A Field Investigation on the Impact of the Wider Water Body on-Air, Surface Temperature and Physiological Equivalent Temperature at Malacca Town

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***Abstract*—Water features that are found in the urban zone influence the micro-climate atmosphere of the encompassing regions positively when natural cooling from the evaporative process is required during the hot radiant day. Consequently, this paper is focused on the influence of the wider water body on air, surface and physiological equivalent temperature at multiple scenarios at a pedestrian level. Where scenarios are based on the different materials being used to construct the footpaths and different width of water body of Malacca town. The climate data includes air temperature (Ta), relative humidity (RH) and wind velocity (v), globe temperature (Tg) and surface temperature (Ts) which were all continuously measured within the Malacca water body area at different scenario via field investigation through the instrument. The RayMan software package was used to elucidate the physiological equivalent temperature (PET) of the six scenarios. The results confirmed the bare red clay pavement materials that are close to adequately wide water body is the best scenario for maintaining low air and surface temperature as well slightly warmer comfort range at the pedestrian levels for creating suitable physiological equivalent temperature. This measurement activity seeks to provide an understanding in the field of climatic urban design, and the potential of utilizing water bodies (water cooling effects), as an urban design tool, about minimize the profound effects of extreme air and surface temperature on human comfort levels (PET) under the hot and humid condition in Malacca Town.**

***Index Terms*—Pavement material, surface temperature, waterbody, physiological equivalent temperature (PET), Malacca town.**

I. Introduction

Current and ongoing changes to the urban density and street mesh of modern urbanity are creating hindrances towards sensing an ideal human thermal comfort level. Previous research posited that pavements could decrease the heat island impact via its use-phase of pavements [1]–[4]. A significant percentage of land in urban areas is covered with multiple types of pavement, encompassing parking areas, streets, plazas, footpaths, and playgrounds. It should be pointed out that an uncomfortable microclimate environment discourages people from taking a walk around an area, which would result, in the long run, in health problems due to the lack of exercise among the populace [5].

Previous works on this topic reported the influence of high albedo materials on outdoor/indoor environments, where most elucidated the application of these materials on roofs. The atmospheric and surface temperature has direct and indirect effects and most direct effects of Urban Heat Island (UHI) which lower the thermal comfort of people in urban spaces [6], [7]. UHI indirectly increases energy consumption for cooling, reduces the air quality in cities, and threatens the ecosystem by warmer water flowing from the cities [8]. The surface temperature studies of urban climate research are of major significance according to [9], [10]. It converts the atmospheric temperature of the city's lowest layers and helps to establish the internal climate [8]. It will also impact the energy exchanges that influence urban residents' thermal perception. Several reports also show that urban air temperatures can be reduced through evaporative cooling [11]–[14]. A good number of researches claimed that water bodies or water feature evaporative cooling is still one of the best ways of passive cooling for cities [15]–[17]. The microclimates around waterways in a variety of past investigations have been discovered to have reduced the air temperatures as compared to the surrounding areas [18]. It has been acknowledged during the hot season in Japan, the air temperature difference between the river and the city was between 1–3 ℃ [19], [20]. UHI mitigation in policy has revealed that even a small body of water can lead to a cooling effect of 1 ℃ in temperatures reduction and the only way in which these cooling effects can be improved by carefully designing the surrounding areas. Due to the flat surface and the large heat capacity, the water body is useful to form an "air duct" for the urban climate regulation and as an important solution of urban climate change responding as well as improving the outdoor environment [21].

However, not many works focused on the effect of pavement on the ground, which is adjacent to the wider water body, upon air temperature, surface temperature and physiological equivalent temperature. This paper used a busy tourist pedestrian footpath adjacent to a water body at Malacca town in Malaysia constructed with different pavement materials. The effect of the wider water body and pavement material on air and surface temperature including PET is tested in this research.

