Impact of Urban Block Configuration and Direction on Urban Temperature Increase in Hot, Humid Regions

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Abstract

Urban temperature increase contributes significant effect to global warming. This phenomenon has been addressed as the real impact of rapid development which occurs in the urban area, which causes urban heat islands (UHIs). One of the influencing factors is building typology that forms urban block configuration. This study which was conducted in Kuala Lumpur, Malaysia aims to investigate the impact of varies of urban block configurations on the air temperature and the variables that affect it. The hypothetical model simulation was used to analyse the measures. It finds out that urban block creates the shades to the outdoor environment which blocks the surface from direct solar radiation. However, it also depends on the direction of urban block configuration towards the expose angle of solar radiation. As the conclusion, the right scenario of urban block configuration and the choice of its direction mitigate the urban temperature increase. This finding suggests planners and designers to perform the similar quantitative analysis in the earlier stage of planning.

*Keywords:*Urban block configuration, urban direction, temperature increase, solar radiation.

1.0 Introduction

It has been well emphasized by urban planners and scientists that global warming as a real threat to the universe, one of the predominantly contributors is unplanned and uncontrolled urbanization. Big cities in the world are growing with their high densities which cause rapid urban development. High rise buildings and big scale developments are the clear results of this phenomenon (Lin and Ho, 2013). Built up area dominates the open space that creates competition for spaces in the city area. These factors are stressed to accumulate temperature increase in the city area that directly becomes the major measure to Urban Heat Islands (UHIs). In detail, both built up and open space ratio and design are formed by the urban block configuration. As there are limited studies investigate the impact of urban block configuration on temperature increase in hot and humid regions like Malaysia, this paper aims to justify this hypothesis through hypothetical simulation study that is set in Kuala Lumpur, Malaysia.

2.0 Urban Block Configuration and Direction Impacts on Air Temperature

Debates on the relationship of urban planning and micro-climate have been addressed in order to urge mitigating the urban development stress on global warming. Variables are justified in measuring it such as air temperature (S. Glawischnig.et al, 2015), pollution concentration (Wai and Chi, 2014), and urban heat islands (A. John Arnfield, 2002). However, in this case, it has been highlighted that air temperature is the most applicable and effective variable. Besides indoor environment that directly relates to thermal comfort, the outdoor environment has an essential influence on the temperature increase. Thus, the argument transforms to which of the urban development policy and practice that results in the significant impact on the temperature increase. Urban and street canyon (Wai and Chi, 2014; E. Andreou, 2014), natural features, architecture passive design (Jhon, 2015), building and urban configuration (J. Lim and R. Ooka, 2014), and building direction are among the features that have been discussed. Urban street canyon, for instance, is scientifically proven show high surface temperature that its surrounding due to the pavement installed on the street canyon. However, scientific studies proved that the air temperature is slightly lower than surrounding when the street canyon shaded by trees and buildings which block the surface from direct solar radiation (Loyde, et. al, 2012) Some other scenario were tested by researchers in discovering further, however, there are still limited study discuss on the hot and humid context like the tested site, Kuala Lumpur Malaysia.This phenomenon raised a question that if the urban spaces are shaded by surrounding buildings especially high-rise buildings that are situated in the closed distance (Sujal, 2014). Urban forms are introduced with some natural design and arrangement, but urban planners and designers however classify them based on some criteria and objectives like building shapes, open space or courtyard, and external components that involved or attached to it (Philip, et. Al, 2000, Mohammad, et al, 2015). Courtyard block as one of the common urban configuration which naturally generated by urban grids shape internal space between buildings justifies this interrelationship (Figure 1). Courtyard space is exposed to maximum solar radiation during daytime. However, the surrounding buildings shade the courtyard space from direct solar radiation, which benefits to the occupants' thermal comfort in doing their outdoor activities. This circle doesn't occur during nighttime, as the daytime heat is absorbed and stored within the courtyard space and released during nighttime. The different phenomenon would occur in the opposite reaction in other urban configuration, such as semi-enclosed and canyon configuration as those configurations provide less shading during daytime and less heat absorption.

