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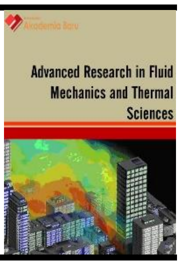

Street Geometry and River Width as Design Factors to Improve Thermal Comfort in Melaka City

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ABSTRACT

This paper addresses the contributions of urban geometry under hot-humid climate in the Melaka City, Malaysia, and their benefits toward optimum cooling effect of water body modification. The aim is to examine quantitatively the potential of the cooling effect from water bodies in combination of street geometries and the development of comfortable microclimate conditions at street level in the city environment. ENVI-met microclimate model were developed to predict the impact of modification according to the proposed hypothetical urban geometries investigated include various street aspect ratio equal to 1, >1, and <1, and river width equal to 18, 36, and 54 meters. The proposed urban settings that resulted from the combination of the various streets and river width are modelled on four different orientations, including EW, NS, NE-SW and NW-SE, and a total of 36 different urban geometries are evaluated. The outdoor thermal comfort was assessed based the outcome developed local physiological equivalent temperature (PET) as reference to evaluate modification benefits towards outdoor comfort level. It is revealed that the existing variation in temperature between the different urban locations in the Melaka water body area was due to the influence of their geometrical characteristics. The conclusions derived from the microclimate modelling point out the necessity for promoting water body cooling effects can be implemented as additional guide lines in urban design to keep the external microclimate conditions in comfort range and influence the bio-climatic factors in urban tropical climate.

Keywords:
Street geometry; water body; Physiological Equivalent Temperature (PET); envi-met microclimate model

1. Introduction

Over time, research on thermal comfort in urban areas has been of great importance for many scientists. The local and global climates are affected by the urban microclimate and therefore it also affected urban habitats. Many factors influence the urban microclimate and these include urban density, urban form, urban geometry, water levels, vegetation, and surface properties. Applying

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these factors unsuitably contributes to climate harshness including high temperatures in urban areas as compared to suburbs and this leads to thermal discomfort. The urban heat island is created by heat that is stuck due to urban geometry, replacing vegetation by built form, urban surfaces, and anthropogenic heat sources [1,2].

About a quarter of urban areas is covered by streets and therefore the design of a street is an important issue when it comes to taking a global approach in environmental urban design. Streets are characterized by different length/width (L/W) and height/width ratio (H/W) ratio and direction defined along its long axis [3]. The presence of these factors in a straight line affect solar radiation absorption and emission as well as urban ventilation and this significantly impacts temperature differences in the streets and the thermal comfort in the adjacent environment. Literature on the topic of study indicates that the time of day and the duration of the thermal stress within a street canyon is significantly influenced by the orientation of the street and aspect ratio (H/W) [4, 5].

Apart from streets water bodies located in urban environments have a key role in the regulation of the microclimate of the urban areas. They improve the thermal comfort of the surrounding environment by maintaining cooler air temperatures through evaporation. In hot summer days, natural cooling as a result of evaporation is very important as water availability means increased evaporation as well as the latent heat lift and additional cooling during the day [6–9]. When water availability is unlimited, an effective latent heat sink is provided as well as enhanced evaporative cooling which contributes towards destabilizing the surface later and therefore improves mixing. These features make the surface temperature of water bodies to be cooler as compared to surface temperature of land. A cooler surface implies that the air is also cooler and therefore the comfort levels are higher. Theoretically, evaporative cooling procedures by rain latent heat exchange between water and air and the absorption of sensible heat and therefore modify the distribution of radiant energy. These features of water bodies makes it possible to use water as a cooling agent in regulating the microclimate in urban areas and therefore assuring comfort for pedestrians [10].

Previously, some studies indicated that water bodies significantly contribute to the cooling of the environment by resulting in the drop in ambient temperature by 4 °C as compared to areas with no water bodies. Additionally, evaporative cooling is promoted by water ponds and this contributes to the mitigation of the urban heat island. It is found that rivers with a width of >40 m, has a stable and significant increase in humidity and a decrease in temperature was noted in the adjacent urban areas. Another study by Beaufort *et al.,* [11] found that a temperature drop of 1.5◦ C was recorded for a river of 35 m wide. Much consideration have not been given to water bodies as compared to other zones such as those in tropical areas in which the evaporative effect of water which can be essential in moderating the temperature of the environment .

