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Original Article

Air temperature Distribution of Different Features and Urban Typology Blocks of Putrajaya City (Malaysia)

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Abstract

The study examines the effects of heat islands on Putrajaya City and evaluates the planned city features effect since climate policies were not deliberatively considered during the planning process. The aim of this study is to explore the effect of air temperature on the different urban forms and residential areas in the completed construction precincts of Putrajaya Boulevard. The investigation was performed using a mobile survey method with a data logger three times a day, during the morning, noon, and afternoon time, for three days during the hottest month in July 2012. It was found that there is no significant difference in variation of the air temperature between the different city features, and urban typology blocks, and the maximum air temperature was 37 °C. Hence, the temperature has remained constant since before the city was built. Therefore, the climate aspect was not considered during the planning process for reducing the temperature and improving environmental comfort. It is, therefore, necessary to establish a strategy and policy that will reduce the high air temperature before the master plan is completed.

***Keywords*:** Air temperature; Urban Heat Island; Putrajaya Boulevard; Residential area; Urban Typology Block

1. Introduction

Literature on the "heat island" phenomenon shows that the intensity of a heat island depends primarily on the city's altitude and climatic characteristics. A city's size and population directly affect the heat island effect [1]. A major contributor to urban heat islands is a human modification of the local climate in situ [2, 3]. Artificially altering the natural ecosystem leads to a climatically imbalanced environment. Changes in land use and modification of buildings have a significant impact on temperature increases at the neighbourhood and city scales and are crucial factors in determining the quality of the environment [4-9]. Urban planning and practice rarely take climate into account [4], site planning and greenery design reduce a great deal of urban heat island effect [10]. Thus, policies and strategies should consider measures that moderate and control urban heat island effects [6]. Ideally, future research should examine design and planning parameters to reduce the effects of urban heat islands, ultimately resulting in better living conditions. Putrajaya is a planned city, and each area that is built within it has important implications for climate, as well as the relationship between air temperature and the surroundings. It encompasses a variety of urban forms, building densities, and urban block typologies.

1.1. Description of the study area

Located at 2.55^{0}N and 101.42 ^{0}E, Putrajaya is a newly planned city based on the theme "A city in a garden". As part of the master plan, the city was divided into two main areas and twenty precincts: five precincts in the core and fifteen precincts in the peripheral areas. Putrajaya Boulevard occupies the major path axis, measuring 4.2 km long and 100 m wide, extending northeast to southwest, and containing large, symmetrical federal government buildings. Putrajaya Boulevard is classified as a dispersed urban form with a moderate density [11]. A peripheral area located 3 to 5 kilometers from the central precinct includes 14 residential neighbourhoods [11, 12]. The climate is typically tropical with hot and humid conditions throughout the year, a maximum annual temperature of 27.5 °C and a minimum of 25 °C, average humidity of 62.6 %, long daylight hours, and 4.39

$kWhm^{-2}$ of solar radiation on average. Light and variable wind generally range from 0-7.5 m/s [13].

1.2. Overview on the Local Plan, Area Guidelines, and Policies

Local planning policies and strategies guided the development of the city; a neighbourhood planning concept was used to plan the residential areas, implementing a systematic housing program based on the topography of the land. The housing types varied from low, medium, medium-high, and high-density (Figure 1). Different typologies of urban blocks result in different urban neighbourhood forms. In the design concept, the different communities, pedestrian pathways, and bicycle tracks are integrated with the neighbourhood to create a hierarchy of open spaces and green spaces. Moreover, low-density developments are located near the waterfront, while high-density buildings are located far away from it. Thus, ensuring adequate daylight, sunlight, air, and spaces for each building facing public spaces to create a sense of openness and privacy.

As part of the precinct, there are green spaces that are situated on the periphery, and landscape buffer zones provide shade from adjacent land uses. Trees and shrubs were planted as screens and for shade, and vegetation was intended for providing a sense of security and variety of interests. The city's urban landscape provides interesting views, vistas, and a sense of place. Hard and soft landscapes were designed for the concept of "city in a garden" and form a continuous green area to shade and cool the city. Most environmental policies focus on water pollution, solid waste, and noise than urban climate.

The street was designed to accommodate public utility systems and drainage systems, providing an acceptable level of safety, and minimizing the negative impact of traffic. Neighbourhood streets serve both as parking spaces and as social spaces for play and interaction. The road links are well connected to the expressway and to the main distributor roads. The city image is enhanced by the streetscape. Located in the heart of the city, the lake was designed to serve as an important feature for enhancing the aesthetics of the landscape. Besides serving as a recreational resource, it serves as a fishing, and water transportation resource as well. A continuous lakefront serves as a recreational resource as well.