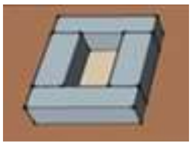

Figure 1: Courtyard Urban Block Configuration Illustration

Temperature increase is proven to raise cooling load and energy demand in a hot and humid region like Malaysia. Every degree of temperature increase results in up to 10% higher electricity bill (Karin and Tord, 2013). This study, therefore, tries to examine if there is a significant impact of the urban block configuration on the outdoor air temperature. If yes, what are the factors involved. In this empirical case, since the study aims to investigate how the urban block shade the open space from direct solar radiation, the four cardinal directions (East, West, South and North) are used to analyse the data.

3.0 Methodology

In order to investigate the impact of urban block configuration on temperature, the simulation study was conducted by examining five hypothetical models of urban block configuration with the different scenario. 10 x 10 grid of hypothetical platform was designed as the urban site (Refer to Figure 2). A 32:68 ratio of built up to open space was set for Model A as the basic model for the simulation. It was designed as four sides' enclosed urban blocks with the center open space. Model B (ratio 28:72) was designed with one side open to solar direction. Model C (ratio 20:80) and Model D (ratio 24:76) were designed with two sides exposed to solar. Lastly, Model E (ratio12:88) with three sides exposed to solar was designed contrary to Model A. Furthermore, the receptor was placed in the constant location which is the center point open space of the urban blocks as well as the set urban site. The receptor is presented as a dark blue spot in the platform of Fig. 2. ENVI-met V 3.1 beta 3D micro-climate analysis simulation software was used to examine this study. This tool was chosen as the most suitable analysis method to simulate the 3D micro-climate study (Lin and Ho, 2014). The simulation was set for 24 hours as this study aims to investigate the temperature increase for both day and night. The property data was set as follow: the wind speed at 10 meters above ground was set as 1.6 m/s, wind direction is at 225, the initial temperature atmosphere was 300K, specific humidity in 2500 meter was 4 g Water/kg air while the relative humidity in two meters was 83%. All Initial Temperature Layer of Soil data were at300°K while the Relative Humidity Layer was at 3%. The building property data was adjusted as follow; the Initial Temperature was 293K, the Heat Transmission Walls was 1.94 W/m²K, the Heat Transmission Roofs was 6 W/m²K, the albedo walls was 0.3, and the Albedo Roofs was 0.5.

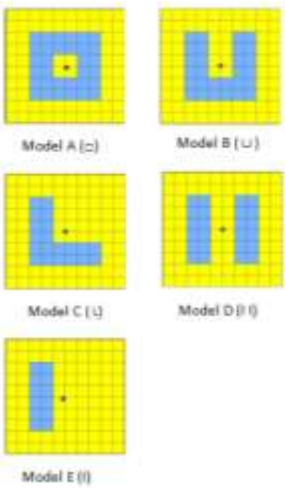

Figure 2: Layout of five hypothetical urban block configurations

The simulation was fixed in Kuala Lumpur (coordinate 3°9’ N 101°43’ E). In this case, it was assumed that the simulation stands alone without disruption of the manmade or natural feature of surrounding environment. Apart from Model A which is enclosed, the four models were adjusted with the open or exposed space to four directions of solar radiation sources.

4.0 Findings and Discussion

The simulation results are presented in the form of layout temperature layer images that shows temperature measures for all model and the temperature charts. In general, this paper presents the outdoor air temperature data of the five models; the images are representing the air temperature at 0m x-y axis layer on 1 pm, while the temperature charts are representing the 24 hours data. However, all data are justified according to the four cardinal directions; East, West, South and North.

4.1. East Direction

At 1 pm, East direction simulation resulted that Model A has the most acceptable air temperature scenario follows by Model B, Model C and Model D, while the worst scenario is represented by Model E (Figure 3).

