Variation of the Urban Heat Island Intensity over One Year in Putrajaya, Malaysia

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ABSTRACT

This research was conducted to evaluate the variation of the urban heat island (UHI) effects in the planned city of Putrajaya over one year. Putrajaya, the administrative capital of Malaysia, is known for its meticulous town planning. The main observations are temperature variation, the changes in wind speed, percentage of relative humidity, and subsequently, the intensity of UHI in the research area. Putrajaya Corporation Complex Precinct 3 (P3) and Precinct 9 (P9) are located in the central business district (CBD) and residential areas respectively. These two places are representatives of UHI's effects on CBD and residential areas. Ultrasonic anemometers which measure 3 components of wind velocities and temperature were employed to analyse temperature and wind patterns. The result indicates the city experienced high temperatures during the day causing human heat stress and discomfort. The UHI intensities of the city are within the range of temperature differences 2 to 3 °C. Land surface cover and numbers of the population are the vital effects of the UHI. Thus, strategies to reduce the existing high air and surface temperature are required in the future.

Keywords: *Planned City; Urban Heat Island; Seasonality*

Introduction

Urban heat island (UHI) is an effect of the energy change between the land surface and atmosphere. Anthropogenic activities, amongst others, produce micro-effects that result in high temperatures in urban areas compared to rural and suburban areas. A planned city is any city that has been meticulously planned from the beginning and is built on previously undeveloped land. In understanding urban sustainability, UHI is an essential measure. This is as highlighted in the Sustainable Development Goals (SDGs) in Goal 11; 'Make cities and human settlements inclusive, safe resilient and sustainable'. UHI is one of the appropriate indicators of public health and energy efficiency [1].

Studies on the UHI intensity (UHII) in some tropical cities in Asia regions are reviewed for the last decade. In the city-state of Singapore, the recently recorded UHII is 2.2 °C, and it can reach up to 2.4 °C in the early morning [4]. At nighttime in India, the UHII is above 2.0 °C and the maximum surface UHI (SUHI) is 8.3 °C in the densely built-up and commercial areas [5]. During the dry seasons, the middle of the cool season in December and in the summer period the UHIIs reported in Bangkok, Thailand, are in the range of 6 to 7 °C, around 5 °C and 2 to 3 °C, respectively [6]-[7]. In the master plan of Hanoi, the capital city of Vietnam, the temperature of air also increases over the expanded and developing area during the nighttime by 2 °C to 3 °C [8].

In the implementation of the master plan city of Hanoi, it is found that the results of such planning do not significantly affect the peak air temperature which is about 1 °C higher at the maximum in the built-up areas. Even though the master plan was implemented, the peak temperature reaches an uncomfortable 41 °C. The strategy of having green space as proposed in the master plan in order to mitigate the heat on the island by producing the cooling effect is insufficient [9]. Urban planners have widely been consulted while preparing the master plan in the hope that such temperature-reducing features in the city could relax the soaring heat in the summer [10].

The distributions of UHI depend widely on the land cover and urban surfaces. The effect of UHI is weakened by green and water surfaces which increase humidity through evapotranspiration and by buildings and trees which shade the ground surface. Meanwhile, the built-up area intensifies it [11]. Hence, attention should be paid to the size of the green-covered area and its distribution within the city. The latter is particularly important; UHI could be mitigated with several blended small green areas more efficiently than one singular park [12]. The air temperature increases more than the surrounding environment due to the urban growth in the city which disturbs human thermal comfort and consequently causes increased demand on cooling loads. In addition to land cover, changes in land use cause UHI to intensify yearly [13].

In highly populated areas, UHI is contributed by the urban inhabitants through the heat and pollutants released in transportation, the usage of air conditioning and other dwellers' activities [14]-[15]. The main consequence of this population shift is due to extreme changes in land use that gradually replaces the pre-existing natural landscape. The energy demand also tends to be higher at the urban centre as a result of the higher population density [16].

Putrajaya is the administrative capital of Malaysia, is also known for its garden-city concept. Under the Putrajaya Structure Plan 2025, the city was established and developed rapidly. The city's difficulty is that city structures and pedestrians are exposed to direct sunshine and, as a result, high temperatures, causing human heat stress and discomfort [2]. This is due to its orientation, low aspect ratio, wide sky view factor, and high surface temperature; it experiences high surface and air temperatures during the day [3]. The climate of the city is typically tropical hot and humid, uniform air temperature during the year with an annual average temperature of 26.1 °C (with an average maximum of 27.5 °C and a minimum of 25 °C), average humidity of 62.6%, long hours of sunshine and solar radiation with an average of 6.1 hours per day and a 4.39 kWh/m^2 of annual average solar irradiation. Winds are generally light and variable with speeds ranging from 0.0 to 7.5 m/s [17]-[18]. However, in many months not within the North-Eastern Monsoon in November-January, the wind speeds are generally within 0.0 to 2.5 m/s except in rainy evenings [19]. Malaysian weather is greatly subjected to the Intertropical Convergence Zone (ITCZ) [20]. The South East Asian nations weather is greatly exposed to the band of low pressure around the Earth, characteristics of ITCZ especially the countries nearest to the equatorial line, Malaysia, Thailand, the Philipines and Indonesia. While reporting the country's Meteorological Department data, Ibrahim et al. [18] highlighted the seasonally strong (North Eastern Monsoon) wind speeds of 5 to 10 m/s with the East Coast of Peninsular Malaysia to expect wind speeds up to 15 m/s. Although eastern states such as Kelantan, Terengganu and Pahang are always associated with yearly damaging strong winds and floods, the 2021's 'extraordinary floods' which claimed more than 50 souls and caused RM6 billion of damages, occurred in the western state of Selangor, a state that encircles Putrajaya.

