, and wind speed together with UHII as potential factors influencing PET can enhance our understanding of the relationship between environmental factors and outdoor thermal comfort in urban settings.

A previous study conducted in Penang, Malaysia, highlighted the PET values found in transitional areas (a sky court, a balcony, and a rooftop garden), which may affect outdoor thermal comfort among occupants. The study reported PET values below 34°C, similar to this study, which found the highest PET at 32°C. However, the thermal comfort range of respondents was broader than the Western or Middle European scale (19-30°C) (Taib and Ali, 2016). A study conducted in Shah Alam Lake Garden, a public park, found that thermal perception based on the PET value of the study indicated that the respondents adapted to the warm perception in the area, which is similar to this study, as more than half of the respondents felt warm as thermal perception (Nasir et al., 2012). These findings suggest that outdoor thermal comfort for the population in Shah Alam can be expected at a warm level, owing to local

meteorological conditions and personal factors of the respondents living in the area.

The findings of the current study revealed a positive relationship between air temperature and UHII with PET, indicating that increases in temperature and UHII correspond to higher PET values in Shah Alam. Conversely, PET was observed to decrease with higher relative humidity levels. Interestingly, despite existing literature highlighting wind speed as a key determinant of thermal comfort, no significant correlation between wind speed and PET was found in this study. However, stepwise regression analysis identified both air temperature and wind speed as significant predictors of PET variations among residents in Shah Alam.

Previous research suggests that lowering relative humidity as temperature increases can improve thermal comfort, while insufficient wind speed can hinder heat dissipation from the human body (Dec et al., 2018). Lower relative humidity facilitates sweat evaporation, and increased wind speed enhances convective cooling, both of which contribute to improved thermal comfort (Dec et al., 2018). Moreover, fluctuations in air temperature have been closely linked to thermal discomfort, with higher temperatures and increased human metabolic heat generation inducing a stronger sensation of heat stress (Hou, 2018). The negative impact of rising temperatures on thermal sensation can be mitigated by increased airflow.

This study has several limitations. First, the use of meteorological data on temperature, relative humidity, and wind speed, rather than measurements of the local microclimate in Shah Alam, may not represent the actual exposure to the urban environment experienced by residents in the study areas, which can affect their thermal comfort levels. Second, although PET is a commonly used thermal index to assess thermal comfort, it was calculated using environmental data and information from residents. The study did not include measurements of heat stress or physiological changes, such as variations in body temperature, heart rate, or breathing rate, which could provide clearer evidence on the implication of the urban environment on thermal comfort among residents. Third, the study was performed in public areas where residents engaged in moderate outdoor activities, rather than in outdoor spaces where residents may perform moderate to vigorous outdoor activities, making them more susceptible to environmental factors that affect their comfort levels.

Due to these factors, the PET values and thermal perception obtained may not entirely represent the residents of Shah Alam, as the data used for PET calculations were sourced from a meteorological station instead of field measurements within the study area. Local microclimates may differ from one area to another in Shah Alam. The PET values can be used to determine residents' thermal comfort. However, due to the subjective nature of the information obtained through questionnaires, such as clothing factors and activities, the accuracy of thermal comfort levels may need to be supported by personal measurements to provide quantitative evidence of thermal comfort. This study also did not include respondents engaged in vigorous outdoor activities, which may adversely affect their outdoor thermal comfort; thus, the findings may only represent Shah Alam residents performing low to moderate outdoor activities. Future research should address these limitations by incorporating local microclimate measurements, physiological monitoring, and a broader range of activity settings. Consideration should also be given to outdoor thermal comfort during extreme weather events, such as heatwaves, with a focus on vulnerable target groups, including children, the elderly, and outdoor workers, who can be adversely affected by surrounding environments, such as exposure to high temperatures during their daily activities.

5. CONCLUSION

In conclusion, this study has examined the influence of meteorological factors, such as temperature, relative humidity, wind speed, and UHII, on outdoor thermal stress, as measured by the PET among residents in Section 7, Shah Alam, Selangor. Temperature and wind speed were found to be the strongest predictors of PET among these residents. However, the roles of UHII and relative humidity in shaping PET should not be overlooked, as both factors also demonstrate a notable impact on thermal comfort among residents in the urban environment. Moreover, UHII was observed to contribute to increased heat stress among residents. With ongoing rapid urbanization in Shah Alam and its surrounding areas, temperature and UHII in Shah Alam are projected to rise, which may further degrade outdoor thermal comfort in the near future. Consequently, this may adversely affect the outdoor thermal comfort experienced by local residents, potentially leading to heat stress and related illnesses that threaten the health

and well-being of residents engaged in outdoor activities in urban areas.

To address these challenges, proactive measures must be undertaken by local authorities and urban planners to mitigate the impact of urbanization on the local microclimate and UHI effects. Such measures include incorporating green infrastructure into urban design, transitioning to renewable energy sources, promoting public transportation, expanding green spaces, encouraging sustainable land use, and adopting circular economy practices to minimize greenhouse gas emissions. These efforts are crucial for supporting Shah Alam and other similar cities in achieving Sustainable Development Goal 11: sustainable cities and communities, which aims to make cities inclusive, safe, resilient, and sustainable.

AUTHOR CONTRIBUTIONS

Conceptualization, N Mohamed; Methodology, NFAM Zeini and NIHK Anwar; Investigation, NFAM Zeini and N.I.H.K. Anwar; Formal analysis-MAM Aminuddin; Visualization; Supervision, N Mohamed; Writing original draft, N Mohamed; Review and editing, N Mohamed.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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