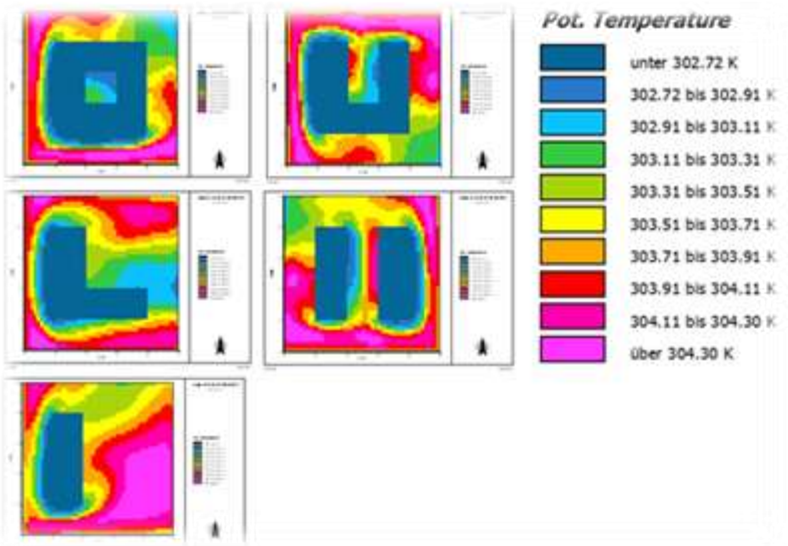

Figure 3: Ground Air Temperature of Urban Block Configuration Facing East

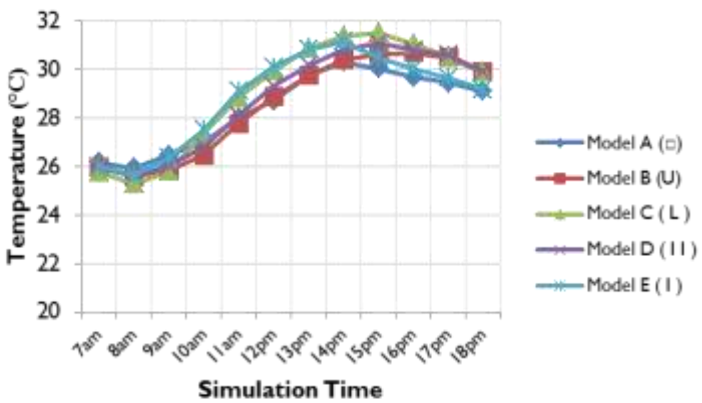

Figure 4: Air Temperature of Each Urban Block Facing East at Daytime

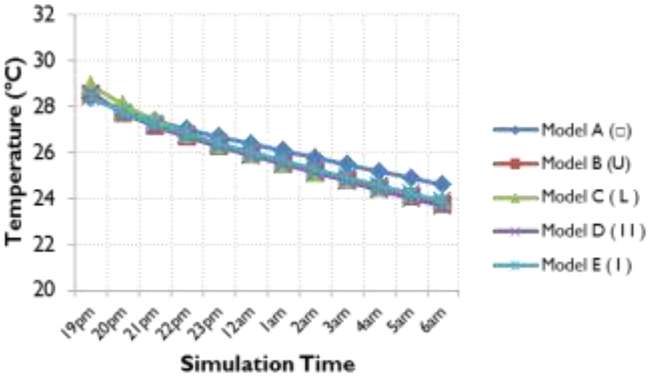

Figure 5: Air Temperature of Each Urban Block Facing East at Night Time

Hourly data for both day and night are almost uniform for all models. For daytime, Model A and Model B have the lowest air temperature follows by Model D, Model E and the highest is Model C (Figure 4). Whereas, for the nighttime, Model D has the lowest air temperature scenario follows by Model B, Model E, Model C, while the highest temperature was indicated in Model A (Refer to Figure 5).

4.2. West Direction

Model B and Model A are showing the most suitable outdoor air temperature for the East direction scenario at 1 pm, follows by Model C. Model D and Model E are presenting the worst air temperature scenario (Figure 6).

