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Studies of Outdoor Thermal Comfort in Bogor Botanical Gardens

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ABSTRACT

This study investigates the use of thermal indexes, specifically Physiologically Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI), to determine outdoor comfort in the Bogor Botanical Gardens (KRB). This park is centrally located in Bogor city, with elevations ranging from 215-260 m above sea level. The thermal sensation was determined using seven references: PET in Europe, Taiwan, Tianjin, Tel Aviv, and UTCI in the Mediterranean, Tianjin, and general contexts. The study involved 284 visitors surveyed for their thermal comfort perceptions. Findings indicate that, based on thermal sensation criteria from the seven references, KRB is generally not within the comfort zone throughout the year, except for the PET in Taiwan, which is comfortable year-round. In-situ measurements show an average daily PET of 33.8°C and UTCI of 34.4°C. According to the Taiwan PET range, the thermal sensation is categorized as somewhat warm to warm (uncomfortable). However, 69.4% of visitors reported feeling comfortable, likely due to the environmental conditions, with 70.3% tree coverage in the 54.7 ha park area.

INTRODUCTION

In the last few years or even a decade, research on thermal comfort has increased due to climate change and increasing urban temperatures. However, there is relatively less research on outdoors compared to indoors.

Thermal comfort for rooms began in 1960 when 4 climatic parameters were used separately, namely: ambient temperature or room temperature, radiation temperature such as radiation from walls, air humidity, and airflow velocity (Mayer & Höppe 1987). All these parameters are always used to create an index of thermal comfort or discomfort in a room. The concept of effective temperature (ET) or standard effective temperature (SET) by adding two other parameters, viz: the difference in the degree of insulation measured from clothing or the term "clo" and the degree of physical activity measured from metabolism or the term "met" (Gagge et al. 1972). The Predicted Mean Values (PMV) comfort or discomfort diagram was developed from the comfortable situation created in an air-conditioned room that depends on clothing and physical activity (Fanger 1970).

The index was designed with indoor use in mind. This need can also be met outside, but SET cannot be used outside without being modified (Spagnolo & de Dear 2003). The primary challenge in evaluating outside thermal conditions is the possibility of far greater climate variability than in indoor environments. Physiological Equivalent Temperature (PET), which seeks to obtain a better approximation for outdoor circumstances, was developed to explain this difficulty (Mayer & Höppe 1987). Furthermore, thermophysiological considerations and climate parameters provide the assumption that outdoor conditions are equivalent to indoors. For example, the human body heat balance indoors with light activity is 80 W, and clothing is 0.9 CLO. This value is also used for outdoor conditions.

Air conditioners (AC) are a simple way to modify the indoor climate, but there are very few ways to create a comfortable outside environment. The interior comfort index is often used to determine outdoor comfort. It is usually questionable when studies are conducted on thermal comfort for outdoor circumstances, and ideas created for interior conditions are applied to outside conditions without modification (Spagnolo & de Dear 2003). In addition to using human elements (clothing and metabolism) and meteorological variables (air temperature, humidity, radiation, and wind speed), an outdoor comfort index based on the energy balance of the human body should also take these into account. When evaluating outdoor comfort indices, however, the greater range of meteorological elements and human characteristics provide more challenges than when evaluating indices for interior situations. The study of outdoor thermal comfort makes use of predicted mean vote (PMV), physiologically equivalent temperature (PET), and standard effective temperature (SET) (Farajzadeh & Matzarakis 2012, Matzarakis et al. 2014, Matzarakis & Matzarakis 2016) and Universal Thermal Climate Index (UTCI) (Blazejczyk et al. 2012, Park et al. 2014) is the index that is most frequently used. Having the same meteorological inputs—wind speed, air temperature, air humidity, and the flux of short- and long-wave radiation—allows these thermal indices to have an advantage over one another.

Because PET integrates air temperature, humidity, wind speed, and cloud cover, it delivers more accurate information regarding environmental thermal conditions (Farajzadeh & Matzarakis 2012). Similarly, using UTCI can yield accurate forecasts for outdoor thermal comfort (Lai et al. 2014). The majority of studies on thermal comfort for Indonesian tourist destinations still utilize the Thermal Humidity Index, with very few using PET and UTCI (Hadi 2012). Because Indonesia's climate has equatorial, monsoon, and local patterns, it is crucial to conduct a thorough analysis of the application of these indices for tourist destinations.

