Influence of Urban Canyon Direction on Long Wave Radiation Pattern in a Tropical Context

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Abstract Poor urban microclimate and thermal comfort has contributed a continues urban energy issue. The urban energy imbalance is caused by the uncontrolled urban development and ignorance to the urban environmental damages. The configuration of urban spaces and development play significant role in the level of urban thermal heat. The high intensity of solar radiation in tropical region makes the urban thermal discomfort a major challenge in creating a comfortable and lively outdoor urban space. The lacking of firmed studies on the relationship of urban configuration and microclimate were the initial background of this study. This study aims to investigate the long wave radiation behavior in four scenario of urban canyon directions. This study was situated in high density residential area of Kuala Lumpur, Malaysia using the ENVI-met V 3.1 simulation. The finding indicated that the East–West direction received inconsistent pattern and significant intensity of long wave radiation over the South-North. This study suggests the strategized and the passive design of urban form to be considered for achieving the climatically responsive urban configuration in the tropical context.

Keywords Urban Canyon · Long wave radiation · Tropical context · ENVI-met · Kuala Lumpur

1 Introduction

Climate change is a global threat that impacts almost all sectors, including the urban life. Therefore, the climate change mitigation and adaptation agenda are still focusing on the city as central position of the agenda [1]. This situation is due to the rapid economic growth and urban development that brings the complex social, political and economic issues. The poor urban microclimates and thermal discomfort causes the phenomena of Urban Heat Island (UHI), the major climate change contributor from urban sector. Both urban microclimate and thermal comfort were highlighted

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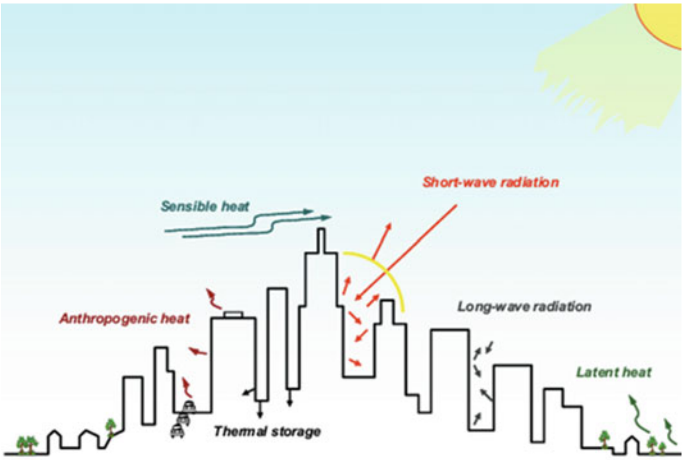

Fig. 1 The heat components in the urban energy balance system. *Source* US Environmental Protection Agency (2013)

significantly influenced by the configuration of urban fabric. The ongoing discussion on the correlation between the urban configuration on the urban microclimates and thermal comfort has been explored in the urban energy balance studies. The poor urban configuration settings have caused the modification of heat components that makes the unsustainable urban energy balance (Fig. 1).

Short wave and long wave radiation are two main heat variables that contribute to the urban energy balance. In a high urban density area, the long wave radiation traps and stores the heat in the urban surface and contributes to the high intensity of Urban Heat Island (UHI) in tropical area. Besides the solar radiation, urban wind also plays significant role in the modification of urban energy balance system, as it mainly eases the heat from one to another urban spaces. Building position and the role of canyon were among the strategies highlighted to maximise the urban wind circulation as well as to minimise the risk of heat absorption [2–8]. Longwave radiation is strongly determined by the geometry of the surface when it absorbs and traps the radiation heat. The high long wave radiation mainly occurs in the dense cities with the low albedo which leads to poor Urban Heat Island (UHI). As the solar radiation set the main source of heat to the modification of microclimate and thermal comfort within the urban space, the need of focus study on the solar radiation especially the long wave radiation is an urgent stage for achieving the sustainable alternative of urban configuration strategies. Therefore, this study investigated the impact of choice of urban configuration with the different setting of canyon features on the intensity of long wave radiation.

2 Literature Review

In the pioneer urban energy studies, solar radiation was discussed as the main source of heat in urban energy balance [9, 10]. The reflection and absorption of short and long wave solar radiation (Fig. 2) results in the modification of main climate variables such as surface temperature, air temperature, mean radiant temperature, and thermal comfort. The micro-scale physical features between buildings in urban spaces cause major heat generators [11]. The study on strong relation of urban climate and urban configuration has been widely explored. Some of studies had discover the urban strategies to modify the solar radiation; including urban fabric and geometry [12–14], urban space structure [15] and building shape and orientation [16, 17].