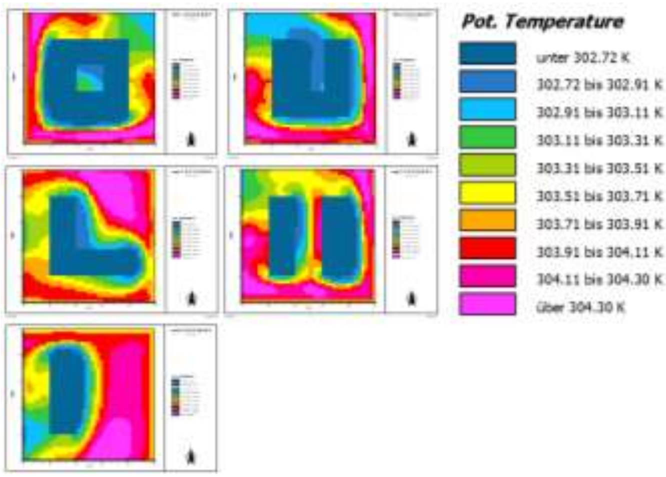

Figure 6: Ground Air Temperature of Urban Block Configuration Facing West

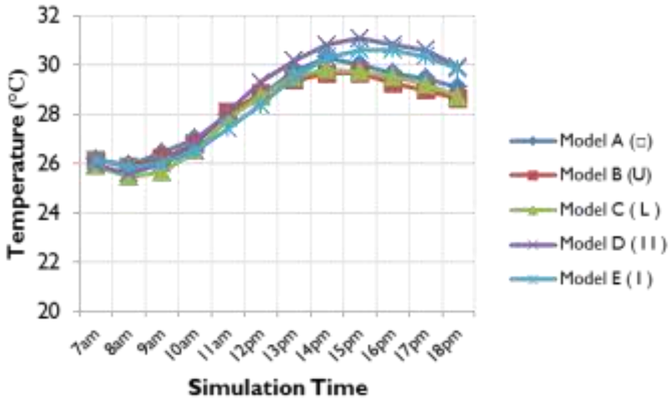

Figure 7: Air Temperature of Each Urban Block Facing West at Daytime

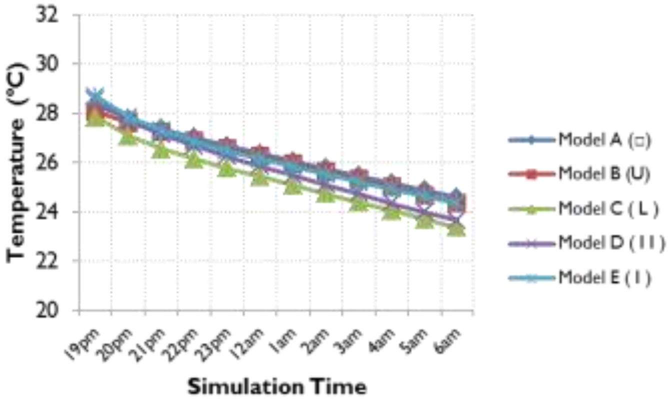

Figure 8: Air Temperature of Each Urban Block Facing West at Night Time

As shown by Figure 7 and Figure 8, the outdoor air temperature for the West direction is almost in a uniform pattern, however, some gaps are shown during evening times. For the daytime, Model C is presenting the best outdoor air temperature scenario, follows by Model B, Model A, and Model E, while the worst scenario could be seen from Model D. For nighttime, Model C, Model D, Model B and Model E are presenting the suitable outdoor air temperature scenario, where Model A generated the worst air temperature scenario.

4.3. South Direction

When facing South direction at 1pm, Model A and Model B are presenting the most suitable outdoor air temperature scenario, follows by Model C and Model D, while Model E shows the highest outdoor temperature which is over 300°K (Figure 9).