Northern Taiwan is the only region in Taiwan with a tropical climate; most prior research and assessments of the usage of PET and UTCI were conducted in sub-tropical and temperate regions. Compared to Taiwan and Europe, North China's PET thermal feeling range is distinct (Lai et al. 2014). Since there are differences in the classifications, it is crucial to classify thermal perception for each region (Lin & Matzarakis 2011). The PET and UTCI calculations in a number of areas have been adjusted, including UTCI in the Mediterranean, UTCI in Tianjin, UTCI in Europe, UTCI in Taiwan, and UTCI in Tel Aviv.

This study aims to address this research gap by assessing outdoor thermal comfort in the tropical climate of Indonesia, specifically in the Bogor Botanical Gardens. There is no classification for thermal sensation in Indonesia, a country with a tropical climate, unlike the sub-tropical areas for which it was formerly employed (Sudiar & Gautama 2023). By comparing thermal sensation categories from seven PET and UTCI references with visitor survey results, this study provides a comprehensive analysis of thermal comfort for outdoor activities in natural tourist destinations in tropical climates.

MATERIAL AND METHODS

Location of Research

This study was carried out at the Bogor Botanical Garden (KRB), which is situated in the center of Bogor city at an elevation of between 215-260 meters above sea level and enjoys a tropical environment. KRB area which has an area of about 77.8 ha with topography including flat with slopes varying from 3-15%. Slightly steep on the banks of the Ciliwung River, which divides the KRB. Schmidt-Ferguson's classification of climate states that KRB has a type A value of Q = 7.8%. Koeppen's classification of climate states that KRB has a tropical forest climate, or climate A, with high temperatures. KRB is more precisely classified as having a tropical rainforest climate, with at least 60 mm of rainfall in the driest month (Af). With January having the lowest temperature of 25.9°C and September having the highest temperature of 27.5°C, the average yearly temperature is 26.9°C. The total amount of rainfall every year is 4,308 mm, with November receiving the most at 610 mm and July receiving the least at 206 mm. The average annual temperature is 78%, the average daily sunshine amount is 6.4 h, and the average annual wind speed is 1.7 km.h^{-1} (Sudiar et al. 2019).

Data

The data used in this study are climate data of Bogor Botanical Garden (KRB) station for 6 years (2012-2017) and Baranangsiang Climatology station for 4 years (2012-2015). In April and May 2018, air temperature, air humidity, and wind speed were monitored in situ at KRB (Table 1). The weather measuring device in use is an ABH-4224 type Lutron brand anemometer that satisfies ISO 9001 standards. Measurements and surveys were carried out during the day from 09:00 to 18:00 WIB. The time range was chosen to adjust to the arrival time of visitors. Measurements were grouped into hours. For each hour, a minimum of five measurements and interviews were conducted. 284 visitors

Table 1: Weather parameter measuring instrument specifications.

Parameters	Range	Resolution	Accuracy
Anemometer	0,9 – 35,0 m/s	0,1 m/s	± (2% + 0.2 m/s)
Temperature	0°C - 50°C	0,1°C	± 0,8°C
Humidity	10% - 95% RH	0,1% RH	≥ 70% RH ± (3% *reading* + 1% RH) < 70% RH – 3% RH ± 3% RH

in total participated in this survey as respondents. Simple random sampling, or the taking of samples at random, was used to choose the responders. The parking lot, the regions around trees, shrubs, ponds, and water fields, as well as pedestrian pathways, major thoroughfares, rest facilities (saung, gazebos, and park benches), and other locations were sampled both inside and outside the tourist area.

Thermal Comfort Index

The Universal Thermal Climate Index (UTCI) and Physiologically Equivalent Temperature (PET) are the two thermal comfort indices utilized. Equation (1) is used for the PET calculation, and equation (2) is utilized for the UTCI calculation. Rayman Pro software version 2.3 Beta is used to make the computation easier.

The Munich energy balancing model for humans (MEMI Model), a thermo-physiological heat balance model, serves as the foundation for the PET index (Lai et al. 2014). PET refers to the concept of a perfectly equal indoor and outdoor temperature or balanced temperature. This specific chamber features calm air (<0.1 $m.s^{-1}$), 1200 Pa air pressure (50% relative humidity at 20°C), and no radiation (Tmrt = Ta). As a result, PET enables the average person to contrast the effects of outdoor temperature conditions with their personal inside experience.

$$M + W + R + C + ED + ER.e + ESW + S = 0 \quad ...(1)$$

Where M represents the rate at which energy is produced internally, W stands for work output, R for net radiation from the body, C for convective heat flow, ED for latent heat flow used to evaporate water that is diffusing through the skin rather than sweat, ER.e for the amount of heat flow used to heat and humidify the air, ESW for heat flow from sweat evaporation, and S for stored heat flow used to heat or cool the body mass.

