Effects of High-Rise Residential Building Shape and Height on the Urban Microclimate in a Tropical Region

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Abstract. Todays, undesirable urban microclimates are becoming a major global phenomenon. The microclimate that people concern most is Urban Heat Island (UHI). With that concern, architects, planners, and builders are now aggressively reshaping their part in the formation of urban microclimates. Previous studies have found that there are significant relationships between urban geomorphology and urban microclimate. Rapid urbanization and change in urban development trends have produced variation in urban morphology which can also lead to climate changes. This study explores the effects of high-rise residential building shape and height on urban microclimate in Ara Damansara, a newly developed high-rise residential township in Klang Valley. ENVI-met and ArcGIS software are used to perform the simulation and analysis respectively. Initial results have shown that existing triangle building shape is the best building shape towards improving microclimate within the study area. Findings have also shown that the building shape and height contributed to the urban microclimate. The wind direction loses stability with the increase of building height, but the wind speed tends to increase in between the building blocks. Results also show that potential air temperature reduces with wind speed and increase building height. Generally, this present study proves that increasing building height can simulate the wind speed for better microclimate in high-rise residential in a tropical region. Further research will focus on integrating other elements such as building massing strategy to promote wind direction and wind speed to decrease the air temperature in high-rise residential area.

1. Introduction
The construction of high-rise buildings becomes a trend in developing countries. Urbanization has become the main factor that leads to this phenomenon and the population density in urban areas is the factor that contributes to the opening of high-density residential development projects. High-rise building typology is gaining popularity in Asian mega-cities, due to its advantages in increasing volumetric density with limited land resources (Yang, 2016). Meanwhile, Population Reference Bureau 2005 has reported that half of the 34 billion total population settle in the urban area and it is predicted to increase to 50 billion by 2030 (Mirzaei & Haghighat, 2010). This rapid urbanization and massive migration to the urban areas have changed urban development trends and produced variation in urban morphology which also leads to climate changes. Major atmospheric and surface changes are related to the development of the cities. Building, road and infrastructure materials together with three-dimensional form of urban landscape also change the thermal, radiative, hydrologic and aerodynamic
of surface and air flow, and water and energy exchanges. Other than that, the emissions of heat, carbon dioxide and pollutants into the air also can result in changes to the climate (Grimmond et al., 2016).

Population growth, climate change and the degradation of natural environment source is the major global challenges for the developing Asian countries. These issues not just threaten lives but the survival of the earth. Therefore, to address this issue, urban development especially high-density residential need to integrate microclimatic aspect into the design process at the early stage. The Sustainable Development Goals (SDGs) which is also global goals have been adopted by all United Nations member states in 2015. These goals are proposed as a foundation for a transformation of the global economies towards sustainable development. Developing country like Malaysia, need to find the balance between development and related action to address environmental change and sustainable utilization of natural endowment towards achieving SDGs. Previous researches on urban geometry related to microclimate have shown that there are significant relationships between height and distance ratio between each building and effect on radiations and wind speeds (e.g. Paramita & Fukuda, 2013).

The study aims to determine the effects of different building shapes and heights on the microclimate of high-rise buildings in Ara Damansara, Petaling Jaya, Selangor. The findings will assist architect, urban planners and related agencies to develop better understanding on the relationship between microclimate and urban design within the context of high-rise building project in Malaysia.

2. Methods
The study consists of two (2) main phases. Phase 1 is a stage to study the effects of high-rise residential building shape towards microclimate while Phase 2 study on the effects of the different height of the residential building towards microclimate in the tropical regions. In the first phase only three different building shapes were tested. In the second phase, only the existing building shape (triangle shape) of three different heights were tested. ENVI-met CFD simulation software was used to simulate microclimate while the ArcGIS software was used to analyse the effects of building shape and height on the microclimate of the study area. The methodology flowchart adopted for this study is shown in Figure 1.