II. Research Method

Malacca town (the capital of Malacca state) has expanded

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over the past 10 years, especially after being designated as a UNESCO World Heritage Site in 2008. Malacca town is located in the south-western part of peninsular Malaysia (2.29 °N, 102.30 °E) and encounter high temperatures and humidity in most of the days over the year, without much fluctuation. A quantitative field investigation was used to quantitatively elucidate air, surface and physiological equivalent temperature in Malacca town. Recently, more than a hundred thermal indices have been formed for measurement of the thermal conditions of the environment around humans [22]. Several indices, including predict mean vote (PMV), standard effective temperature (SET), effective temperature, outdoor SET (OUT-SET), universal thermal climate index (UTCI), PET, and enhanced conduction-corrected modified effective temperature (ETEE), were employed to determine the outdoor thermal comfort [23]–[31]. PET is discussed extensively in the studies as the other suitable thermal index in the study by [27]. Other latest studies have also shown that PET and SET * are the best options to evaluate thermal comfort outside instead of indoor based thermal indices [32], [33]. Recent studies, however, compare PET and SET * with the same outdoor circumstances to select the most accurate index. The respective studies suggest the use of PET as the most precise outdoor thermal index for thermal calculation in outdoor surroundings [34]. Similarly, [35] highlight the appropriateness of the PET index for outdoor thermal studies while describing the index as the best strategy for predicting thermal comfort in outdoor environments. Besides, the respective studies convey the efficiency and flexibility of calculating PET through the interconnected RayMan computer software as the thermal software available for free [36]. This research, therefore, chooses the PET as the suggested index for the thermal component assessment of the chosen outdoor areas where the survey was focused on determining the impact of the wider water body on the aforementioned outdoor spaces at pedestrian levels of Malacca town.

Fig. 1. Bird's eye view of the experiment field measurement area.

The first phase of this research method involves collecting principal data via information from the site, encompassing observation (i.e. walkthrough), meteorological data, reports, material, and electronic documents. On the back of this data, site conditions were generalized and categorized into seven scenarios, as per the context of the current situation and planning, the width of the water body, pedestrian pavement material, and distance from the water body. During the first phase, specific information on all the scenarios was gathered. With the help of that information, field measurements were conducted, which was the second phase of this work. This experimental method was conducted during regular days from March 15, 2019, to March 19, 2019, from 10:00 a.m. to 6:00 p.m. The third phase involves concentrating on micro-climate variables and outdoor thermal comfort index, also called PET. The influences and insights were collected and reported in the form of guidelines for the improvement of outdoor space at pedestrian levels in the context of Malacca town. Table I describe the instruments used for the field investigation.

TABLE I: DETAIL THE INSTRUMENTS' USED FOR THIS PURPOSE

Instrument Name	Measurement Parameters	Range	Accuracy	Resolution
GM816A Digital Anemometer	Va (ms^{-1})	0–30 ms^{-1}	±5%	0.01
RC-4HC Data Logger & External sensor for Surface Temp	Ta (°C), RH (%) Ts (°C)	-30–+60 °C 0–99% -40°C~+85°C	±0.18 °C ±2.5 %	0.02 °C 0.03%
General Handy Heat Index	Tg (°C)	0°C–50 °C	±1°C	0.1

A. Filed Measurement Scenarios

These scenarios can be split into 3 categories depending on the river width and pedestrian walkway material (Fig. 1). The experimental field investigation outlined seven scenarios on the base of the existing situation of the water body and current setting of the footpaths of the Malacca town. However, in the interest of accurate quantification of the influence of the wider water body, one scenario, on vegetation, was omitted. In scenarios III and scenarios IV had a fixed river width of 15m where pedestrian side walkway pavement material is brick. Again scenario III is adjacent to the river and scenario IV is 35m away from the river. Once more scenarios II and scenarios VI had a fixed river width of 18m where pedestrian side walkway pavement material is clay, where scenario II is adjacent to the river and scenario VI is 30-35m away from the river. Furthermore, Scenarios V and scenarios VII had a fixed river width of 15m where surface material of pedestrian side walkway is also clay title identical of, and scenario V is next to the Malacca River whereas scenario VII is 30m apart from Malacca River. These scenarios are tabulated in Table II.