The air temperature (Ta) of the reference condition that results in the same model response as the real condition is known as the Universal Thermal Climate Index (UTCI). The mean radiant temperature (Tmrt), wind speed (va), humidity represented as relative humidity (RH) or water vapor pressure (vp), and actual air temperature all affect the offset or the difference between the UTCI and air temperature. It is expressed mathematically;

$$U\ TCI = f\ (Ta;\ Tmrt;\ va;\ vp) = Ta + Offset\ (Ta;\ Tmrt;\ va;\ vp) \quad ...(2)$$

For the reference environment, assumptions are used:

- Wind speed (va) ≅ 0.5 $m.s^{-1}$ at 10 m height (approximately ≅ 0.3 $m.s^{-1}$ at 1.1 m height)
- Average radiation temperature (Tmrt) = air temperature (Ta)
- At high air temperatures (>29°C), the reference humidity is assumed to be constant at a pressure of 20 hPa. Vapor pressure (vp), reflecting 50% relative humidity.

RESULTS

Historical Thermal Comfort

Thermal comfort was calculated with historical data spanning six years (2012-2017) and using PET and UTCI. Daily values are UTCI and PET. In June, the lowest daily average PET score is 27.4°C, while in December, the maximum value

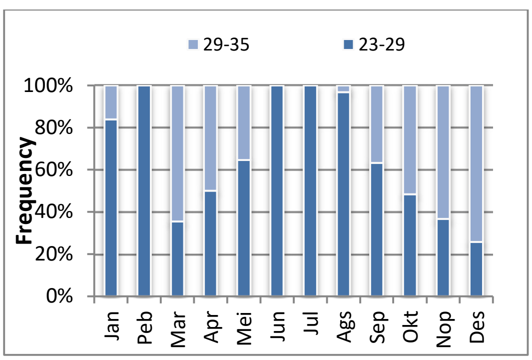

Fig. 1: Daily European PET.

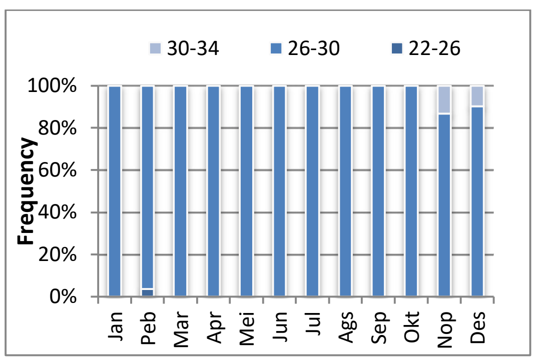

Fig. 2: Daily Taiwan PET.

is 29.3°C. The variation in the PET score during the year was 1.9°C. Between the rainy and dry seasons, there is no discernible difference in PET scores. In every season, there aren't any extraordinary scores.

Multiple references were consulted to ascertain the KRB area's temperature perception, including PET Europe, PET Taiwan, PET Tianjin, and PET Tel Aviv (Table 2). The thermal sensation of the KRB area on PET Europe is slightly warm and warm. In June and July, the thermal sensation is fully slightly warm. Throughout the year, the frequency of slightly warm (dark shading) was 244 days and warm (light shading) 121 days (Fig. 1).

The thermal sensation of the KRB area in PET Taiwan is slightly cool, comfortable, and slightly warm. Dominant throughout the year the KRB area is comfortable (dark shading) for 357 days. Somewhat cool (light shading) only one day and slightly warm (light shading) 7 days (Fig. 2).

The thermal sensation of the KRB area in Tianjin PET is slightly warm (dark shading) throughout the year (Fig. 3).

The thermal sensation of the KRB area in PET Tel Aviv is comfortable, slightly warm, and warm. Comfortable sensation (light shading) is only 1 day in February. The frequency of warm sensation (dark shading) is 262 days more than slightly warm (light shading), which is 102 days. March and September were the fully warm months (Fig. 4).

The average temperature measured by the UTCI was 29.0°C in February, the lowest, and 30.6°C in May. The 1.6°C variation in UTCI score throughout the year is not very significant. UTCI Mediterranean, UTCI Tianjin, and UTCI are the references we use to determine the thermal sensation of the KRB area (Table 3).