As a planned city, Putrajaya experiences high temperatures in the daytime even though a garden city concept was implemented [21]. Although the new city planning principles are based on strong concepts, plans often fail to consider local climate conditions which led to poor environmental conditions. The target of this research is to evaluate the spatial and temporal variation of UHII in Putrajaya with climatic conditions. This was done by analysing a one-year climate pattern in Putrajaya which was carried out by measuring the temperature, relative humidity and three components of wind velocities at business and residential sites in the city. The most challenging task facing urban planners although planned cities provide the opportunity to create master plans to suit the local needs and aspirations is creating cities that are responsive to the local climate and contribute to a sustainable environment.

Methodology

Data were collected from two sites in the Federal Territory of Putrajaya which is located in Precinct 3, in front of Putrajaya Corporation Complex and Precinct 9, a residential area in Putrajaya. A map of these sites is represented in Figure 1. Putrajaya is divided into two main areas, the core and the periphery which consist of 20 precincts. The core, where the main five precincts are intended as the Malaysian administrative and symbolic centre for the city and the country. Besides, this is meant to showcase the city's identity through a grand civil infrastructure. The periphery with fifteen precincts is designed for residential neighbourhoods' areas, schools, shopping centres, commercial offices, exhibition and convention centres, private colleges, medical centres, and various tourism attractions.

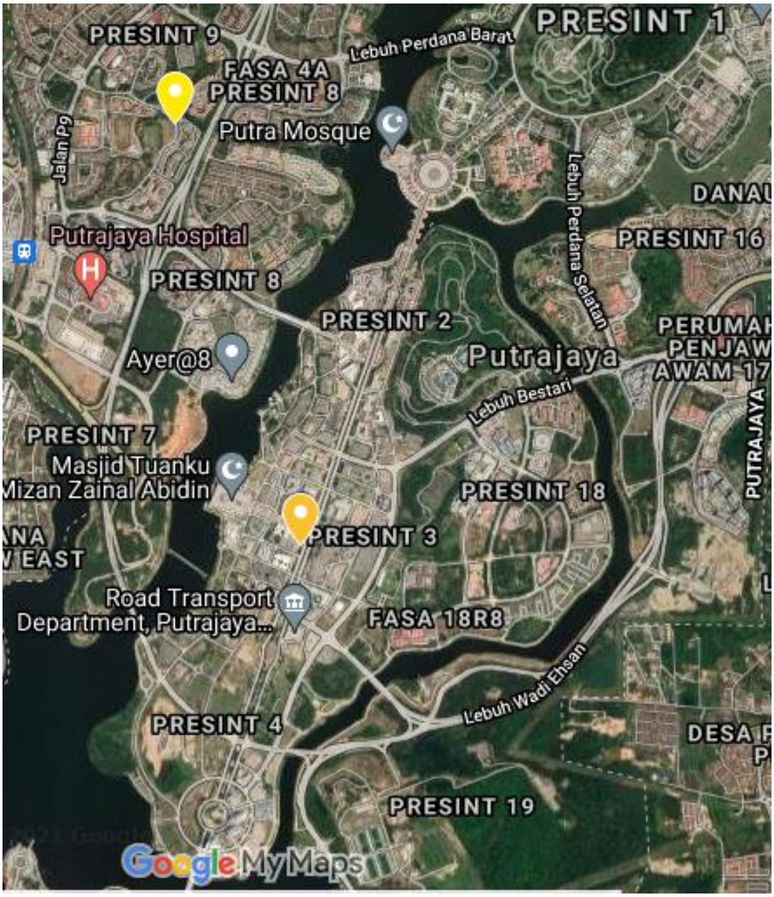


Figure 1: Map of the data acquisition sites

Putrajaya is a balanced city which includes the density of buildings, the presence of water bodies such as from nearby lakes, and also green areas. Putrajaya Corporation Complex in Precinct 3 (P3) is located in the central business district (CBD), with the longest boulevard connecting Dataran Putra in the north to the Dataran Gemilang in the south, dispersed urban form with a low-density government buildings configuration and the main access to the public. As for residential areas in Precinct 9, the area is more secluded, and the greenery area is more spacious. The research used existing equipment by the authority Putrajaya Corporation, locally known as Perbadanan Putrajaya (PPj) as well as newly installed equipment.

Devices

Delicate equipment are used for the study. An ultrasonic anemometer is used for wind direction and SmartSense is used for temperature. The list of equipment used in the analysis is shown in Table 1.