All of the above policies and strategies centred on urban design and gave priority to accessibility, safety, aesthetics, amenities, society, privacy, as well as psychological and visual comfort. Climate-responsive policies were confined to buildings, while a broader review of the city or neighbourhood, green areas, building layouts, and avoiding "heat islands" as a means of enhancing wind velocity, reducing air temperature, and reducing air pollution was ignored.

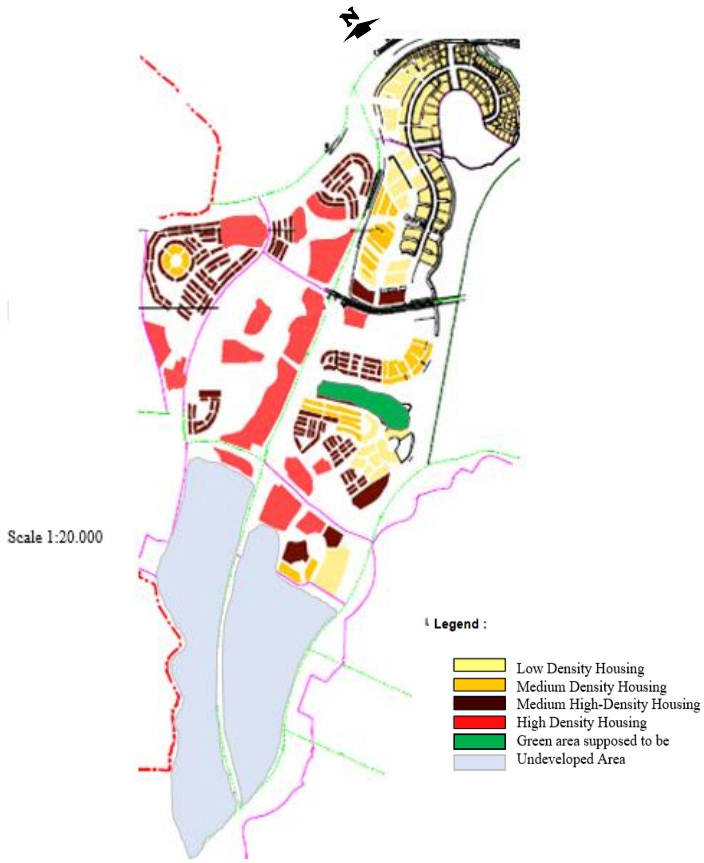


Figure 1. Map of residential area houses in precincts 8 and 10 (modified from [14])

As a result, this study will examine these constructed features (urban form of residential area, street orientation, vegetation, trees, open and green spaces, natural woodland, topography) within the city in terms of climate and investigate how these features reduce air temperature and how the absence of a climate strategy affects the city climate. This study focuses on the western peripheral areas of precincts 8 and 10 and Putrajaya Boulevard (1, 2, 3, and 4) because 90 % of the development in these areas has already been completed during the study period. It is part of a series of studies in Putrajaya city investigating its climate conditions [15-18].

2. Methodology and Material

2.1. Mobile survey

As the city is planned, every area within it is considered important and worthy of attention. A mobile traverse is a preferred method for monitoring air temperature in different locations in a city in order to show the distribution of ambient air temperature patterns in different parts of the city [19-25], it also used to gather the air pollution data within the city [26]. Two distinct routes were determined, each with its own ambient features and characteristics. A four-kilometer stretch of Putrajaya Boulevard runs through the administrative area (precincts 1, 2, 3, and 4), as shown in Figure 1 and 2 and classified in Table 1, requiring an observation time of 15 minutes. A series of streets about 8 km long pass through different residential areas (Precincts 8, 10), which require 30 minutes of observation time. The streets which have been measured are Lebuh Sentosa, Jalan Presint 8, Persiaran Seri Perdana P10, and Jalan Presint 10 C. As shown in Figure 2 and classified in Table 2, these streets are surrounded by various urban landform features. Data was collected using a temperature data logger installed in a well-insulated PVC tube and mounted on the roof of the vehicle. Data loggers were programmed to automatically record temperature and humidity every minute [16].