The thermal sensation of the KRB area in the Mediterranean UTCI is moderately hot and very hot. The very hot sensation (dark shading) is more dominant at 321 days, while the moderately hot sensation (light shading) is 44 days (Fig. 5).

The thermal sensation of the KRB area in UTCI Tianjin is moderately hot (dark shading) throughout the year (Fig. 6).

Table 2: Thermal sensation of PET.

Thermal sensation	PET Eropa (ºC)1	PET Taiwan (ºC)1	PET Tianjin (ºC)1	PET Tel Aviv (ºC)2
very cold	< 4	< 14	< -16*	< 8
cold	4 – 8	14 - 18	-16 - (-11)*	8 - 12
cool	8 – 13	18 - 22	-11 - (-6)*	12 - 15
slightly cool	13 – 18	22 - 26	-6 - 11	15 - 19
comfortable	18 – 23	26 - 30	11 - 24	19 - 26
slightly warm	23 – 29	30 - 34	24 - 31	26 - 28
warm	29 - 35	34 - 38	31 – 36	28 – 34
hot	35 - 41	38 - 42	36 - 46*	34 – 40
very hot	> 41	> 42	> 46*	> 40

Table 3: UTCI thermal sensation.

Thermal sensation	UTCI Mediterania (ºC)[1]	UTCI di Tianjin (ºC)[1]	UTCI (ºC)[1]
extreme cold	< 4,1	< -21*	< -40
very strong cold	4,1 - 5,9	-21 - (-16)*	-40 - (-27)
very cold	5,9 - 9,1	-16 - (-11)*	-27 - (-13)
moderately cold	9,1 - 14,0	-11 - (-6)*	-13 – 0
somewhat cold	14,0 - 17,4	-6 - 12	0 – 9
Comfortable	17,4 - 24,5	12 - 25	9 – 26
moderately hot	24,5 - 29,1	25 - 33	26 – 32
very hot	29,1 - 34,1	33 - 39	32 – 38
very strong heat	34,1 - 37,7	39 - 47*	38 – 46
extreme heat	> 37,7	> 47*	> 46

Notes:
* = sensation value obtained from linear regression
1 = (Lai et al. 2014)
2 = (Cohen et al. 2013)

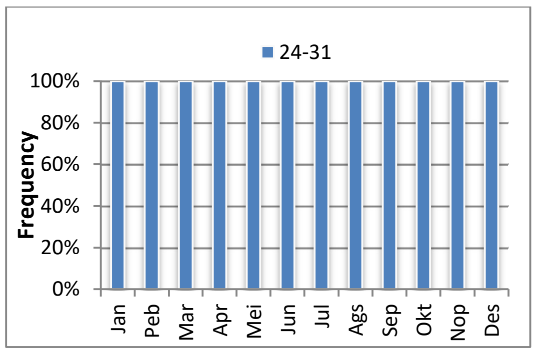

Fig. 3: Tianjin daily PET.

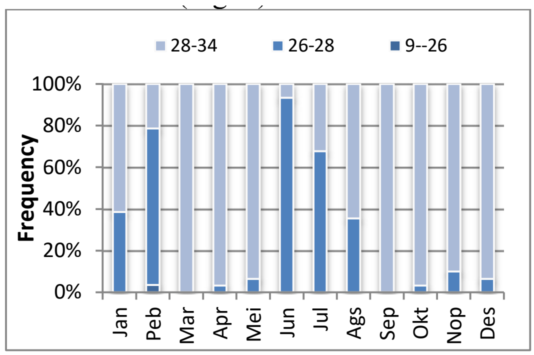

Fig. 4: Daily Tel Aviv PET.

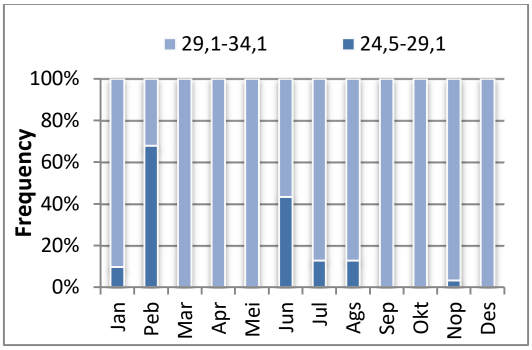

Fig. 5: Daily Mediterranean UTCI.