As the short-wave radiation is emitted directly from the solar radiation and surface while the atmosphere discharges the long wave radiation [10]. Therefore, the urban outdoor heat stress would be influenced by short wave radiation during the daytime and long wave radiation during the night-time. The direct radiation and diffuse radiation are mostly influenced by the vertical obstruction on the ground surface [18, 19]. Pioneer study [3] formulated the Height to Width (H/W) aspect ratio and Sky View Factor (SVF) on the canyon configuration and its' impact on the maximum heat island stress. It was stressed that the maximum air temperature exposed to the canyon space were for highest H/W aspect ratio and smallest SVF [20]. In this context, both H/W and SVF determines the intensity of the affecting long wave radiation within the canyon space. However, the direction of canyon was not detailly discussed in the said formula [21, 23]. Therefore, this study aimed to investigate the impact of

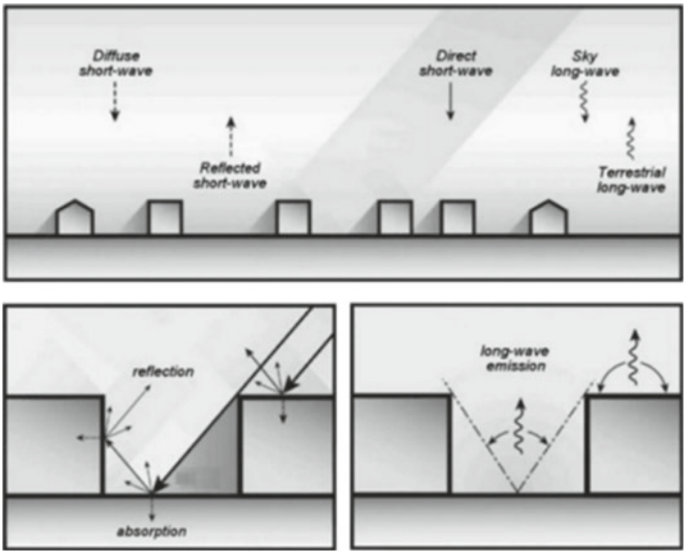

Fig. 2 Solar radiation short wave and long wave on the urban surface. *Source* Erell et al. [10]

urban configuration alternatives on the intensity of long wave radiation in the tropical context of Kuala Lumpur.

3 Methods

Two empirical sites of residential blocks in Kuala Lumpur city were investigated in this study, with the urban configuration scenario with the canyon direction of East – West (parallel with sun path) and North–South (perpendicular to the sun path). Both sites are with the high-rise residential blocks in Kuala Lumpur. The existing site urban configuration is Courtyard Canyon with a canyon in the center of the outdoor courtyard. This study set other three urban configurations for simulation; Courtyard, U and Canyon. The four urban configurations were investigated with the said two scenarios of East–West and North–South (Fig. 3).

ENVI-met V3.1 Beta simulation used in this study, with the grid cells of x = 210, y = 210 and z = 30. The site coordinate was set in Kuala Lumpur, Malaysia (3O8'51"N101O41'36"E). The model was simulated for 21 June 2015 with the simulation time of 24 h. The microclimatic data were inserted as follow: initial temperature of 303.15 (°K), specific humidity of 4, relative humidity of 83%, wind speed of 1.4 m/s, wind direction of 225 (South West), albedo walls of 0.3 and albedo roofs of 0.5.

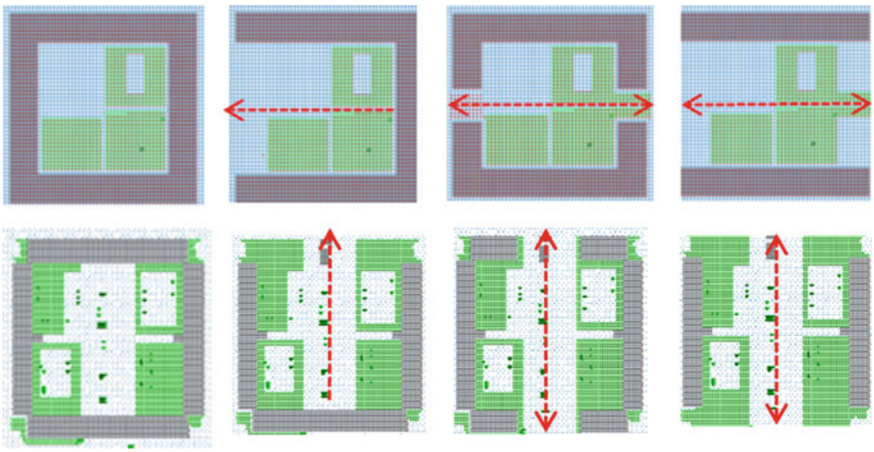

Fig. 3 The four urban configurations setting in ENVI-met for two Canyon direction scenarios: East–West and South–North

Table 1 Mean of long wave radiation (W/m^2) in two scenarios of Canyon direction

Urban configurations	Canyon direction facing East–West	Canyon direction facing South–North
Courtyard	488.60	518.39
U	489.27	514.57
Courtyard Canyon	466.38	513.44
Canyon	472.18	509.64

4 Results

This study presents two sets of 24 h records of long wave radiation according to the setting canyon directions; East–West and South North (Table 1). The results show that there was significant gap between the diurnal and nocturnal long wave radiation pattern. Overall, the mean of long wave solar radiation was recorded gapping between the two settings of canyon direction East–West and South-North. Data show that the urban configurations with canyon direction facing East–West (Table 2) cause lower long wave radiation over the South-North (Table 3). This situation indicated positive correlation with the earlier discussion that the trapped and absorbed heat within the enclosed area results in high long wave radiation intensity, especially during the night.