The aim of this paper is to examine quantitatively the potential of the cooling effect from water bodies in combination of street geometries and the development of comfortable microclimate conditions at street level in the city environment.

2. Methodology

Among the numerical models being reviewed, 3D model ENVI-met version 4.0 is regarded as the most suitable for the simulation, since it simulates the microclimatic conditions within urban environments in a high spatial and temporal resolution, and it will be used in this case due to its fastness and low-cost [12,13].

The generated numerical models in this study are agree with the building regulations of Melaka Town in terms of local street width, Melaka River width, building heights and the common building materials used in Melaka. Different parametric characteristics of the urban canyons are subjected to adjustment. The effect of the following design parameters on microclimate is analyzed:

i. Street geometry (H/W ratio)
ii. Street orientation
iii. River width

The H/W ratio is selected to reflect the measurement sites. H/W < 1 is reflecting Melaka old heritage zone and H/W> 1 is reflecting Melaka new modern zone. The street orientations for each H/W ratio: EW, NS, NE-SW and NW-SE is analyzed for all simulations. The real width of the Melaka River, which is twice or thrice wider than the original, is simulated as well.

After the simulation was validated in previous studies [14], the same main model domain was used to simulate 36 different hypothetical scenario conditions, in three groups based on river's width. The outputs from the current conditions and 36 proposed scenarios were compared and analyzed in order to discuss the outcome from each resulting modifications. In order to confirm the presence of benefits other than mitigating temperature and increased cooling effects from the river body, the meteorological outputs from each simulation result were used to analyze the impact on the outdoor thermal comfort of Melaka study area's users. The outcome was subsequently used (in analyzing the influence of microclimate modification towards thermal comfort level) as a reference when comparing the outdoor thermal comfort levels of the current conditions and post-modifications, which was based on the meteorological output from ENVI-met simulation. In this study, information on weather types and cloud conditions from the Melaka water body study area was needed to identify a single clear day (i.e. June 21st, 2018) for computer simulation and meteorological basic settings in the ENVI-met software (i.e. cloud cover) within a 48-hour time span.

The Ray-Man model was used to determine the comfort level index in PET values, and finally, the modification results from the ENVI-met were compared to the current simulation model comfort range. In this study, the upper discomfort limit proposed by Wei [18] Shahidan [17] and Lin *et al.,* [16] for the hot humid climate in Singapore, Malaysia and Taiwan, respectively which roughly corresponds to a PET of 30°C was included as a reference for Melaka (Table 1) [15–18].

Table 1
Thermal sensation and PET classes for Singapore, Malaysia, and Taiwan [16-18]

Thermal sensation	PET range for Singapore[a] (°C PET)	PET range for Malaysia [b] (Persiaran Perdana) (°C PET)	PET range for Taiwan[c] (°C PET)
Very cold	not applicable	not applicable	<14
Cold	not applicable	not applicable	14-18
Cool	not applicable	not applicable	18-22
Slightly cool	not applicable	not applicable	22-26
Neutral	26-30	23.9-31.6	26-30
Slightly warm	30-35	-	30-34
Warm	35-39	31.6-39.3	34-38
Hot	39-43	39.3-47	38-42
Very hot	>43	>47	>42

3. Hypothetical Urban Geometries in 3 Groups

The first group contains three urban settings of River/Street typology at three successive heights; 8 m, 12 m and 16 m. The modelled urban settings are varied in their street aspect ratios (H/W = 1, H/W >1 and H/W <1), but the river widths are similar, at 18 m (RW= 18 m). Each urban setting was modelled at four different orientations, combining NW, EW, NW- SE, and NE-SW. The vertical sections through the river and the street canyons are illustrated in Figure 1.