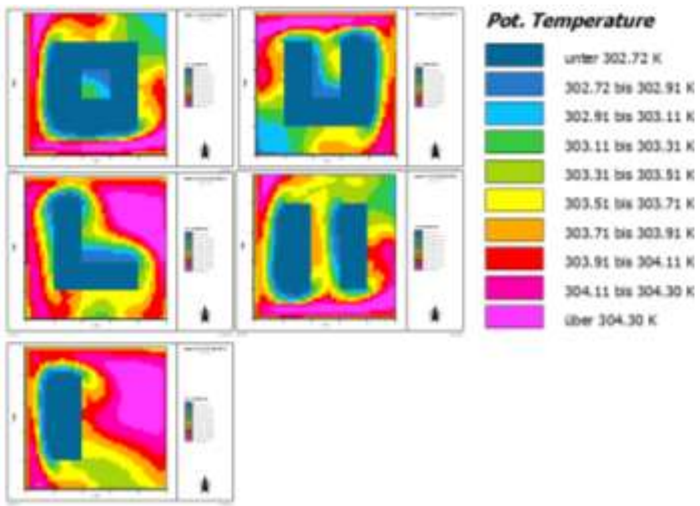

Figure 9: Ground Air Temperature of Urban Block Configuration Facing South

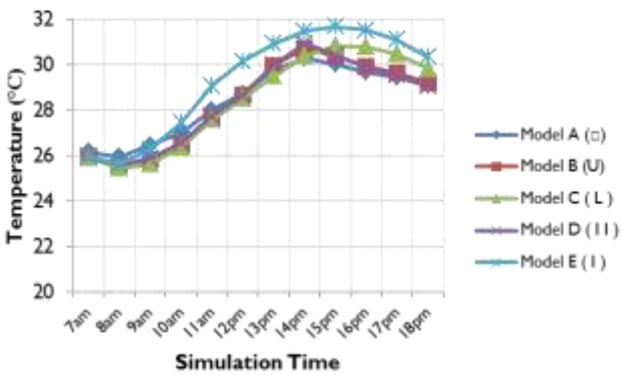

Figure 10: Air Temperature of Each Urban Block Facing South at Daytime

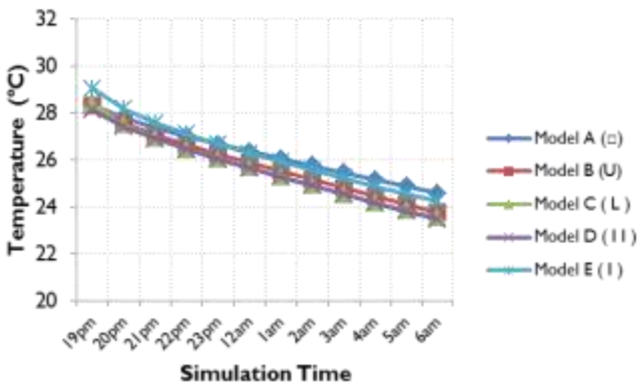

Figure 11: Air Temperature of Each Urban Block Facing South at Night Time

The trend of outdoor air temperature for both day and night that is facing South direction is almost uniform for all models (Figure 10 and Figure 11). However, there is a slight gap between Model E with other four models at daytime. For the daytime, Model B, Model D and Model A presents the most suitable outdoor air temperature scenario, follows by Model C and Model E. For the nighttime, Model D and Model C represent the lowest air temperature follows by Model B, Model E and Model A.

4.4. North Direction

While facing North direction, Model B and Model A shows the lowest outdoor air temperature at 1 pm, follows by Model C, Model and Model D, where Model E resulted the worst air temperature scenario(Figure 12).