Table 1: List of weather devices and location

Device Code	Location	GPS Coordinates	Equipment	Parameter	Description of sensor location
UKM01	Precinct 3	2.91689, 101.68459	Ultrasonic 87000	Temperature, velocity and direction of winds, RH	Central Business District (CBD), Putrajaya Corporation Complex Precinct 3
UKM02	Precinct 9	2.93763, 101.67841	Ultrasonic 87000	Temperature, velocity and direction of winds, RH	Residential area
WMS01	Precinct 1	2.94354, 101.70075	Rain monitoring station	Temperature, velocity and direction of winds, rain gauge	Recreational area

The urban heat island in Kuala Lumpur campaign which was completed recently [15] has used less internet-friendly approaches and this has caused unnecessary trips to the site for downloading data and fixing equipment. The preparation for the Putrajaya campaign was done quite extensively i.e., since solar-based energy would be used, the power requirement and therefore battery size were calculated. The weight of all equipment and including the arm's static and dynamic moments (wind factors) have been calculated too. The list of equipment and its accessories for UKM01 and UKM02 are listed in Table 2.

Uncertainty analysis

Station UKM01 and UKM02 belong to the university (UKM), therefore it is possible to provide uncertainty estimates of the data acquired from these stations. For wind speed, calibration for the ultrasonic anemometer was performed at UKM wind tunnel [22]. The temperature calibrations were done in-situ using the portable device UNI-T series UT-363. For wind speed, a resolution of 0.01 m/s and an accuracy of ±0.05 m/s, both up to two decimal, are more than sufficient for any analysis which require only one decimal precision. The temperature sensor tolerance of ±0.5 °C provides 2% errors assuming a median temperature hovering 25 °C. Detailed uncertainty estimates are provided in Table 3.

Table 2: List of accessories for ultrasonic anemometer Youngs 87000

The equipment	**Specification**	**Intended work**
Solar Panel	680 × 540 × 25 mm 50 Watt	Providing the energy
Young 81000 Anemometer Ultrasonic	3-axis with no moving parts wind sensor	Measure wind speed (3D) and temperature
Remote terminal unit (RTU)	-Lead-acid battery 12 A and 12 V -GSM/4G LTE	Data acquisition and upload

Table 3: Uncertainties analysis

	Sensor	**Parameter**	**Uncertainties**
1	Young 81000 Anemometer Ultrasonic	Wind speed	Resolution: 0.01 m/s Accuracy: ±0.05 m/s
2	SmartSense	Temperature	Range: -10 - 125 °C Tolerance: -0.3 - ±0.5 °C
		Humidity	Range: 10% - 100% Tolerance: ±0.5%
3	Pyranometer YJ-SR100 (Yuga)	Solar irradiance	Range: 0 - 1500 W/m^2 Resolution: 1 W/m^2

Measurement procedures

PPj is known for its strict enforcement of laws ranging from traffic laws, to recreational activities as well as any equipment to be attached to the existing structure. Since the ultrasonic equipment has to be installed such that it can detect the appropriate temperature patterns and wind movements, a good choice is to attach this equipment to existing lamp poles. Figure 2 shows the installation works of UKM01 (a) and the final installation for UKM02 (b).

(a) Ultrasonic anemometer being installed in Precinct 3 (UKM01)

(b) Final installation of ultrasonic anemometer in Precinct 9 (UKM02)

Figure 2: Installation of UKM01 and UKM02 (ultrasonic anemometer Young 87000 and accessories)

Result and Discussions

This section discusses the effect of the climatic parameter on UHI for the research area. The analysis was focused on the temperature change, UHI intensity, relative humidity, wind speed and wind direction in research areas P3 and P9. All the parameters were measured within 48 hours in October and December 2020, January, March and June 2021 starting in the early morning to midnight in the second day for continuous 48 hours (00:00:00 hours to 11:59:59 hours). The exact dates and descriptions of the months in which the data were acquired are shown in Table 4. For the wind rose visualisation, Pavanaarekh v5 was employed. Data download from the cloud server is set such that frequency, f is 0.0333 (1 data every 30 s) for temperature and wind speed. The equipment can be set at a much higher frequency if there is a need.

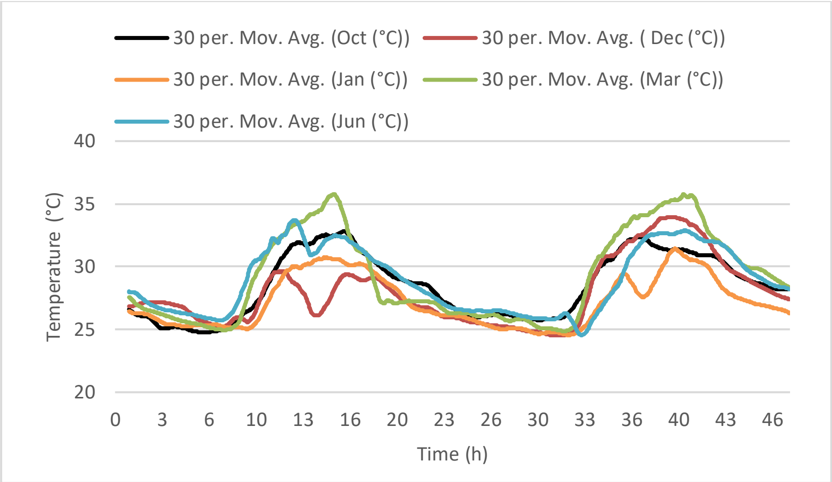
Table 4: Month selections

Date	Abbreviation	Description of month
25-26 October 2020	Oct	Change from dry and hot to wet and cold weather (North-Easterly Monsoon)
24-25 December 2020	Dec	The peak of wet and cold weather
12-13 January 2021	Jan	Wet and cold weather
3-4 March 2021	Mar	Stable
7-8 June 2021	Jun	Dry and hot weather (South-Westerly Monsoon)