2.1. Study Area
The study area is a newly developed high-rise residential township in Ara Damansara, Petaling Jaya. It is situated along the Sultan Abdul Aziz Airport Road, next to Tropicana and Bandar Utama Damansara. This residential township can potentially develop into a prestige township because of its strategic location and easy accessibility. Ara Damansara is selected because of the rapid growth of new high-rise residential development that consists of a variety of design shapes, massing designs and orientation. The Ara Green Residences, a multi-generational and harmonious development project is selected as specific site for this initial study. This precisely planned 7.5 acres site consists of residential and community space with cutting-edge architecture and energy efficiency technology that form every aspect of modern living. Ara Green Residences building envelope consist of concrete materials and a glass curtain wall, and windows with a horizontal balcony as a sun shading (refer to Figure 1). Basically, Ara Green Residences consist of six (6) residential blocks. The basic form of each of the building blocks is triangle in shape. Because of the triangle shape, the orientation of the facades of first three buildings are West, South to South-East and North to North-East orientations while the other three building facades face East, North to North-West and South to South-West direction. Each block of the residential consists of 15 floors, which is approximately 49.5 meters in height. The building envelope consists of concrete materials and a glass curtain wall, and windows with a horizontal balcony as sun shading. Within this development, there are 21 feet wide internal roads with two (2) lane ingresses and egresses to the basement parking.

2.2. Construction of Simulation Models
For the Phase 1, initial simulation was based on existing building shape (i.e. triangle). The other generated alternative shapes tested were circle and square building shapes. These additional building
shapes were generated based on the existing triangle building shape within the existing geometric. The models for these three (3) alternative cases were generated based on existing 15-storey building height. Alternative case scenario models were generated using ENVI-met SPACE. The model is created using a 4-meter pixel which covered the mesh of 90 x 90-pixel grid. The total height for the model is 50-pixel grid. Basically, the process starts with generating model for the existing building layout at the selected site. Then, two other alternative cases are generated with the same building height, environment and climatic condition for comparison.

In Phase 2, the study continues with analysing the effects of height on only the triangle shape buildings. Three (3) case models which are Case 1b model (i.e. actual building height - 15-storey building blocks), Case 1a with height reduction by half (8-storey) and Case 1c with height up to 23-storey. The simulation models focus on the building block neighbourhood for better analysis. The model is created based on a 2-meter pixel which covered the mesh of 140 x 140-pixel grid, while the total height for the model is 80-pixel grid. All the three (3) cases are generated with the same environment and climatic conditions but different building heights for comparison.

**Figure 1.** Methodology flowchart of the study. (Source: Aerial view from Google Map)
2.3. Microclimate Simulation

ENVI-met numerical simulation is used in this study to compare differences in microclimate characteristic of three (3) different alternative cases of high-rise residential building blocks. ENVI-met is used for this study because of the ability for analysis of design impact on local environment which can help to mitigate UHI. Microscale Computational Fluid Dynamic (CFD) simulation also has ability to yield progressively right recommendations compared to other techniques which can provide solution for the fundamental physics equations with the effect of comprehensive three-dimensional geometry and local natural conditions (Houda et al., 2011). The configuration data for Phase 1 simulation is shown in Table 1. In Phase 2, the simulation date is selected base on the actual weather condition at the study area. The day with the highest temperature and highest wind speed is selected base on the weather historical data. The model of 2-meter with 140 X 140-pixel grid covered an area of 78,400-meters square. The simulation date is 9th of June 2020 and start at 14:00 hour for two (2) hour.

| Table 1. Configuration data for Phase 1 ENVI-met simulation. |
|---------------------------------|---------------------------------|
| **Model Domain** | **Model Location** | **Name of location** | **Ara Damansara, Petaling Jaya, Selangor, Malaysia.** |
| **Position on earth** | **Latitude (deg.,N,-S)** | **3.12** |
| **Longitude (deg.,W,+E)** | **101.58** |
| **Reference time zone** | **Malaysia time** |
| **Model Geometry** | **Model Dimensions (x-Grid,y-Grid,z-Grid)** | **90,90,50** |
| **Size of Grid Cells** | **(dx,dy,dz)** | **4.00,4.00,4.00** |
| **Simulation Timing** | **Start simulation at day (DD/MM/YYYY)** | **09.06.2020** |
| | **Start simulation at hour (HH:MM:SS)** | **07:00:00** |
| | **Total simulation at time (h)** | **24** |
| **Meteorological Data** | **Wind Speed** | **2.2 m/s** |
| | **Wind Direction** | **180° (south)** |
| | **Temperature** | **35°C** |