B. Estimation of Air (Ta), Surface (Ts) & Physiological Equivalent Temperature (PET)

Air Temperature (Ta), Globe Temperature (Tg), Surface Temperature (Ts), Relative Humidity (RH), and Wind Speed (Va) were regularly measured at 10-minutes interval on each survey day. The survey was started at 10:00 a.m. as, during this time, both the solar radiation and Ta, Ts are started to increase. The instruments followed the reference standard and kept on a tripod at 1.1 m above the ground [23]. The data on Ta (°C), RH (%), Va (m/s), Mean Radiant Temperature (Tmrt) (°C), (Ts), cloud cover (which is considered 0 oktas), and water vapor pressure (vp) were calculated through RH conversion in the Rayman 1.2 Model in order to yield the PET values. Subsequently, the Tmrt is achieved by substituting Ta, Tg, and v into the following equation [30]:

$$Tmrt = [(Tg + 273) + 2{:}5 \times 10^8 \times v^{0.6} (Tg - Ta)]^{1/4} - 273 \quad (1)$$

The thermal influence of the radiant fluxes was assessed by a globe thermometer. Based on Tg (℃), the globe's emissivity (εg), the globe's diameter (D in mm), and mean radiant temperature (Tmrt in ℃) were calculated for forced convection and in sunshine conditions under direct solar radiation. Höppe [37] and Jendritzky and Höppe [38] established the energy balance of the human body as an advanced strategy that derives the bio meteorological thermal indexes and describes and quantifies the outcomes of the thermal environment in humans. To determine the thermal comfort range in the tropical regions, a study was conducted in Taiwan outdoor climate [39]. This study classified the thermal comfort for temperate climates for further modifications of the PET classes that would suit the tropical and subtropical climatic conditions. The results showed significant thermal comfort range of respondents when compared with the tropical scale which was based on the study performed in the tropics [39]. Trough RayMan contrast revealed an only slight difference in PET (within 0.1 ℃) among men and women of standard height and weight. Thus, the present study selected males of 1.75 m height, 70 kg weight, and 35-years-old for statistical analysis. The activity type of 87% of the tested individuals on the pedestrian side walkway was walking (0.9 m/s), and therefore, the corresponding metabolic rate of 115 W/m^2 was considered as the calculation parameter. Furthermore, the clothing insulation was 0.90 clo.

TABLE II: DESCRIPTIONS OF SCENARIOS

Scenarios	Pavement Material	River Width	Distance from Water Body	Parameter	Selection
Scenario I	Brick	18m	0-3m	Trees	x
Scenario III	Brick	15m	30-35m	N/A	√
Scenario IV	Brick	15m	0-3m	N/A	√
Scenario II	Clay Tile	18m	0-3m	Nominal Vegetation	√
Scenario VI	Clay Tile	18m	30-35m	N/A	√
Scenario V	Clay Tile	15m	0-3m	N/A	√
Scenario VII	Clay Tile	15m	30-35m	N/A	√

III. RESULTS

A. *The Air and Surface temperature of Scenarios Respectively*

The air temperature (Ta) value in scenarios IV was generally completely greater in terms of assessment outcomes of the Ta values of scenarios III. The results indicate that the air temperature in scenarios III varied approximately between 34.5 ℃ and 31.5 ℃, while in scenarios IV, between 32 ℃ and 31.0 ℃ was recorded. Variations in ground surface temperature appear during the day beginning at 11:00 a.m. and rising dramatically until they achieve a peak at 1:00 p.m. Moreover, the greater reflected heat from the surface temperatures (Ts) usually leads to higher air temperature. This is due to elevated solar radiation exposure and dry ground surfaces that cause thermal sensitivity instead of latent heat. The more temperatures the surface is, the greater the air temperature during peak time. Based on Fig. 2, it can be observed that in Scenario III and Scenario IV regarding Ta and Ts there is no such contrast. It can be concluded that as the pavement is brick in both scenarios, the temperature difference is very nominal, which not affect the 15 m wide bodies of the water. The results for scenario II and scenario VI showed that for the whole duration of data collection in scenarios IV, the air temperature value (Ta) is higher than the Ta value from Scenarios II. The conclusions indicate the approximately, the air temperature varied from 30.6 ℃ to 40.8 ℃ in scenario II while 33.6 ℃ to 43.5 ℃ was recorded in scenario VI shown in Fig. 3.