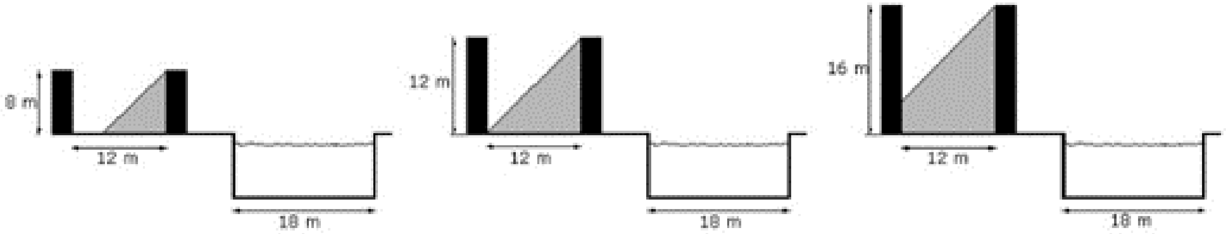

Fig. 1. Cross vertical sections through the river and street canyons in Group 1

The results shows, the coolest conditions at the pedestrian level were obtained in case studies with EW axes. This was expressed by the shorter duration of the Tmrt maxima irrespective of the aspect ratio. Indeed, street orientations, with respect to water body, played a distinguishing role in determining the duration of extreme Tmrt within the street canyons in all urban settings being analyzed in the first group.

The second group contains three urban settings of River/Street typology at three successive heights: 8 m, 12 m, and 16 m. Each urban setting was modelled at four different orientations (EW, NS, NE-SW, and NW-SE) in order to evaluate the respective impact on outdoor thermal comfort. The evaluated models vary in their street aspect ratios (H/W = 1, H/W >1 and H/W<1), but have similar river widths equal to 36 (RW = 36). The vertical sections through the river and the street canyons are illustrated in Figure 2.

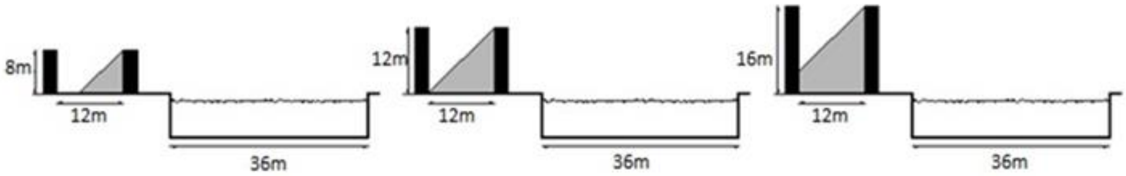

Fig. 2. Cross vertical sections through the river and street canyons in Group 2

Generally, the second and the third urban settings in the second group showed relatively better thermal conditions at the pedestrian level as a result of the shorter durations of extreme Tmrt, mostly in the EW oriented canyons. Yet, the shorter durations of extreme Tmrt within both urban settings were observed relative to different canyons.

The third group contains three urban settings typology at three successive heights: 8 m, 12 m, and 16 m. Each urban setting was modelled after four different orientations, including EW, NS, NE-SW, and NW-SE. Therefore, the results of 12 microclimate conditions were obtained in order to evaluate their respective impacts on the outdoor thermal comfort. The evaluated models vary in their street aspect ratios (H/W= 1, >1 and < 1), but have similar river widths, at 54 (RW= 54). The vertical sections through the river and the street canyons are illustrated in Figure 3.

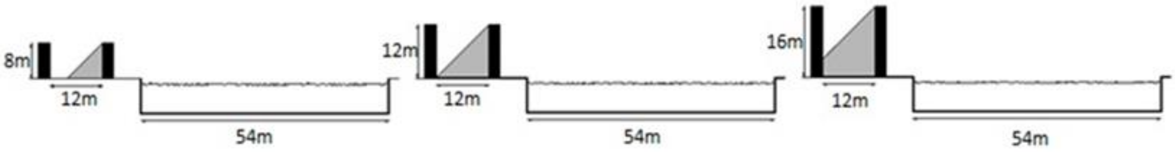

Fig. 3. Cross vertical sections through the river and street canyons in Group 3

According to the results, the street canyons with the EW axis have the shortest duration of Tmrt, irrespective of canyon's geometry and aspect ratio factors. In terms of the other orientations (NS, NE-SW, and NW-SE), the results show considerable reductions in the duration of extreme Tmrt within the deep street as a result of the relatively larger shading produced by the surrounding buildings at the street level and the wider river width. This is evident via the considerable reduction in the duration of extreme Tmrt within the deepest street canyon oriented to NE- SW and NW-SE (H/W>1) compared to the corresponding one observed within the widest street canyon (H/W <1), where the duration of extreme Tmrt at the pedestrian level decreased.