2.4. Assessment of Results

Wind and air temperature are the two factors to assess the microclimate model (in terms of the overall model and spatial distribution). Wind direction, wind speed, and potential air temperature were used as indicators in study. This is because the increase of air temperatures is due to the UHI effect and a decrease in wind speeds which is due to wind shielding (Allegrini, et al., 2015). Previous study by (Zhang, et. al., 2019) had proved that increasing air flow can mitigate air temperature This factor can be considered towards mitigating the UHI effect since natural wind flow contributes towards thermal comfort in urban area. For Phase 1, simulation result of all the three factors (wind direction, wind speed and air surface temperature) were analysed for every 6-hour at 03:00, 09:00, 15:00 and 21:00 hours. The results were compared based on each building shapes (i.e. triangle, circle and square). In Phase 2, the simulation results from ENVI-met software are converted to ArcGIS for further statistical analysis. Spatial distribution maps for the different building heights at 15:00 hour are visualized using Leonardo in ENVI-met. The cutting plane for ENVI-met simulation is at 1.8-meter height for both wind and temperature characteristic analysis.

3. Results

3.1. Simulation Results of Phase 1

The ENVI-met simulation for wind direction shows similar pattern for each of the compared cases. The spatial distribution of wind direction at cutting plane 2-meter height for the 15-storey building blocks shows no significant difference in terms of the pattern at the monitored time except the clear path between each block allows stability for wind direction from the source (refer to Figure 2a). The results have shown that different building shapes do not significantly affects the wind direction within the selected study area. Visually, the spatial distribution of wind speed shows a specific trend
for each of the building shapes. The clear straight path within each building blocks for Case 1 creates a wind corridor which increases the wind speed significantly. The result also shows the increase of wind speed at the building corners (refer to Figure 2b).

![Image](image.jpg)

**Figure 2.** Spatial Distribution of (a) Wind Flow and Wind Direction, (b) Wind Speed and Potential Air Temperature.

As shown in Figure 2b, the temperature field characteristic (i.e. potential air temperature) for the different building shapes (Case 1, Case 2 and Case 3) varies significantly. The spatial distribution of high temperature for Case 1 (triangle shape building) is minimum as compared to the other two cases (round and square buildings). Case 3 shows the high spatial distribution for the high potential air temperature at 3:00, 9:00, and 21:00 hours as compared to the other two cases. However, for 15:00 hour, Case 3 shows domination in lower temperature compared to the rest.

The spatial distribution of potential air temperature of Case 1 shows the high distribution of high temperature at 15:00 hour. The high-temperature spatial distribution is less at 3:00, 9:00, and 21:00 hours compared to Case 2 and Case 3. Potential Air Temperature are higher at 15:00 hour and lowest at 9:00 hour. It can be concluded that Case 1 (existing triangle shape building) produce the best microclimate spatial distribution as compare to the other two (2) alternative shapes i.e. Case 2 and Case 3. Based on these results, simulation in Phase 2 only consider the triangle shape building to evaluate the effects of building heights on the microclimate.

3.2. **Simulation Results of Phase 2**

The results of the microclimate simulations of the three (3) different building heights are shown in figures 3a, 3b and 4. Spatial distribution of the wind direction (as shown in Figure 3a) shows that building height has significant effects on wind direction. In case 1c, the 23-storey building blocks shows the wind directions angle range are between 112.5 to 157 degree and 225 to 247.5 degree. While, the lowest building, Case 1a shows the wind direction range between 157.5 to 202.5 degree, i.e. parallel to the south wind direction. As shown in Figure 3b, the spatial distribution of wind speed clearly shows that building height has an effect on wind speed of the study area. Spatial distribution map for Case 1c (23 storey) shows higher wind speed compared to Case 1a (8 storey) and Case 1b (15 storey). For Case1a, the 8-storey building height shows the minimum spatial distribution of higher value wind speed. This shows that wind speed increases with the increase of building heights. As shown in Figure 4, the spatial distribution of potential air temperature maps of all three building heights tested varies significantly. Based on the results, Case 1a is the only model with temperature above 35°C air temperature. Case 1c shows that most of the temperature zone is in Class 7, which is between 34.00 to 34.25°C. The results proved that high building promotes lower air temperature within the study area.
4. Discussion