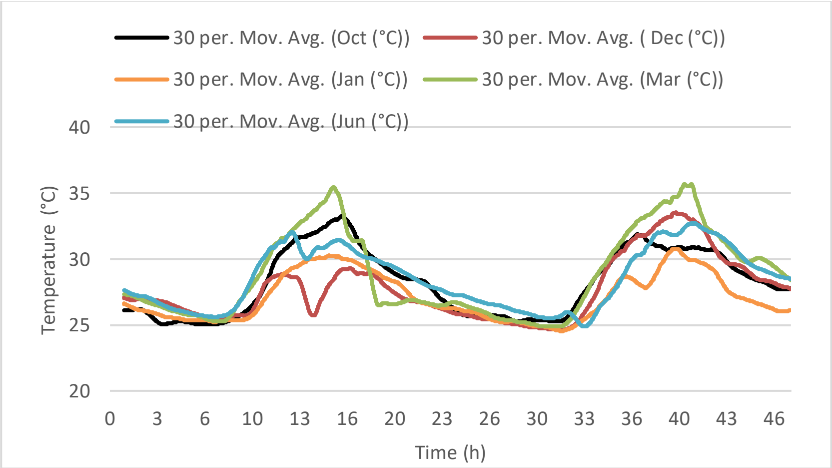
Temperature

Figure 3 shows the temperature variation within 48 hours in the selected months for (a) UKM01 (Precinct 3) and (b) UKM02 (Precinct 9). Although the data downloaded from the cloud server is set at $f = 0.033$, a smoothing function was employed to avoid visually fluctuating data in the temperature analysis. In Figures 3, the note '30 per. Mov. Avg.' stands for smoothing function employing averaging of 30 data, or simply 30-point moving average. Generally, the temperatures were within 26-28 °C in the early morning (00:00 hour). The temperatures gradually dropped to 25-26 °C by 6.00 am, the temperature variation was only 1 °C across the stations compared to 2 °C at 00:00 hour. The temperatures rose with sunrise which was at 7.30 am. The temperature variation was maximum around 12.00 pm to 4.00 pm which is around 33 °C to 37 °C. At night, the temperature decreases due to thermal radiation from the earth to space. On the second day, the minimum temperatures recorded occurred from 6.00 am to 7.00 am which were 24 °C to 25 °C. In P3, the temperature recorded was higher than P9, due to the excessive energy usage and anthropogenic heat from the vehicles which contributes to the increased temperature [23]. Besides, the existence of water bodies nearest also affected the temperature [23] in P3.

Data for March (the month that is after the colder November-January North Eastern monsoon), shows a longer time for temperature > 35.0 °C for P9. For the two days, P3 and P9 recorded 3 hours and 12 min vs. 1 hour 38 minutes of temperature > 35.0 °C. That is two times longer of heated time of day. It is possible that the shading effect of the many tall adjacent buildings surrounding the station caused this effect. In contrast, for the two days, P3 and P9 recorded 4 hours 6 minutes versus 3 hours 4 minutes of temperature < 25.0 °C. That is a generally longer temperature below 25.0 °C by one hour for P3 in comparison to P9 in the two nights.



(a) Precinct 3 (UKM01)



(b) Precinct 9 (UKM02)

Figure 3: Temperature variations in Oct, Dec, Jan, Mar and Jun

Although slightly colder by two counts above, P3 is located in the CBD with activities starting as early as 7 am and only slowing down by 10 pm. Other than office buildings, banking services, and a place for social interactions, there is a large open-space parking lot in the nearby area to this station. A recent study shows that the intensity of a green canopy helps keep an area cool. Planting trees with dense canopy, criteria that fit P3 (over P9), provides microclimate and outdoor thermal comfort benefits [24].

Another station located at a hilltop with a nearby luxury hotel, surrounded by grass, sparsed with big trees in Precinct 1 is chosen as the reference point, P1. The UHI intensity can be determined by using Equation (1):

$$\text{UHI intensity, } T\ (°\text{C}) = T_u - T_r \quad (1)$$

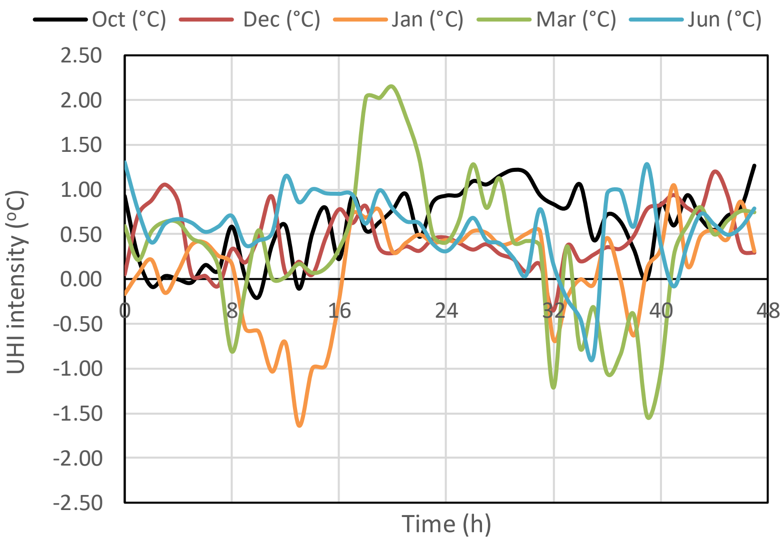
T_u is the average temperature of the urban area
T_r is the average temperature of a rural area

The UHI intensity at night ranges from 1 °C to -1 °C, whereas it increased in the daytime to 4 °C. In both research areas, the temperature at noon in December showed the values dropped to 25 °C, due to cloudy weather and a rainy day. The highest temperature was recorded in March.