Figure 2. Mobile survey routes

Table 1. Description of Putrajaya Boulevard area (areas 1 to 7) according to master plan, existing urban planning, and climate zone classification of Stewart and Oke [27]

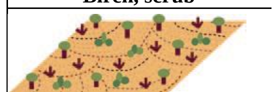
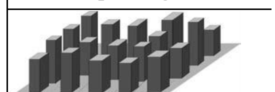
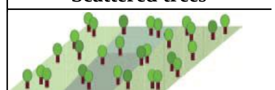
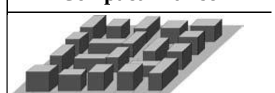
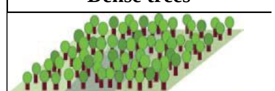
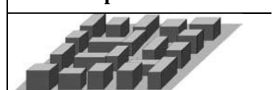
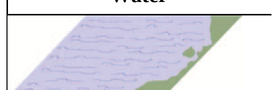
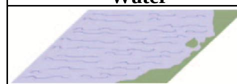
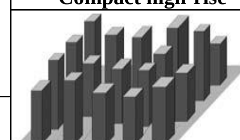
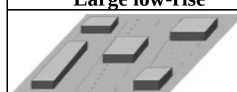
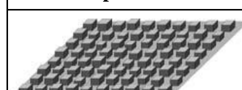
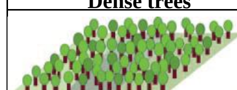
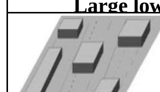
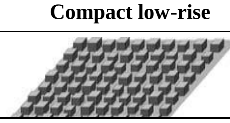
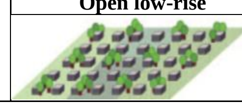
Area No	Area classification according to urban planning	Existing Putrajaya boulevard descriptions	Classification according to climate zone classification
1	**Undeveloped area**	Area of free land, greenery, grass and scattered trees bordered by bare lands and pavement on both sides.	**Low plants** 
2	**Planted islands between roads**	Trees on the island between boulevard roads are surrounded by open grass and green space.	**Birch, scrub** 
3	**Built up area**	Administrative area, both sides consist of massive buildings and moderate level of greenery.	**Compact high-rise** 
4	**Road flanked by dispersed tree/building**	One side flanked by midrise government buildings, the opposite side has separately planted trees.	**Scattered trees**  **Compact midrise** 
5	**Road flanked by dense trees /building**	Dense trees along the road on one side; opposite side features a long midrise building.	**Dense trees**  **Compact midrise** 
6	**Putra Bridge**	A bridge crosses the lake with small tress surrounded	**Water** 
7	**Open area**	"Dataran Putra" Circular wide paved area, trees are aligned along the perimeter.	**Baved cover** 

Table 2. Description of the Residential area (areas 1 to 10), according to master plan, existing urban planning and climate zone classification of Stewart and Oke [27]

Area No	Area classification according to urban planning	Existing residential area descriptions	Classification according to climate zone classification
1	**Undeveloped Area** – **Seri Saujana Bridge**	A bridge crosses the man-made lake used as a connector.	**Water** 
2	**Undeveloped Area** – **Highway road**	Surrounded by a spacious area of land, greenery, grass and scattered trees bordered by bare lands, pavement on both sides, some places excavated for construction.	**Low plants** 
3	**Relatively High topography road**	Different level land surrounded by a cluster of high-rise buildings.	**Compact high-rise** 
4	**High density housing**	High rise density buildings	
5	**Medium high-density housing**	Low rise building of 2 storeys	**Large low-rise** 
6	**Medium density housing opposite green area**	Attached and semi attached 2 story buildings / natural woodland	**Compact low-rise**  **Dense trees** 
7	**Medium high-density housing**	Dense attached buildings	**Large low-rise** 
8	**Medium density housing**	Attached buildings	**Compact low-rise** 
9	**Low density housing**	Separate buildings surrounded by trees	**Sparsely built** 
10	**Low density cluster housing**	Buildings of 2 story detached surrounded by trees	**Open low-rise** 

A mobile survey was conducted on 16, 17 and 18 July 2012. Measurements were taken every four hours starting at 08:00 LST and ending at 04:00 LST the following day. The mobile traverses were carried out three times a day (08:00, 12:00, 16:00 LST) and three times at night (20:00, 00:00, 04:00 LST) (Table 3) at a constant speed of 40 km/h. Based on a review of the measured data, the data from 16 July was used for analysis as it was a sunny day. In the analysis process, data recorded at traffic light locations were excluded to prevent reading errors caused by exhaust gas discharge from cars. The data collected along the routes were treated as actual temperatures. The data distributed along the route was based on the known route length and time spent travelling the route. The climate zone classifications of Stewart and Oke [27] were used to analyze the city urban form.