4. Comparison of PET Based on Modification Scenarios

The final step involved the combination of the changes to the microclimate at the street level and the "Best Case" scenario. In the first group, it can be seen in the EW oriented streets, can strongly prove the influence of the water body. The value of PET in outdoor spaces in hot-humid climate regions is closely driven by solar irradiations to an analysis of outdoor thermal comfort to conducted on one case study, which maintained the minimal duration of extreme Tmrt during the day amongst other evaluated urban settings. The NS axis offer the best thermal situation, but did not differ much from the EW axis. The street canyon with the EW axis is not as uncomfortable as expected, as detailed in Table 2). On the other hand, the deepest street canyon (H/W >1) resulted in a relatively cooler condition at the pedestrian levels compared to the other urban settings in the first group. Within the urban setting with the deepest street canyon, the NS axis has, on average, proved to possess superior thermal conditions. The E-W axis, due to the existence of a water body, experience better thermal comforts compared to the intermediate orientations.

Table 2
Comparisons of PET based on current and modification scenarios in Melaka water body area

St. Orientation		Air Temperature, PET and Comfort Level											
		NS St.			WE St.			NE-SW St.			NW-SE St.		
Groups	Aspect Ratios	Ta (C°)	PET (C°)	COMFORT LEVEL	Ta (C°)	PET (C°)	COMFORT LEVEL	Ta (C°)	PET (C°)	COMFORT LEVEL	Ta (C°)	PET (C°)	COMFORT LEVEL
G1. River Width=18	H/W <1	27.97	29.98	Neutral	27.93	33.13	Warm	28.93	32.28	Warm	29.02	31.74	Warm
	H/W =1	27.77	28.77	Neutral	27.80	29.57	Neutral	28.61	30.32	Warm	28.77	30.24	Warm
	H/W >1	27.83	28.16	Neutral	28.03	29.68	Neutral	28.40	29.60	Neutral	28.59	29.99	Neutral
G2. River Width=36	H/W <1	27.97	29.94	Neutral	27.93	33.00	Warm	28.90	32.19	Warm	28.91	31.54	Warm
	H/W =1	27.76	28.74	Neutral	27.79	29.48	Neutral	28.59	30.27	Warm	28.64	30.06	Warm
	H/W >1	27.80	28.13	Neutral	27.97	29.61	Neutral	28.38	29.52	Neutral	28.42	29.76	Warm
G3. River Width=54	H/W <1	27.97	29.89	Neutral	27.93	32.90	Warm	28.88	33.84	Warm	28.88	31.43	Warm
	H/W =1	27.76	28.70	Neutral	27.77	29.40	Neutral	28.59	30.22	Warm	28.62	29.96	Neutral
	H/W >1	27.80	28.10	Neutral	27.95	29.57	Neutral	28.38	29.49	Neutral	28.41	29.66	Neutral

In the second group with respect to the adopted scale of warmth in the outdoor spaces of Melaka City, however, the spatial and temporal distributions of the PET index showed that the selected urban setting is generally uncomfortable. The EW orientations have relatively larger proportions of lower PET values compared to that observed within the canyons with NS and the intermediate axes. It should also be pointed out that lower PET values being recorded across the NW-SE street canyon can be attributed to the larger portion of lower PET during the day compared to the ones observed within the NS and WE axes. Apart from this, there are no visible differences that could be discussed.

Apparently in the third group, the orientation of the NS showed a noticeable improvement in the thermal condition at the pedestrian level compared to the conditions within the other orientations in this urban setting, as shown in Figure 4. This is evident from the larger proportions of lower PET values during the day compared to other orientations. In contrast, and with respect to the scale of warmth in outdoor spaces determined during the comfort study in Melaka City, the selected urban setting with EW axis resulted in less thermal stress than expected. The potential of NE-SW and NW-SE street in regulating the climate comfort resides in its ability to maintain better over-shadowing at street level, as well as in its cooler conditions, as a result of the shorter duration of exposure to the extreme climatic conditions during the day.

One of the urban settings studied in this group have maintained relatively lower thermal conditions outdoors compared to the remaining urban settings in the third group. This is the third urban setting with street aspect ratios exceeding. Due to a relatively considerable decline in the thermal condition within the NS oriented street canyon expressed by the shorter duration of heat stress and lower PET maxima, the third urban setting (H/W > 1) has on average lower PETs among the remaining urban settings being analyzed in the third group. The potential of the NS street in regulating the climate comfort resides in its ability to maintain better over-shadowing at the street level. In reference to the best case scenario found from the Street/river urban settings (H/W >1 and the RW= 54), the case scenario of the settings in the third group (H/W<1, RW= 54) was on average slightly warmer due to the limited protection afforded by the geometry itself against the direct solar radiation.