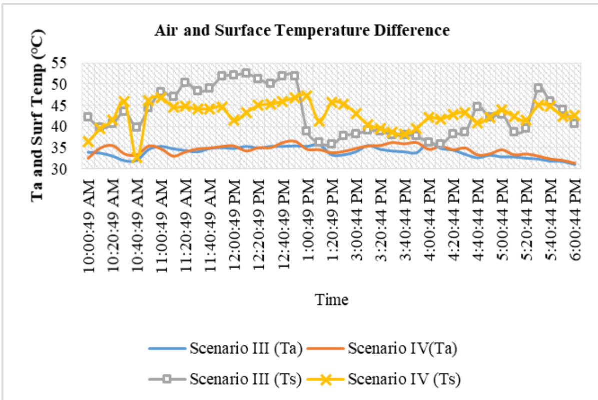

Fig. 2. Scenario III & IV- air and surface temperature variations.

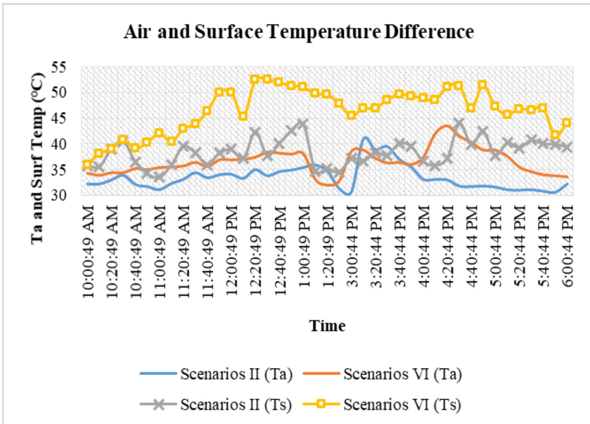

Fig. 3. Scenario II & VI- air and surface temperature variations.

Fig. 3 described for a further explanation concerning air temperature and the relative modification of humidity of the evapotranspiration process from the water bodies to the ground surface temperature. At Scenario II, it was observed that both the surface and air temperature decreased at the point where the width of the river was 18 meters. Scenario VI, however, is away from the water body and the surface temperature is significantly higher than scenario II. The findings for the last two scenarios showed that for the period between 1:00 p.m. and 6:00 p.m. on measuring days the value of air temperature (Ta) in scenarios V was lower than the Ta values of scenarios VII. Yet again average temperature alteration between both scenarios is very nominal 1.24 ℃ (see Fig. 4).

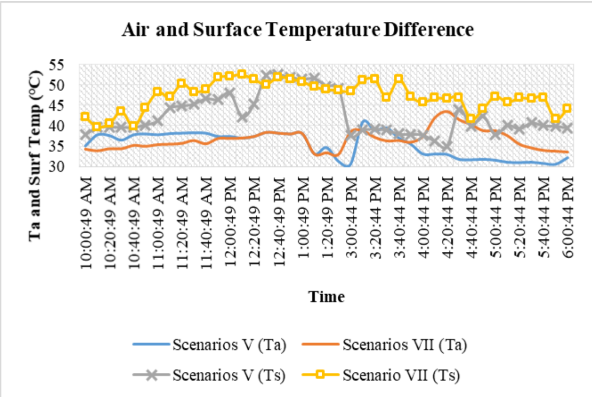

Fig. 4. Scenario V & VII - air and surface temperature variations.

The surface temperature of the ground appears to be divided between 11:00 a.m. and rise drastically during the day to a peak at 1:00 p.m. However, from Fig. 4, it can be noted that there is a difference in scenario V and scenario VII. As scenario V is near to water body though the width of the water body is only 15m wide it shows less ground surface temperature from scenario VII which is 35m away from the water body. It is therefore sufficient to mention that two important microclimate entities correlated with one another are the air and surface temperatures.