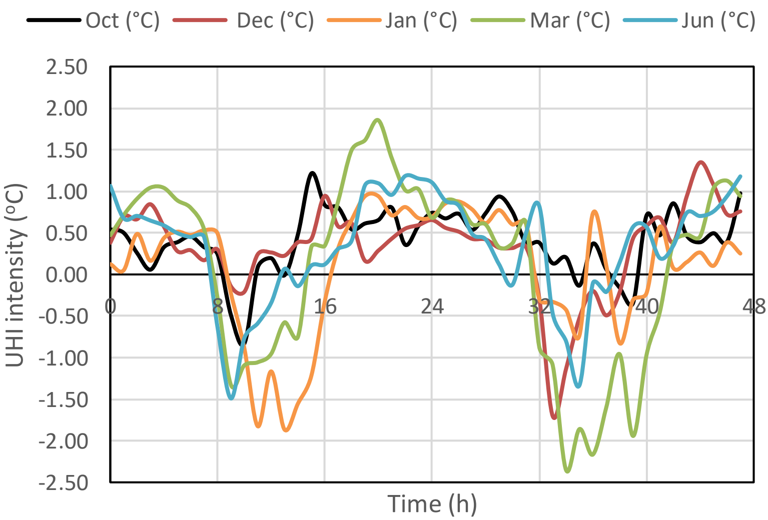
Figure 4 shows Urban Heat Island Intensity (UHII) as defined in Equation (1). UHII is maximum for the hot month of June which is in the range of about 2 °C. The range of UHII is within that measured by Harun et al [15] and simulated by Morris et al. [25] of about 4 °C and 3 °C respectively. This shows that the intensity in the planned city can dampen the UHI effect. The UHI intensifies at the calm midnight and diminished during the daytime. The higher UHII in Kuala Lumpur compared to Putrajaya is due to the contribution of massive heavy traffic and the waste heat from the air conditioning systems.

Rain

One obvious variation in Figures 3(a) and (b) is that the temperatures dipped in the afternoon on 24 Dec 2020. Only one scenario is selected here and it is possible that different rain episode brings about a different scenario, for example, a longer rain time, in a different month and different intensity brings different cooling effect. A recent study in Kuala Lumpur shows that rain falls significantly alter the probability density function of wind strength and directions, and these different winds also have different structures before, during and after the rain episode [25]. Low temperatures in the midday rarely occur, however, these are possible in December. The North-East Monsoon brings thick clouds from the South China Sea. These winds originate from the cold North and accumulate their water content along the way as temperature rises [24]. This is exacerbated by the low-pressure band due to the characteristic of ITCZ which are conditions of precipitations [20]. Figure 5 shows midday rain on 24 Dec 2020 where P3 collected 5.8 mm while P9 collected almost 8 mm of rainwater. This rain caused the temperature to dip to its lowest level of the day. The temperature rose drastically after 2 pm but did not recover to otherwise a daily high of 30 °C. In contrast, a short rain at about 9 am on 8 June caused an immediate temperature dip. As the rain stopped, the temperature rose normally and reached a typical day high of above 30 °C.



(a) Precinct 3 (UKM01)



(b) Precinct 9 (UKM02)

Figure 4: UHI Intensity variation over 48 hours for Oct, Dec, Jan, Mar and Jun

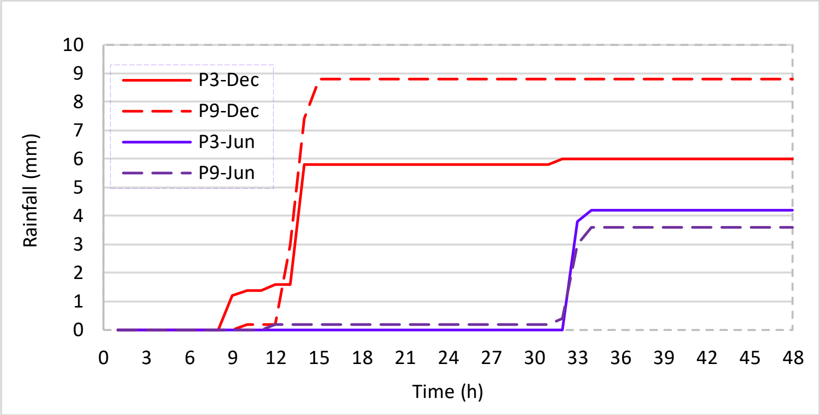


Figure 5: Rain gauge readings in Dec and Jun

Relative humidity

Relative humidity (RH) is based on total water vapor in the air. In Malaysia, located nearer to the equator, the climate is categorised as equatorial being hot and humid throughout the year. The formation of UHI also can be measured with the percentage of the relative humidity of the area. Besides, the highest temperature shows a low RH, and the lowest temperature value shows the highest humidity. Figure 6 demonstrates the RH within 48-hours in the research area (a) Precinct 3 (UKM01) and (b) Precinct 9 (UKM02).