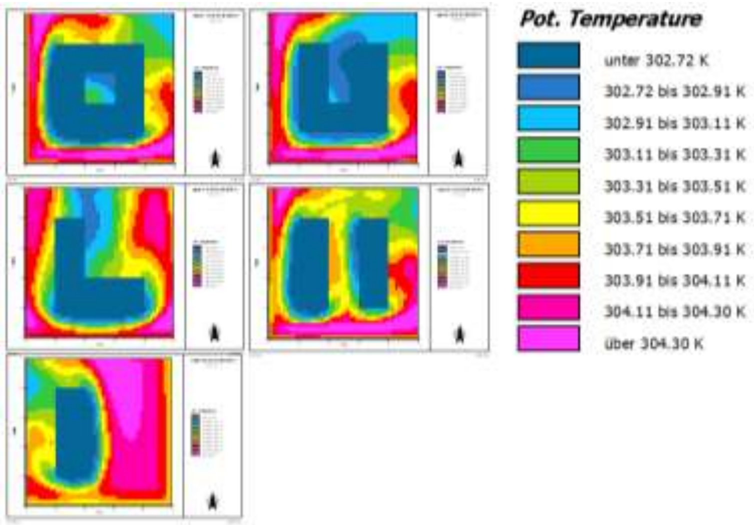

Figure 12: Ground Air Temperature of Urban Block Configuration Facing North

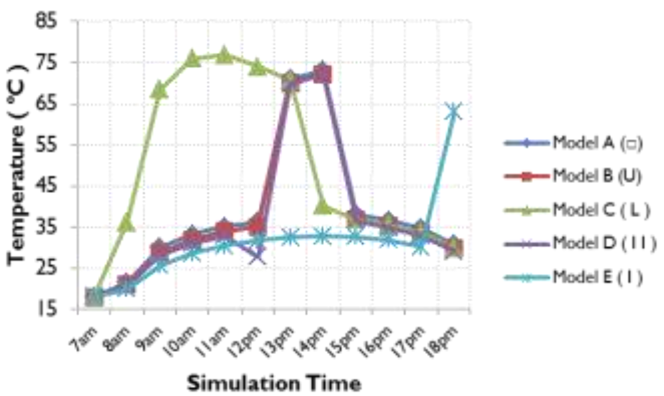

Figure 13: Air Temperature of Each Urban Block Facing North at Daytime

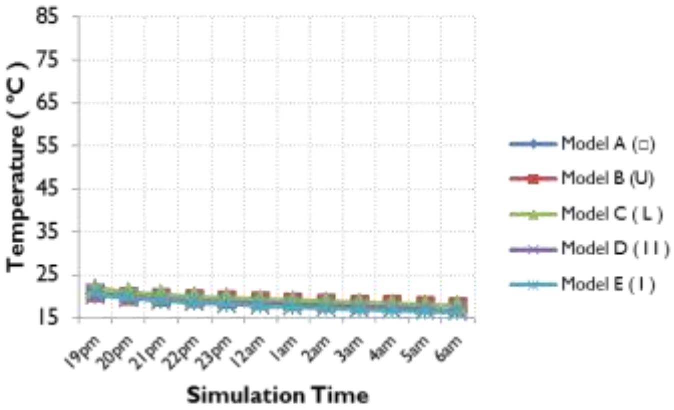

Figure 14: Air Temperature of Each Urban Block Facing North at Night Time

A significant change of air temperature trend appears on the North direction during daytime. Model A, Model B, Model C and Model D result in the constant temperature measure (Figure 13). Model C starts rising from 7 am and falls at 1 pm, while Model A, Model B and Model D shows almost same temperature trend (Figure 14). However, Model B shows the best air temperature scenario and Model C resulted in the worst scenario. For the nighttime, the air temperature results same pattern and almost constant. Model C shows the lowest air temperature while Model D indicates the worst.

4.5. Summary

In conclusion, all the hourly data for both day and nighttime are compiled according to the four cardinal directions in the form of average data. This is to compare the day and night data and different directions for each model (Figure 15 –Figure 18).