This study compares the condition of urban microclimate in a tropical region with different building shapes and building heights. It is found that the shape and height of a building have significant effects on the microclimate of the study area. Previous research has shown a significant connection between urban morphology and the rising air temperature in urban areas (Hien et al., 2011). Other study by Isa et al., (2018) have also shown that the urban climatic map can be used as a tool for environmental understanding for better meteorological response design.

Figure 3. Spatial Distribution of (a) Wind Direction of 3 different heights, (b) Wind Speed of 3 different heights.

Figure 4. Spatial Distribution of Potential Air Temperature of 3 different heights.
Results from Phase 1, reveals that different building shapes produce very minimum effect on wind direction. This could be due to the use of course 4-meter pixel size that covers the whole study area. The use of higher resolution pixel model can help produce a high pixel spatial distribution maps, hence generate a more accurate maps in terms of visualization and interpretation. However, in terms of potential air temperature, triangle building block shape produces more sustainable microclimate condition compared to the other two alternative shapes, especially at 3.00 hour. This result match with the simulation output for wind speed in which the existing triangle shape shows higher wind speed for every monitored hour. According to You et al., (2019), building with round corners experience an increase in wind speed of up to 13%, as compared to regular corners, while corner cuts increased wind speed up to 15%.

In Phase 2, analysis reveals that building height shows a potential effect on wind diversion. The high building will increase the potential wind tilting from the main direction. This result proved that low building is more stable in maintaining the wind direction. The number of building facade which block the wind direction potentially cause significant effect on the amount of wind diversion in urban microclimate. This shows that building height strategies can be used to mitigate the UHI effect by simulating wind direction around the high-rise residential development. Air flow is one of the many identified strategies to reduce and mitigate UHI effects (Rajagopalan et al., 2014). Simulation output in this phase also proved that, increase in building height plays important role in increasing wind speed around building especially between building blocks. The close proximity between blocks creates a wind tunnel effect which causes the wind to move faster and reduce air temperature.

This study also proved that building shape has minimal effect on wind speed. The wind speed increase at building corners which are clear of obstruction and parallels the main wind direction. However, wind speed will increase significantly by the increase in building height. The clear path between each of the building block creates a wind corridor. The wind tunnel effect strengthens by the increase of the corridor ratio created by the building height. Previous research reveal that wind corridors is one of the main strategies to mitigate UHI effect (Hsieh & Huang, 2016). The increase of wind speed in high building blocks also lead to low potential air temperature. The high building promotes high wind speed which also lead to low potential air temperature in the study area. This proved that there is a significant relationship between wind speed and potential air temperature in urban areas.

5. Conclusions
This study explores the condition of urban microclimate in a tropical region with different building shapes and building height. It can be concluded that the shape and height of a building have significant effects on the microclimate of the study area. Wind direction loses stability with the increase of building height. But the wind tunnel effect created by the building height has a significant effect on wind speed. Wind speed increase with the increase of building height in between the building blocks. As a result, potential air temperature also reduces with the wind speed and increased building height. It was found that potential air temperature peak at 15:00 hour. This present study demonstrates that increasing building height can simulate the wind speed hence contribute to better microclimate in high-rise residential areas in a tropical region.

The increase of the air temperature in the urban areas significantly affect the thermal comfort level especially in the high-rise residential building hence increased utilization of energy for cooling which leads escalates pollutant concentration in that area. Further comprehensive research needs to be done to study the vertical microclimate condition to promote UHI effect mitigation especially in tropical region high-rise residential area. Future research will also focus on integrating other element such as building massing strategy to promote wind direction and wind speed hence decrease the air temperature in high-rise residential area.
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