Table 3. Traverse times

No	Traverse	GSM+08:00 LST
1	Traverse	08:00 LST
2	Traverse	12:00 LST
3	Traverse	16:00 LST
4	Traverse	20:00 LST
5	Traverse	00:00 LST
6	Traverse	04:00 LST

The sunrise in Putrajaya city during July is at 7:00 LST and the sunset is at 19:00 LST. Clouds cover affect the sunshine and thus solar radiation. The maximum solar radiation incident during the measurement period reaches 1035 W/m^2 on a sunny day, and the maximum wind speed ranged between 1-2 m/s. It was primarily a southwesterly wind throughout the measurement period. Table 4 shows the sky conditions, air temperature and relative humidity during the measurement day.

Table 4. Climate conditions during the field measurement

Date	Air Temperature °C		Relative Humidity %		Solar Radiation W/m^2		Sky Conditions		
	Max	Min	Max	Min	Max	Min	Morning	Noon	After noon
16-Jul-12	32	25	93	68	1035	105		Sunny	
17-Jul-12	30.5	25	94	72	990	83	Cloudy	Rain	Cloudy
18-Jul-12	31.7	24	93	66	965	95	Rain	Cloudy	Cloudy

3. Analysis and Result

3.1. Results of residential area mobile survey

As shown in Figure 3 (a), traverse 2 at 12:00 LST was the hottest hour. The low plant area (undeveloped area) and sparsely built and open low-rise areas were hotter as they were exposed to direct sunlight. As dense trees (small natural woodlands) cover compact high, mid, and low-rise areas, the air temperature was significantly lower in these areas. Low-rise residential building areas also indicated low air temperature values. In the compact high-rise, middle-rise and low-rise areas, many streets are perpendicular to the lake, which reduces air temperature. This is confirmed by air temperature patterns and humidity as shown in Figure 4. The street has no shadows since it is oriented East and West. The air temperature in streets parallel to water bodies is higher than those perpendicular to water bodies. However, parallel streets further away from the lake show higher temperatures compared to streets closer to the water body (Table 5).

Figure 3 (b) shows that the air temperature decreased dramatically through the night. In traverse 4, the highest temperature was recorded at 20:00 LST, which is natural since trapped and stored heat is released during this time. The air temperature decreased by around 2 °C between traverses 4 and 5 at 00:00 LST and by about 1 °C or less between traverses 5 and 6 at 04:00 LST. It is possible that the unequal rates of decrease are due to wind movement; water vapor might be higher between 20:00 and 00:00 LST compared to 00:00 to 04:00 LST. In addition to the residential urban forms (buildings, trees) and the openness of the area, the reduction in air temperature is also influenced by the residential urban forms. In general, the more open the area, the higher the temperature is.

The temperature difference in Traverse 4 at 20:00 LST is higher than that during the daytime; the low plants' area (undeveloped area), the sparsely built and the open low-rise areas were the hottest during the night. There may be anthropogenic heat at the low plants' area (undeveloped area) contributing to higher night air temperatures, while calmer conditions in the sparsely built and open low-rise areas contribute to reduced air temperatures. However, the compact high, mid, low-rise areas recorded significantly lower temperatures.