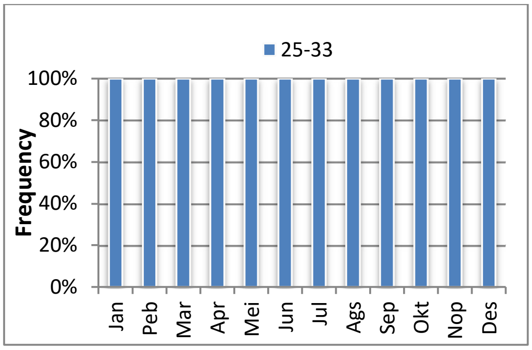

Fig. 6. Daily Tianjin UTCI.

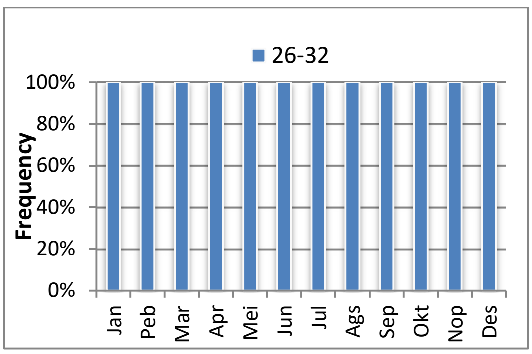

Fig. 7. Daily UTCI.

The thermal sensation of the KRB area at UTCI is moderately hot (dark shading) throughout the year (Fig. 7).

Thermal Comfort During Survey

Based on the responses to the questionnaire, the assessment of the thermal experience that guests to the KRB tourist region experienced. The temperature impression experienced by the visitors was elicited using closed-ended questions. The answer selections are grouped into seven categories: very cold, very cold, moderately cold, hot, hot, and slightly hot. Measurements of the atmospheric temperature, humidity,

Table 4. Weather parameter measurements in KRB.

	Temperature (°C)	Humidity (%)	Wind speed (m/s)
Minimum	28,3	48,2	0.1
Average	32,0	62,0	0.5
Maximum	36,0	78,7	2.0

and wind speed were taken simultaneously before visitors responded (Table 4).

Of the 284 respondents asked, 197 people (69.4%) answered that the thermal sensation of the KRB area was moderate, 30 people (10.6%) answered rather hot, 24 people (8.5%) answered hot, and 22 people (7.7%) answered rather cold (Fig. 8). Most guests agree that the temperature is ideal for tourist visits. The following results are obtained from the calculation of thermal comfort using in situ data: daily average PET = 33.8°C and daily average UTCI = 34.4°C. These results show that most visitors reported a moderate temperature sensation, with PET and UTCI values of about 33.8°C and 34.4°C, respectively. When it comes to the thermal sensation category, 33.8°C and 34.4°C fall into the categories of extremely hot and intense heat (thermal

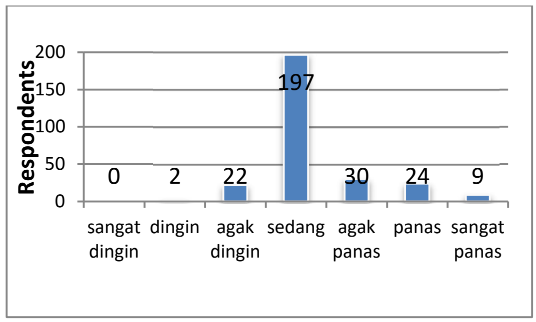

Fig. 8. Thermal sensations felt by visitors in the KRB area.

Table 5. Data collection locations.

Landscape	Number (People)	Percentage (%)
Parking lot	0	0
Trees	66	23,2
Shrubs	31	10,9
Shrubs	1	0,35
Grass	73	25,7
Water tourism	4	1,4
Pedestrian path	30	10,6
Main path	48	16,9
Rest area (gazebo/park bench)	30	10,6
Others	1	0,35
Total	284	100

sensation UTCI) and quite warm and warm (thermal sensation PET).

A total of 264 people (93%) visitors were interviewed inside the KRB tourist sites and 20 people (7%) outside the KRB area. The locations where visitors were interviewed and weather parameters were measured included parking lots, around trees, around shrubs, around bushes, grassy areas, water tourism, pedestrian paths, rest areas (gazebos/park benches), and main roads (Table 5). Most visitors were interviewed around grass (25.7%) and around trees (23.2%).