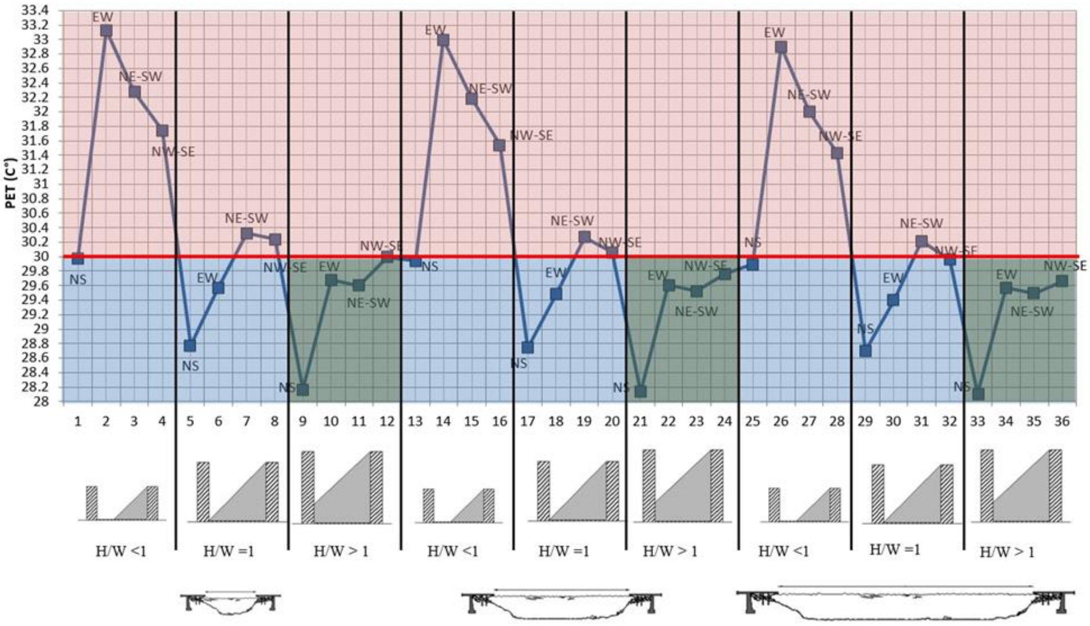

Fig. 4. PET of 36 modification scenarios in Melaka water body area

In the current situation, the Melaka old heritage zone was uncomfortable due to its exposure to radiation. For instance, the areas that were categorized as H/W <1 or H/W =1 with NE-SW and NW-

SE orientations resulted in an "uncomfortable" experience. On the other hand, although a wider river reduced the temperature, the scenarios are still regarded as being "warm". Ultimately, it can be seen that thermal comfort was optimally improved from "warm" to a "neutral" via a combination of high aspect ratios and wider rivers.

5. Conclusion

The final step involved the combination of the changes to the microclimate at the street level and the "Best Case" scenario. The results of the numerical modelling on a number of proposed urban settings prove the duality and the influence of urban geometry upon outdoor thermal comfort. The aspect ratio (H/W) was found to be quite influential in the determination of outdoor comfort. The best and worst performances of the urban settings being studied resulted from alterations to the river's width. The urban setting of buildings, with a street aspect ratio of (H/W >1) and river width (RW) of 54 m (group three) are advantageous over urban settings with H/W <1 and river width (RW) of 18 m (group one), and is regarded as the best case scenario among the analyzed urban geometries. This is rather obvious from its lower average PET at the pedestrian levels.

Solar access in urban canyons is directly influenced by street orientations and street geometry (H/W ratios) and therefore this influences thermal comfort at pedestrian level. Additionally, higher comfort in the streets could be achieved by having buildings of various heights as well as introducing the cooling effect of water bodies. In this study, a theoretical calculation of thermal comfort was done and estimation of comfort limits was conducted on the basis of other studies. From this study, it can also be deduced that design strategies might lead to lower air temperatures but they may not contribute to increasing the outdoor comfort level.

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