Tough the solar radiation was fully received throughout the day; the long wave radiation was recorded high during the night time. The significant gap was also found in the long wave radiation pattern in four urban configurations when canyon set facing East–West. However, the uniform pattern was recorded when canyon feature was directed to South–North. Technically, the urban configuration with canyon features in East–West scenario (occurs in Canyon and Courtyard Canyon configuration) results in low long wave radiation intensity over the urban configurations without canyon features (Courtyard and U configuration). In this tropical context, the recommended urban configuration with high to low SVF that set better scenario of long wave radiation are; Canyon, Courtyard Canyon, U and Courtyard.

Table 2 Diurnal and Nocturnal long wave radiation with Canyon facing East–West

Diurnal long wave radiation (W/m^2)													
Urban configuration	**7am**	**8am**	**9am**	**10am**	**11am**	**12pm**	**1pm**	**2pm**	**3pm**	**4pm**	**5pm**	**6pm**	**Mean**
Courtyard	475.94	476.55	480.88	484.81	488.31	492.28	502.64	508.58	508.74	513.96	500.73	496.21	494.14
U	473.92	473.81	477.82	483.79	488.68	492.61	505.64	509.52	510.35	508.99	504.75	504.67	494.55
Courtyard Canyon	455.5	453.63	467.29	480.69	484.84	469.31	477.2	501.94	503.24	500.88	480.95	473.7	479.10
Canyon	462.41	460.39	475.13	490.8	500.56	505.24	507.99	508.34	506.96	503.09	494.93	483.02	491.57
Nocturnal long wave radiation (W/m^2)													
Urban configuration	**7pm**	**8pm**	**9pm**	**10pm**	**11pm**	**12am**	**1am**	**2am**	**3am**	**4am**	**5am**	**6am**	**Mean**
Courtyard	491.79	489.2	487.28	485.64	484.2	482.91	481.74	480.67	479.67	478.73	477.86	477.04	483.06
U	494.69	491.68	489.25	487.1	485.23	483.62	482.21	480.96	479.82	478.76	477.76	476.81	483.99
Courtyard Canyon	463.94	459.1	456.69	455.03	453.76	452.72	451.87	451.16	450.58	450.09	449.69	449.38	453.67
Canyon	466.5	460.2	457.19	455.08	453.37	451.93	450.67	449.56	448.55	447.62	446.76	445.96	452.78

Table 3 Diurnal and Nocturnal long wave radiation with Canyon facing South-North

Diurnal long wave radiation (W/m^2)												
Urban configuration	**7am**	**8am**	**9am**	**10am**	**11am**	**12pm**	**1pm**	**2pm**	**3pm**	**4pm**	**5pm**	**6pm**	**Mean**
Courtyard	476.61	476.31	484.54	521.53	558.36	584.8	602.64	568.68	546.97	578.92	568.84	531.98	541.68
U	476.35	475.83	482.67	517.97	552.94	578.38	595.57	562.18	541.22	572.6	562.5	526.59	537.07
Courtyard Canyon	475.85	475.06	481.87	518.04	553.71	578.87	595.72	562.36	541.69	572.71	562.39	526.67	537.08
Canyon	475.18	473.94	479.61	515.18	550.07	574.79	591.27	558.44	538.54	568.98	557.89	522.61	533.88
Nocturnal long wave radiation (W/m^2)													
Urban configuration	**7pm**	**8pm**	**9pm**	**10pm**	**11pm**	**12am**	**1am**	**2am**	**3am**	**4am**	**5am**	**6am**	**Mean**
Courtyard	516.17	508.04	503.06	499.38	496.43	493.94	491.77	489.82	488.04	486.37	484.81	483.32	495.10
U	511.93	504.38	499.71	496.24	493.44	491.07	488.99	487.12	485.38	483.76	482.22	480.75	492.08
Courtyard Canyon	511.64	503.45	498.29	494.45	491.36	488.74	486.42	484.33	482.39	480.57	478.84	477.2	489.81
Canyon	507.82	499.36	494.04	490.1	486.94	484.26	481.91	479.78	477.82	475.98	474.24	472.59	485.40

5 Conclusions

The setting of urban configuration plays significant impact on the pattern of long wave radiation modification. Tough this study did not investigate the correlation with the modification on other microclimate features, the intensity of long wave radiation was found varies in different altitude time. The orientation of canyon feature towards the East and West mainly influenced the intensity of long wave radiation, with the significant gap between the diurnal and nocturnal. In this context of study, the urban configuration with canyon feature facing the East–West recorded a more variety of long wave compared to the South-North. One of the contextual main factors was the wind direction facing South-West. However, urban configuration with canyon feature (mainly canyon and courtyard canyon) performed lesser heat stress over a non-canyon urban configuration. The findings pinpointed those alternative strategies of canyon direction in urban configuration creates significant impact to the outdoor heat stress of tropical urban environment.

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