B. The Physiological Equivalent Temperature (PET) of Scenarios Respectively

Fig. 5 shows the calculated values of PET for scenarios III and IV. PET values of both scenarios are usually above the maximum Comfort Limit of 30 ℃ during the investigation. In Scenario III, next to the water body of Malacca, with a brick pavement for a footpath without surroundings operational screening, most of the moment, the comfort is essentially the least. It is visible in Fig. 5 particularly around noon during the measurement moment, in scenario IV the PET values are closer to the very hot range and it was away from Malacca water body with same brick pavement for a pedestrian walkway without any effective screening generated by environ. It has been shown that PET values for both areas are above the acceptable range (less than 34 ℃) the whole time of the assessment operation, in spite of the significant variations of their heat circumstances between the situations.

It is nevertheless apparent that values of PET calculated in Scenario II (Fig. 6) significantly less than the Scenario VI. Consequently, Scenario II was 18 meters wide with clay pavement, close to the Malacca River, for sidewalks and rests which readily can transmit solar radiation. Clay tile is naturally contained of transparent crystalline particles with directional anisotropic refractive indices. According to Sameera et.al, (2017) bare red clay tile can achieve Near Infrared Radiation (NIR) for high solar reflectance (capability to reflect sunlight) and high thermal emittance (potentiality to radiate heat) remain cool in the sun [40]. Thereby, approximately, the acceptable period of the thermal condition within Scenario II was obtained in the late morning and late afternoon.

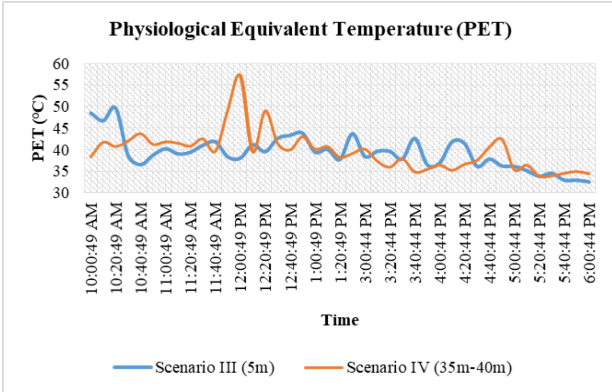

Fig. 5. PET variations in scenarios III & IV.

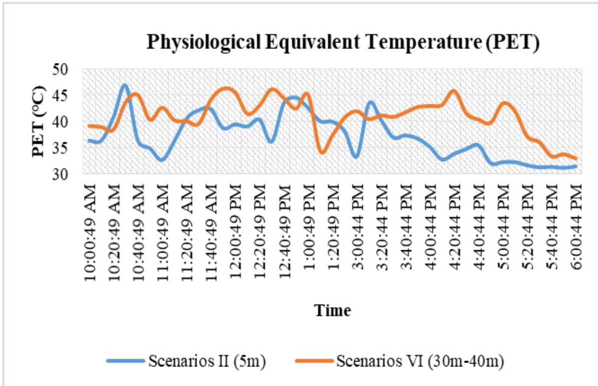

Fig. 6. PET variations in scenarios II & VI.

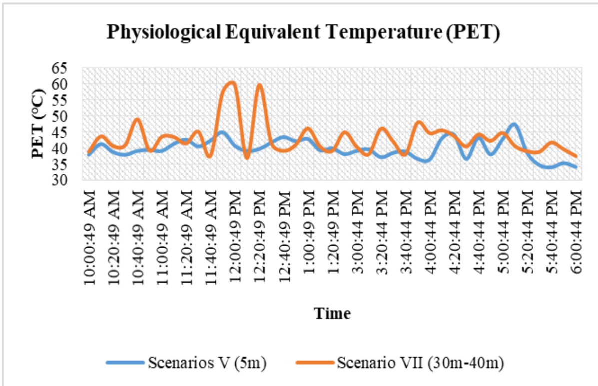

Fig. 7. PET variations in scenarios V & VII.