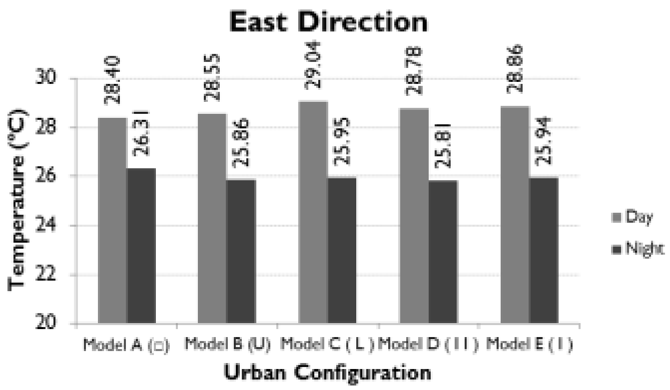

Figure 15: Air Temperature of Each Urban Block Facing East at Day and Night

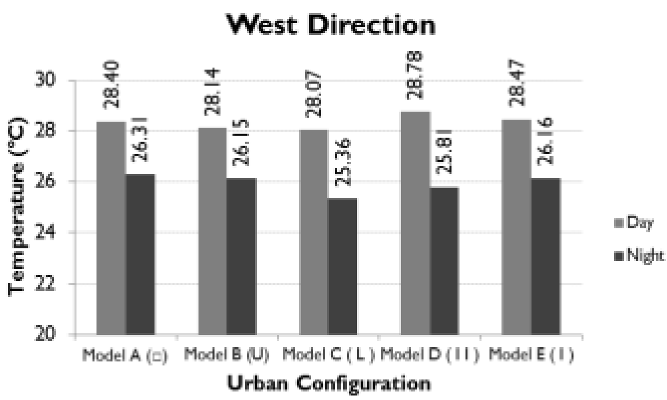

Figure 16: Air Temperature of Each Urban Block Facing West at Day and Night

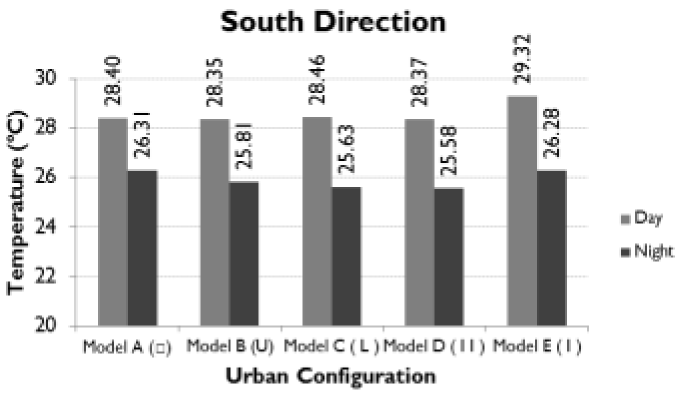

Figure 17: Air Temperature of Each Urban Block Facing South at Day and Night

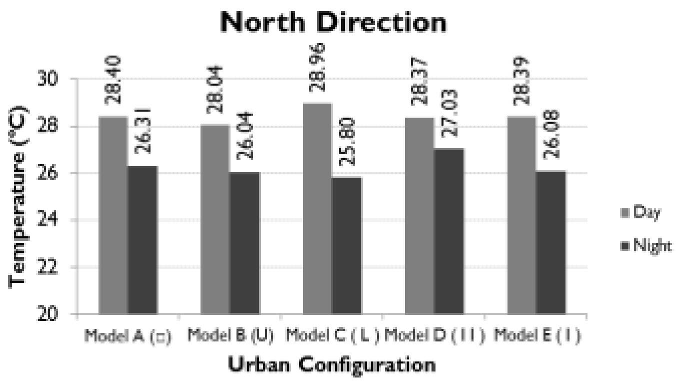

Figure 18: Air Temperature of Each Urban Block Facing North at Day and Night

The data show that Model B has the lowest air temperature among the five models, while the highest air temperature results by Model E. From the open space orientation, West orientation shows the lowest air temperature while the East orientation indicates the highest air temperature. The findings also justify that the air temperature during both day and night are affected by the exposure of the open space to the solar radiation. The data indicate that during the day, East and South exposure results the highest air temperature, which will affect energy consumption to adjust daytime indoor thermal comfort, while during nighttime, East and West exposure shows the highest air temperature which will indirectly affect the Urban Heat Islands.

5.0 Conclusion

The compilation of data indicates that urban block configuration and its' direction have an impact on the outdoor air temperature. In this case, the choice of urban block configuration may cause 0.19 °C temperature increase. Furthermore, the choice of urban block direction (according to cardinal direction) may result in 0.32 °C air temperature increase. Both strategies could be proposed to urban planners and designers in order to mitigate Urban Heat Islands. In this empirical case, for instance, single podium, canyon, and courtyard type of urban configuration results in the highest air temperature. This is affected by the exposure of the open space that is not shaded by the urban block from the direct solar radiation. For courtyard type where all sides are shaded by the urban blocks, other variables are involved, such as long wave radiation where the solar radiation is trapped within the spaces between the building, building material transmission, etc. Therefore, this study concludes that the measure of microclimate or outdoor air temperature specifically could be adjusted by using the urban block scenario to shade the outdoor environment from the direct solar radiation. Besides the choices of direction to avoid solar radiation, the building configuration alternatives by choosing the best scenario to adjust the building block to shade the ground open space from solar radiation would mitigate the urban air temperature. This strategy suits the need of preliminary study for urban planners and designers to perform the quantitative analysis before proposing the urban configuration for the new development. By applying this strategy, the mitigation of UHIs could be achieved from urban planning and design approach. However, further studies are needed to examine some other variables that may have a significant impact on the air temperature.

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