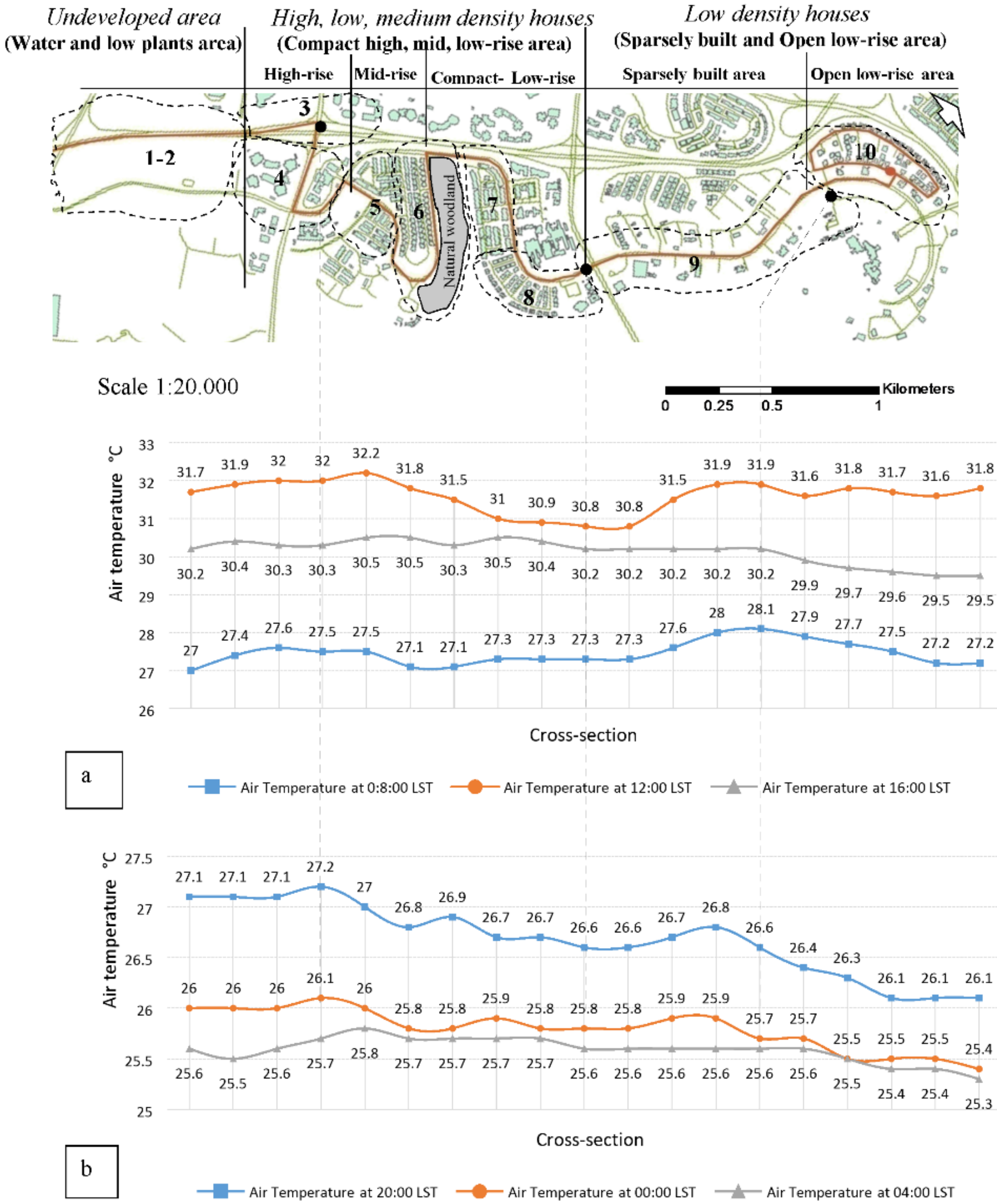


Figure 3. Daytime (a) and Nighttime (b) Air temperature of mobile survey 16/7/2012

Table 4. Street characteristics and layout

Area	Street Name	Street Orientation	Street Width (approximately)	Street layout for the lake	Lake Orientatio
Water and Low plants area	Lebuh Sentosa (highway)	Northeast-Southwest	30M	Parallel	Northeast-Southwest
Compact high, mid, low-rise area	Jalan Presint 8 (Major)	Southeast-Northwest	30M	Perpendicular	
	Jalan Presint 8E	Southeast-	15M	Perpendicular	
	Jalan Presint 8 (minor)	Southeast-Northwest	22M	Perpendicular	
Sparsely built and Open low-rise area	Jalan Persiaran Seri Perdana P10	Northeast-Southwest	20M	Parallel	
	Jalan Presint 10 C	Northeast-Southwest	8M	Parallel	

Low-rise open areas around the buildings had lower air temperatures during the night and during the day, except for 12:00 LST, when the temperatures were slightly higher because of intense radiation. Because the narrow streets are arranged to be sheltered from solar radiation, the temperature is lower during most of the day and night. Hill-shade and downhill location in low topographical land contribute to variations in air temperature in residential areas. According to Figure 3, compact high-, mid-, and low-rise residential areas have lower air temperatures than low plant areas (undeveloped areas) and sparsely built areas, which have high temperatures day and night. Variations in temperature are therefore influenced by environmental characteristics.