DISCUSSION

The KRB area is not in the thermal comfort zone throughout the year, except for PET Taiwan, according to reference thermal comfort categories (PET Europe, PET Taiwan, PET Tianjin, PET Tel Aviv, UTCI Mediterranean, UTCI Tianjin, and UTCI). The daily average PET in the KRB area throughout the year is in the range of 26-30°C, which means it is in the comfort zone based on Taiwan PET (Fig. 9). Conversely, the majority of tourists who participated in interviews reported moderate temperatures, with an average PET score of 33.8°C and an average UTCI of 34.4°C. Given that portions of Taiwan are in the tropics, PET Taiwan's UTCI and PET computation scores indicate values that are near the thermal comfort zone when combined with the findings of visitor interviews. These findings put our ability to categorize thermal comfort-particularly in the tropics-to the test.

According to the findings of the respondent interviews, the reason why local tourists feel at ease in the uncomfortable zone relative to existing references is the relatively low annual temperature change (<2°C). Locals have probably adjusted to make themselves comfortable in this circumstance. Additionally, there is not much of a temperature variation between the rainy and dry seasons. Additionally, the comfort of visitors is also influenced by environmental factors.

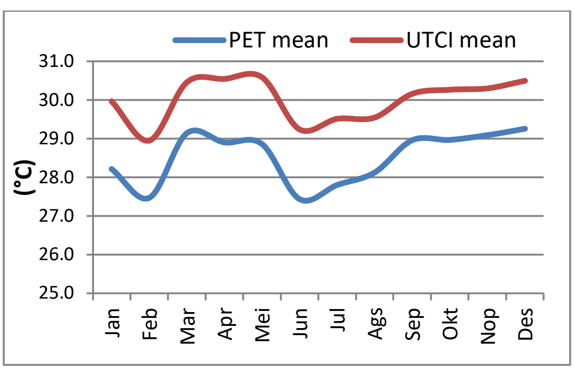

Fig. 9: Average PET and average UTCI in the KRB area for the period 2012-2017.

Interviews with most tourists took place in the shade. Visitors feel comfortable despite the "high" estimated air temperature, thanks to the presence of trees, footpaths, and rest spaces. The tree canopy contributes as a microclimate by reducing daytime air temperatures during hot days and thus increasing human thermal comfort during hot daytime conditions (Coutts et al. 2015).

We can infer from the study's findings that it's critical to classify thermal perception in Indonesia. Further research is required to fully understand the range of thermal comfort and to provide a description that is suitable for each region. Because Indonesia is on the equator, there are very few seasonal fluctuations in temperature. The dry and rainy seasons do not considerably differ in PET and UTCI ratings. PET and UTCI scores tend to be lower in the dry season due to low air humidity during this period. In the transitional season, PET and UTCI scores rise again because the sun reaches its culmination point at the equator, and the energy received in the equatorial region is maximum (Bayong Tjasyono, 2003), which results in temperatures tending to rise. Furthermore, the equator experiences low pressure, which is sufficient to boost convectiveness and have an impact on how solar energy is absorbed by the Earth's surface layer (Fadholi 2013).

CONCLUSIONS

The KRB area is not in the comfort zone throughout the year, except for PET in Taiwan, based on thermal sensation criteria from seven references (PET in Europe, PET in Taiwan, PET in Tianjin, PET in Tel Aviv, UTCI in the Mediterranean, UTCI in Tianjin, and UTCI). The PET and UTCI score fluctuations are negligible (<2°C), indicating no discernible change between the wet and dry seasons.

The daily average UTCI is 34.4°C, while the daily average PET score is 33.8°C based on in situ observations. Based on PET Taiwan's thermal sensation range, the area falls into the warm (uncomfortable) category. However, visitor responses indicate that they feel comfortable, likely due to their adaptation to the climate and the relatively little temperature variation throughout the year. Most visitors were interviewed in shaded areas like among trees, walking trails, and rest spots, suggesting that environmental factors also significantly influence their comfort levels.

To enhance thermal comfort in KRB, it is recommended to expand shaded areas through additional tree planting and shaded rest spots, introduce cooling features like fountains and misting systems to lower ambient temperatures, use reflective and light-colored materials for pathways and seating areas to reduce heat absorption, and design open spaces to promote natural ventilation and improve air circulation.

Future research should include long-term monitoring to evaluate the effectiveness of implemented strategies across seasons, expand studies to diverse tropical climates to understand thermal indices comprehensively, investigate the impact of visitor behavior and clothing on thermal comfort, utilize modern technology like wearable sensors and mobile apps for real-time data collection, and study adaptive strategies used by locals and tourists to inform the design of more comfortable outdoor spaces.

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