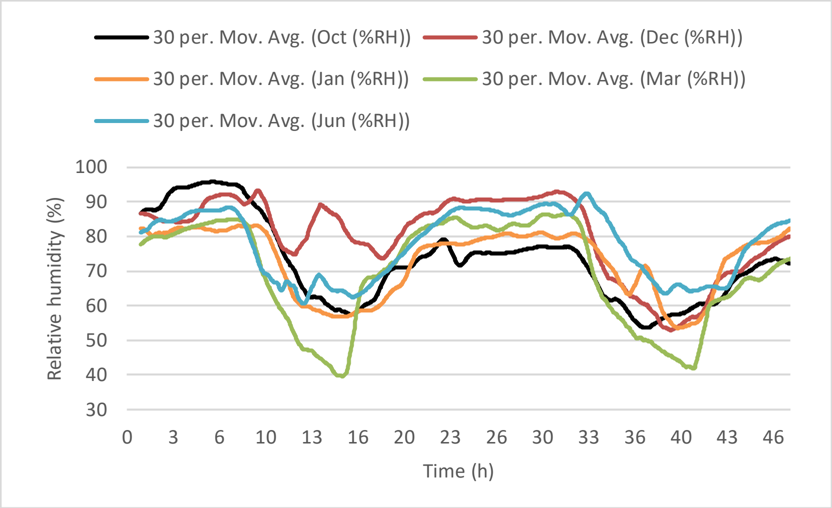
During the maximum temperature recorded on 3 March 2021 at noon, 10.00 am to 3.00 pm, the RH was low, in the range of 40% to 60%. Typically, a higher RH of above 90 % was recorded in the morning. As the sun rose and the temperature increased, RH fell. The midday rain that occurred on 24 Dec 2020 caused RH to increase almost for the entire day. The RH maintained almost a constant level for the entire night. The short morning rain on 8 Jun cause a slight increase in RH.

Wind

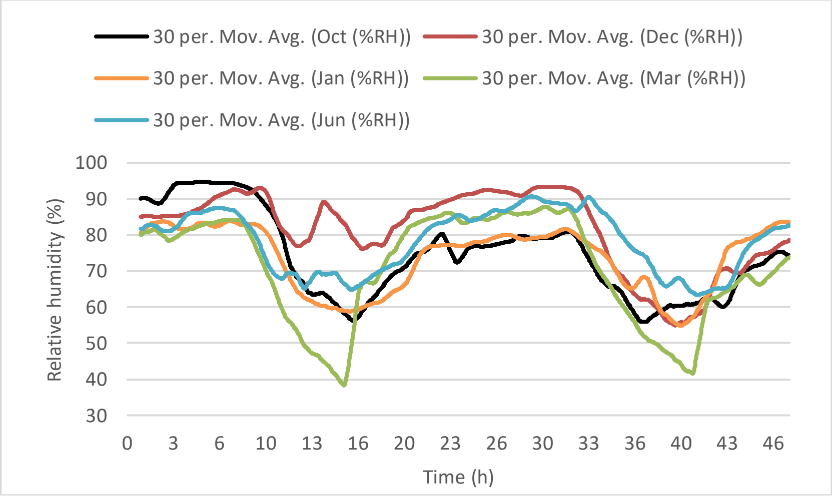
Elevated wind speeds which depend on city location and climate can decrease urban temperature (UHI strength) and dilute pollutants. Accordingly, wind speed has been employed to analyze UHI. As the ultrasonic sensor recorded all three components of wind, only the horizontal components *u* and *v* are required to calculate a velocity vector. The wind speed is calculated by using the following equation:

$$Wind\ speed, V = \sqrt{(u^2 + v^2)} \tag{2}$$

where *u* and *v* are the horizontal components of the wind speed.



(a) Precinct 3 (UKM01)



(b) Precinct 9 (UKM02)

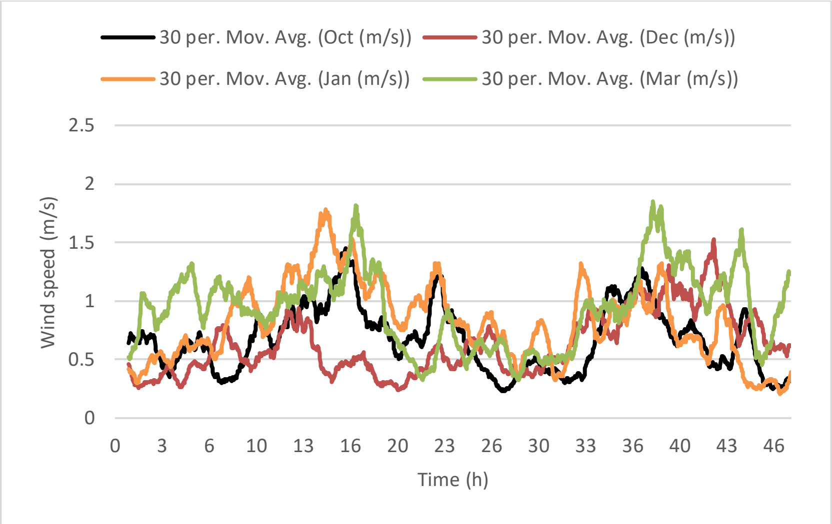
Figure 6: Relative humidity (RH) over 48 hours for Oct and Dec, Jan, Mar and Jun 2021

Figure 7 illustrates the change in wind speed within 48-hours in the research areas for Oct and Dec 2020, Jan and Mar 2021. The winds in P9 were demonstrated to be stronger than P3. This is due to the characteristics of the area; where P3 is the Central Business District, densely populated with the government office buildings and thus, blocked the airflow in the area. In Malaysia, the typical wind speeds are below 5 m/s, this is reflected by the overall wind speed pattern shown in Figure 7 which barely reached 2 m/s. Again, this is nowhere near to the descriptions by Ibrahim et al. [18], where the average wind speed is 10 m/s. Generally, in both areas P3 and P9, winds are stronger in the afternoon as compared to the strength in the night and the morning.