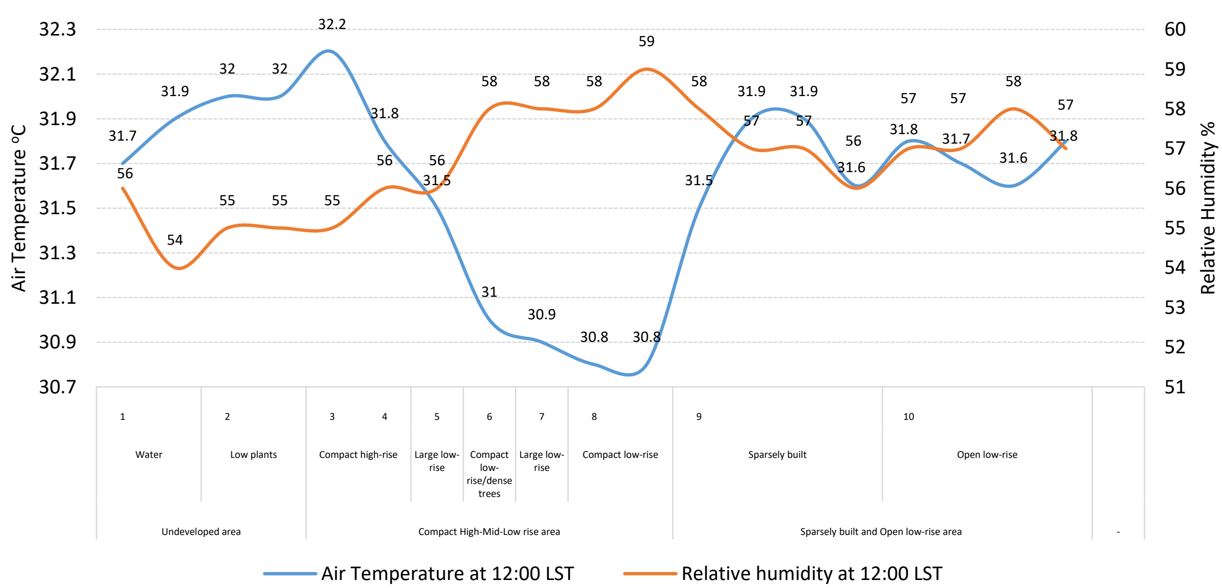


Figure 4. Relative humidity and air temperature of residential area at noon 12:00 LST

