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Does the orientation of urban canyon justify the deviation between the microclimate and thermal comfort? A tropical context

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Abstract - Climate change and the urban heat island phenomenon are significant concerns in the current urban discussion. The increase in heat stress causes high cooling loads in tropical cities. The recent studies on urban climate discuss ranges of physical design alternatives in fulfilling the climate change mitigation and adaptation agenda. Urban canyon, as the primary form of urban space, was explored through the alternative of urban configurations in this study. The urban configuration was situated in the outdoor space of residential high-rise blocks in Kuala Lumpur, Malaysia. The ENVI-met V.3.1 simulation was used to investigate the impact of urban canyon directions on both urban microclimate and thermal comfort. The results indicate the significant gap between air temperature (T_a) and Mean Radiant Temperature (T_{mrt}) due to the urban canyon exposure to East and West and the role of reduced wind velocity in the dense city center. The finding suggests the strategy of urban configurations to adapt to local physical and climate context.

Keywords: Climate change, Urban canyon, ENVI-met V.3.1 simulation

I. INTRODUCTION

The rapid increase of population and urban development are ongoing issue in big cities [1,2]. United Nations (2011) predicted increase from 7 billion population in 2011 to 9.3 billion in 2050 [3]. The trend is also followed by the expansion of urbanisation, including Malaysia. Federal Department of Town and Country Planning Peninsular Malaysia (2006) projected the Malaysia urbanisation will be up to 75 % in 2020. Thus, the issues continuously deliver ranges of challenges including social problem, environmental damages, and economic issues. Among the unavoidable challenges are the temperature increase and thermal discomfort. Kuala Lumpur with its tropical context has been struggling with the rapid increase of heat stress [4-6]. The Kuala Lumpur's Urban Heat Island (UHI) was recorded up to 1.7 ºC to 2 ºC [4]. The UHI rise from 4 ºC in 1985 to 5.5 ºC in 2004 [6]. Latest studies further confirmed this phenomenon [7, 8].
Besides the implication on the rainfall pattern [9], the UHI also creates great impact on the thermal comfort. The urban thermal stress majorly influences the indoor and outdoor thermal comfort [10]. Studies emphasise that the temperature increase and thermal discomfort of tropical imposes the implication on the cooling load demand [11,12]. The factors that influence the modification of urban microclimate and thermal comfort has been broadly discussed in recent studies [13]. Among the factors are the geometry of urban structures. Ranges of studies on relationship between urban climate and urban geometry also confirmed the modification of microclimate was strongly caused by the alternative of urban configuration settings [14,15]. This concern is explored in this study, with the context of tropical region investigation. This study highlights the gap of urban microclimate and thermal comfort as the result of urban configuration settings.
Urban configuration is one of the major determinants in the system of urban energy balance [16,17]. The micro scale of urban spaces between buildings is the center of heat stress generator [18]. Specifically, studies clearly shown that urban microclimate is the main parameter in urban energy balance and UHI [18,19]. Furthermore, studies pointed out that thermal discomfort is an inference of modified microclimate [20,21]. The climatically well-planned outdoor configuration creates a comfort urban spaces that also reduce the dependence on the energy demand for indoor air conditioning [5,22]. The interrelationship of urban microclimate, thermal comfort and energy efficiency is termed as Climatically Responsive Urban Configuration. In this context of study, as the major determinant of microclimate and thermal comfort, air temperature (T_a) and mean radiant temperature (T_{mrt}) were investigated in this study.
Studies on the impact of the urban configuration on the modification of microclimate emphasised the need for alternatives of urban configuration strategies in mitigating the UHI and thermal discomfort. The pioneer study in UHI conducted by Oke, T.R [16, 23, 24, 25, 27] has framed that the maximum UHI is

formed by a big Height to Width (H/W) aspect ratio (dT max = 7.45 + 3.97 * ln H/W) and low Sky View Factor (SVF) values (dTmax = 15.27 – 13.88 * SVF). This concept clarified that the high UHI intensity occurs in the dense cities with the narrow spaces between crowded high-rise buildings. The close distances between buildings and the increase of building heights makes the worse scenario of modification of microclimate and thermal discomfort.

Besides the setting of urban configuration, the canyon feature in urban geometry determines the heat balance in the outdoor spaces. Specifically, the geometry of urban spaces modifies the solar radiation into the short wave and long wave radiation. The long wave radiation creates the stored stress in urban canyon [16, 17, 27]. In tropical context, the sun path area receives the maximum of solar radiation, the main source of the thermal stress. Therefore, the East-West canyon direction is definitely influenced by the maximum intensity of solar exposure [28, 29, 30]. Furthermore, canyon feature in this context is seen as a 'canyon tunnel' that encourage the ventilation and the better outdoor thermal comfort [31]. Therefore, this study explores the impact of urban canyon direction in urban configuration settings on both microclimate and thermal comfort.

II. URBAN CONFIGURATION SIMULATION

This study was conducted in the city center of Kuala Lumpur Malaysia (3O8'51"N101O41'36"E). A residential block was simulated by using Envi-met 3.0. The hypothetical study of urban configuration was set from the existing Courtyard Canyon configuration, with the canyon direction faced East-West. The investigated urban configurations with the SVF value as shown in Figure 1: Courtyard (0.275), U (0.309), Courtyard Canyon (0.438) and Canyon (0.676). The receptor was situated in the center of the courtyard space with the surface material of concrete. The model was set for 24 Hours on 21 June 2015.