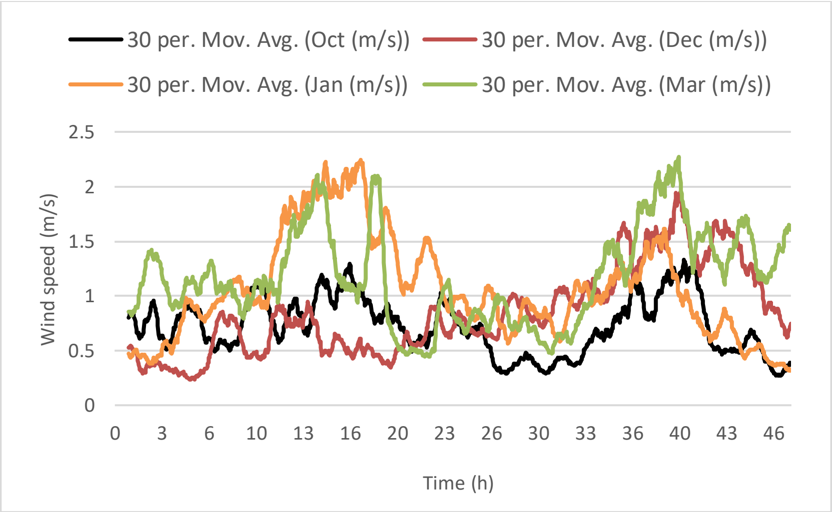
The winds brought humidity to the atmosphere, as well as hot or cold airs to the surroundings where it affected the pattern of the weather from one area to another. The main factor in determining the wind direction is the air pressure, Coriolis effect, and topography. Coriolis effect is the result of earth rotation from the west to the east, where it made the wind flow in a counter-clockwise and clockwise motion. Meanwhile, topography refers to the diversity of the landscape, hills, forested areas and tall buildings are important aspects of topography. The plotted wind roses of the average wind speed, direction and frequency are illustrated in Figures 8 (P3) and Figure 9 (P9).

In the wet month of Dec, only P9 shows the signature North-East Monsoon (Figure 9(b)) which is supposed to have the prominent North-East winds. P9 is located in the hillside, and is exposed more to the effect of the North East monsoon and furthermore, the pedestrian level sensor location was blocked by the arrangement of the high building in P3. The wind speeds were strongest in the month of March in both areas.

The street geometries, including the orientation and aspect ratio, presence of a green canopy, exert certain impacts on urban microclimates and outdoor thermal comfort [26]-[27]. Wind speed closest to the grounds are affected by the topological shape of the surrounding, as there are more obstructions to the winds, its strength is dampened resulting in low velocities. Thermal comfort at pedestrian levels is affected since heat and air pollution do not get dissipated as quickly as needed [28]-[29]. In the study using a climate modelling tool ADMS-Urban for the city of Kuala Lumpur, it was found that a strong inverse correlation between wind speeds and urban temperature [30].



(a) Precinct 3 (UKM01)



(b) Precinct 9 (UKM02)

Figure 7: Wind speed variation over 48 hours for Oct and Nov 2020, Jan and Mar 2021