3.2. Results of Putrajaya Boulevard Mobile Survey

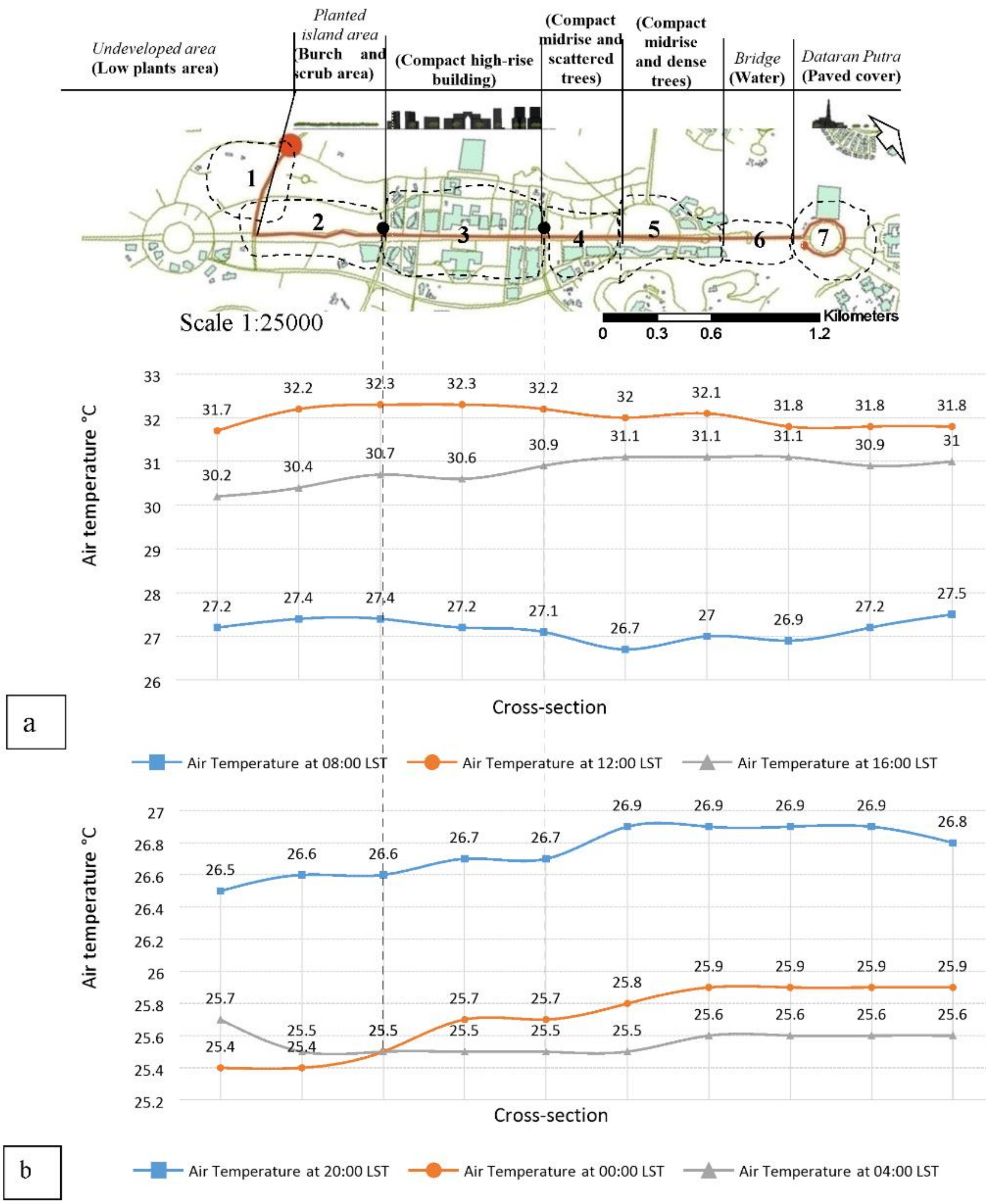


Figure 5. Temperature variation at Putrajaya Boulevard at daytime and night

The variation in the daytime and nighttime air temperature of Putrajaya Boulevard is shown in Figure 5(a) and (b) respectively. Figure 5(a) shows that the air temperature increased by 5ºC at noon compared to the morning and decreased by a maximum of 1-1.5ºC at 16:00 LST compared to noon. The air temperature at 08:00 and 12:00 LST gradually increased from the beginning of the survey and gradually declined in the compact high-rise building area; thereafter, the air temperature fluctuated, reaching its maximum in the paved cover area "Dataran Putra" in the morning and very close to stable at noon. Although there were trees in the middle of the street, their presence did not have a significant impact on reducing the air temperature.

At 16:00 LST, the air temperature trend was opposite of those in the morning and afternoon. The air temperatures were lower until the end of the compact high-rise building; thereafter, the air temperatures were higher and stable. Natural open or built-up sites differ in their air temperature due to the different angles of the sun during daylight hours. As the sun rises at 08:00 LST, for instance, buildings facing north-west have lower temperatures due to the shading from buildings on the other side. The lowest temperature was recorded at 26.7 °C in compact high-rise buildings and 26.9 °C in compact midrise buildings and scattered trees. Dataran Putra's paved cover area, the low plant's area, and the birch and scrub area are exposed to the sun, resulting in increased temperatures of 27.5 °C and 27.4 °C respectively. Due to the lower sun angle at 16:00 LST, the lack of shade on midrise buildings facing the southeast and scattered and dense tree areas contribute to the higher air temperature. As a result of the shading effect, the compact high-rise building recorded lower temperatures. At 12:00 LST, lower air temperatures were observed in the paved area of Dataran Putra, which was receiving a breeze and holding water vapour (Figure 6). Low plants' areas recorded higher temperatures due to higher exposure, and low humidity levels.

Figure 5 (b) illustrates the nighttime air temperature. During the night, the air temperature was higher in parts of the less built-up area up to the open area compared to the areas before the built-up areas. This is primarily due to the urban surface releasing heat at sunset hours, which is absorbed by the open sky area that is shown on the daytime analysis as being the reason for increased air temperature here.