Nevertheless, Scenario VI was considered to higher for thermally comfortable comparing to Scenario II with the abovementioned periods. During the measurement periods, at Scenario VI, PET was gone to 44 ℃ which indicated a very hot environment and from 11:20 a.m. to 4:30 p.m. Nonetheless, it is visible that the values of calculated PET of scenario V and scenario VII were noticeably higher than any of the previous scenarios for the period of the measurement procedures in Fig. 7. During the measurement periods, at Scenario VII which is away from the water body, PET was 39 ℃ to 44 ℃ which indicated a very hot environment and from 11:20 a.m. to 5:00 p.m. The probability was nevertheless very low at PET < 34 ℃ (acceptable range) for Scenario V though it is close to 15m wide water body, whereas, because of the high amount of solar radiation at the location, the calculated PET values were largely above the limit from 11:40 a.m. to 4:30 p.m.

IV. Discussion

Field Investigation on the footpath beside the water body of Malacca town confirmed that light, laid bare on the red clay tile pavement with 18m wider water body render the microclimate of the area during daytime. We utilized six scenarios in the context of the pavement materials, river widths, and distance from the river to observe its respective corresponding on air and surface temperature as well as PET differences. The air temperature, surface temperature, and PET values and width as well distance from the water body are interconnected. The findings of the urban scenarios show the duality and the effect on outside thermal comfort from paving materials and water bodies. In determining outside micro-climate, the pavement material on the footpath was discovered to be quite important. The largest Ta, Ts, and PET in Scenario VII is discovered where the surface is bare red clay tile and 35 meters from a water body of 15 meters. Indeed, it is clear that Ts and Ta are the most critical regions in a comparable situation. Therefore, greater ground surface temperatures are associated considerably with greater air temperatures and vice versa. In scenario VII ground surface temperature is found highest and it is thought that this is one reason why the air temperature is greater in this scenario which leads to a very hot outdoor PET index. On the contrary lowest PET was found in scenario II where pavement material is bare red clay tile and near to 18m wide water body. In this scenario, the ground surface temperature is found less than another scenario due to the effect of 18m wider water body. The method of evaporation can be discovered owing to the water content stabilization. Water systems are efficient. Enhanced river width contributes to cooling and thermal comfort outside [18]. This explores the fact that the air temperature and surface temperature in this scenario II vary considerably. As a result, the air is less warm, air temperature is lower, and other scenarios leading to scenario II, PET in the warm thermal comfort zone are the highest. The best and worst results of the studies are due to changes in the width of the river. The urban scenario of Malacca town on a pathway with a bare red tile of clay and an 18 m river width is advantageous over urban scenarios with a brick pavement, a bare red tile and 15 m river width.

V. Conclusion

The conclusion can be made, that the wider body of water with adequate surfaces improves the air temperature, surface temperature and physiological equivalent temperature of the outdoor at the pedestrian level in the Malacca town. The potential of urban water bodies to mitigate the surrounding temperature has various benefits including the reduction in levels of energy consumption, improved thermal comfort of pedestrians in outdoor environments. These changes provide increased interceptive and evapotranspiration processes in the decreased atmosphere and optimally boost the relative humidity by average radiant temperature. These findings highlight the potential of pavement material and water body to lowering the air temperature and surface temperature as well as improve the PET at the pedestrian level. It is recommended that in future studies, the different forms of the implementation of water body via pavement material considering the amount of vegetation in the case of the urban landscape for the mitigation of the urban heat island and stimulating outdoor thermal comfort at pedestrian levels be investigated.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

G. Manteghi and T. Mostofa conducted the research and experiments, analyzed the data, and wrote the paper; Md. P. Noor contributed to paper contents and edited and proofread the final paper; all authors approved the final revision of the paper.

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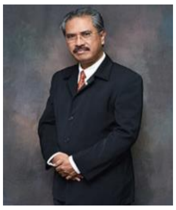

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