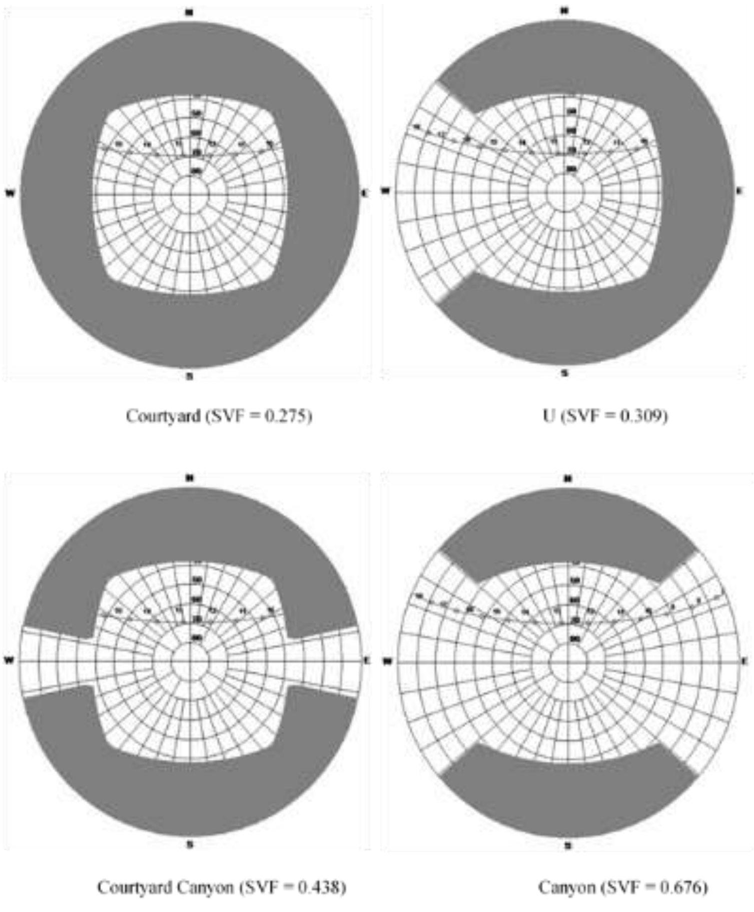

Figure 1 RayMan-generated Fish Eye SVF of Four Urban Configurations

The model domain was with x=210, y=210 and z=30 the grid cells and the 6 nesting grid. The input microclimate were; wind direction of 225 and a wind speed of 1.4 m/s, the initial of temperature 303.15 °K and the relative humidity of 83%. The Height to Width (H/W) aspect ratio was set constant for the 19 storey (60 meters heights) high-rise building blocks. The ENVI-met V.3.0 simulated air temperature (T_a) and mean radiant temperature (T_{mrt}) were analysed to investigate the impact of urban configuration settings. The deviation was derived through the mean of both variables.

III. RESULTS DISCUSSION

This study presents the behaviour of the air temperature (T_a) and mean radiant temperature (T_{mrt}). Table 1 presents that the comparison of both variables in the four urban configurations. The results indicated the ranges of T_a and T_{mrt} among the four urban configurations, as a 2.44 °C gap was reported between the highest to the lowest. It was recorded that the deviation between the two were from 2.16 °C to 7.4 °C. It presented that the Canyon configuration resulted the biggest deviation, followed by U configuration, Courtyard Canyon and Courtyard. When the physical configuration reviewed, the receptor area in the Canyon configuration was fully exposed to East-West, U configuration was fully exposed to West, Courtyard Canyon was partially exposed to East-West and Courtyard was fully shaded. Figure 1 shows the 24 Hours pattern of T_a and T_{mrt} in the four urban configurations. In general, the T_{mrt} pattern was almost similar in the four urban configurations, while T_a was recorded varied.

Table 1. The Air Temperature and Mean Radiant Temperature in Four Urban Configurations

Urban Configuration	**Mean of T_a (° C)**	**Mean of T_{mrt} (° C)**	**Mean of T_a and T_{mrt} (° C)**	**Deviation of T_a and T_{mrt} (° C)**	**P value**
Courtyard (SVF: 0.275)	31.34	33.55	32.48	2.16	0.001
U (SVF: 0.309)	31.40	35.63	33.77	4.23	0.000
Courtyard Canyon (SVF:0.438)	31.28	34.32	32.80	3.04	0.013
Canyon (SVF: 0.676)	31.22	38.62	34.92	7.4	0.000

The results generally described the significant deviation between the T_a and T_{mrt} in the four urban configurations. The T_{mrt} was found significantly higher over the T_a while the mean of the T_a and T_{mrt} were varies according to the type of the urban configuration. In general, the deviation was majorly influenced by the direction of the canyon feature. In this context, the canyon direction towards the East West. The source of the highest intensity of solar radiation is the contributor of the thermal stress in the tropic. The impact of the SVF is also significant, where the mean and the deviation of the T_a and T_{mrt} were increased in the higher SVF. However, the mean and the deviation were recorded higher due to the receptor area was exposed to the highest West Solar Radiation and the blocked ventilation.

IV. CONCLUSIONS

This microclimate and thermal comfort simulation study concluded that the canyon feature in urban configuration scientifically contributes to the deviation between the air temperature and mean radiant temperature. The direction of the urban canyon towards the East West solar radiation determines the outdoor thermal stress in tropic. The impact of the ventilation was not major due to the weak urban wind in the city center and the extreme high solar radiation of the tropical context. This study recommends the Courtyard configuration that offers the shading effect to the outdoor spaces, while Canyon configuration is not suggested as it faces the East and West solar radiation. The finding of this study is a significant reference to the urban planners and policy makers in implementing the climatically urban configuration in tropic region.

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