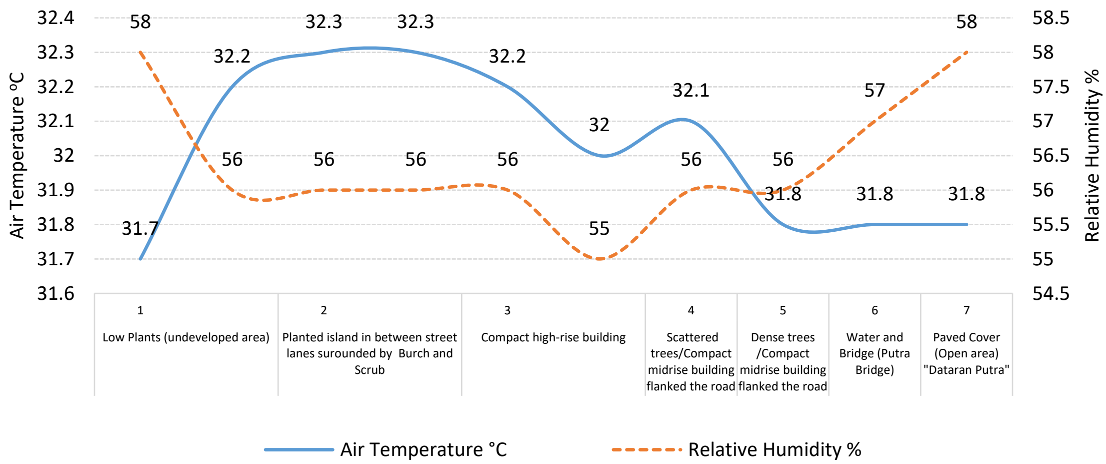


Figure 6. Relative humidity and air temperature of Boulevard Street at 12:00 LST

4. Discussion

The study examines the influence of land use, green spaces, and an artificial lake on Putrajaya city's microclimate, as well as identifying planning strategies that enhance city cooling. The study was conducted in the western peripheral areas of precincts 8 and 10 and Putrajaya Boulevard (precincts 1, 2, and 4). The climate zones classified by Stewart and Oke [27] were used to classify and analyze these precincts which were adopted in several studies [28-30]. These results are consistent with previous studies [2, 22]. Putrajaya's air temperature remains high or unchanged at present unless appropriate measures are taken.

The mobile survey results indicate that the variations in air temperature within the city are primarily caused by different urban typologies. The higher the openness, the higher the air temperature. Inbuilt residential areas and Putrajaya Boulevard, for example, have relatively low temperatures, while non-built-up low-planted areas have higher temperatures during the day/night. This result contradicts most research that mentions that built-up areas have higher temperatures [2, 22, 31]. This could be due to the low wind velocity during the night, which dissipates heat. However, further research is needed to determine the climate of the open area and the restricted area during the day and at night. In low-mid latitude regions (which have high wind movement) and tropical regions (which have slow wind movement), the open area and restricted area climates have both been studied, and all show that the more open the area, the cooler the nighttime temperatures and the warmer the daytime temperatures. In contrast, the more restricted the area, the higher the nighttime temperature and the lower the daytime temperature. Due to the effect of the man-made lake and the wide sky view of the Boulevard, Putrajaya Boulevard is hotter than residential areas during the day and cooler at night. The results are in agreement with [32, 33]. Putrajaya Boulevard's main challenge, however, is to reduce daytime temperatures while maintaining cool nighttime temperatures. The design of the lake was not a priority to cool the city. Using green spaces and vegetation within the city as a shading source was well integrated with the built form to support reducing the temperatures.

In the compact low-rise area, temperatures are reduced during the hottest hours due to the dense trees (natural woodland) adjacent to it, which provide a cooling effect [34-36]. As a result, future new development areas should be surrounded by natural trees to prevent negative climate impacts.

In a broader context, air temperature is more sensitive to the residential urban form than to the typology of buildings. Low-rise, high-rise, and compact residential areas are better than sparsely built areas with few trees. Compact low-rise areas are ideal for keeping the moist breeze cool, and compact high-rise areas provide shade. More than the boulevard area, the lake breeze is most noticeable in the residential areas, particularly in the street layout. Due to shading, high-rise buildings offer a "cool" effect, while low-rise buildings produce a "heat island".

5. Conclusion

In this study, the air temperature behaviour in a partly constructed area of the planned city of "Putrajaya" is investigated. During the planning process, no consideration was made to the fact that air temperature varies little between the different elements of the city. By 2025, the Putrajaya Master Plan is expected to be complete, and the present study may help to compare its future microclimate. Adapting future developments to microclimate conditions remains a challenge. However, the current trend is also alarming since the future climate of the city may become even worse after the master plan is completed. Consequently, there will be more built-up areas and a greater number of residents, resulting in an increase in population and mobility.

As a consequence, a policy strategy is needed to reduce the current high air temperatures, which are expected to reach 37 °C before the master plan is completed. As a result of the new policy recommendations, the city's climate will remain sustainable. However, the suggested policies would be rejected as the city is under construction in accordance with the completed master plan. In order to avoid the climate issue in the future, the city must implement a new strategy, even if it means altering the master plan concept. A further study is needed to compare the current air temperature behaviour with the future air temperature once the city is fully constructed. The use of satellite imagery data is recommended to measure the air temperature over the city and compare the climate in 2012 and 2025.

Acknowledgment

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