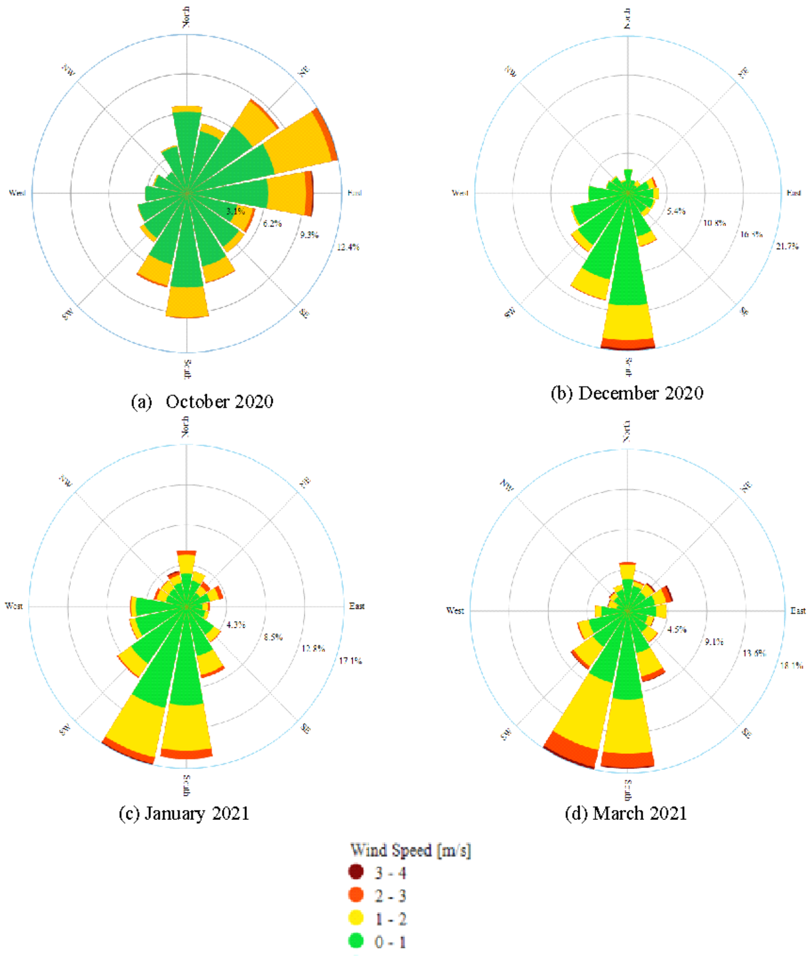


Figure 8: Wind roses of the wind speed (m/s) and frequency (%) at P3

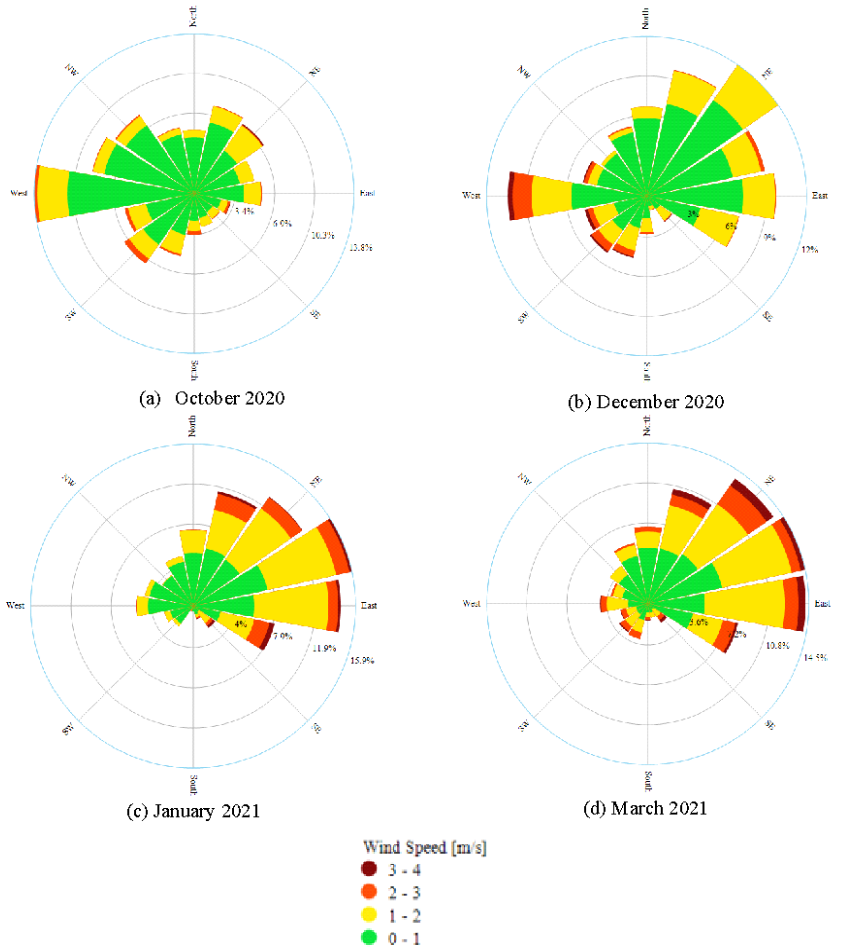


Figure 9: Wind roses of the wind speed (m/s) and frequency (%) at P9

Conclusion

A recent review based on stakeholder dialogues on UHI has profound social, economic and environmental impacts, this is categorized into five broader impacts i.e., public health, acceleration of urban migration patterns and preference in more comfortable areas, productivity deterioration, spiralling energy consumption and deterioration of environmental quality and natural resources [31]. In recent years, anthropogenic activities have led to the demand for natural surfaces with vegetations to be replaced with impervious surfaces and a rise in greenhouse gas emissions [32]-[35] increasing the global-scale UHI phenomena. This study is to evaluate the variation of the effect of UHI in the planned city of Putrajaya. The problem of the city is those city buildings and pedestrians are exposed to direct sunlight and consequent high temperatures, thus increasing human heat stress and thermal comfort. The changes in the land surface cover and increase in population are the drivers of UHI. The parameters; temperature variation, intensity of UHI, relative humidity, wind speeds and wind directions were measured and evaluated within 48 hours for one year in Putrajaya. The evaluations were done for October 2020 to June 2021. The intensity of UHI in the planned city is within 2 °C, lower compared to that of Kuala Lumpur. In 2025, the development of the Putrajaya master plan is to be completed. However, the challenge remains that any future developments must respond to the micro-climate conditions and reduce more than the present state, or at least maintain it. Based on the present trend, the city's future climate may get worse once the master plan is completed, due to the more built-up areas, the increase of the population, and mobility. Therefore, it is required to have strategies to reduce the existing high air and surface temperature to prevent climate issues in the future, even if such an action requires modification of the master plan.

Acknowledgment

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