THE EFFECT OF NATURAL ENVIRONMENTS ON THE URBAN MICROCLIMATE BY USING ENVI-MET Ver 4.3 SIMULATION PROGRAMME

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ABSTRACT

One is the environmental impact of rapid urbanization is the Urban Heat Island (UHI). This climatic phenomenon can directly affect urban dwelling discomfort and indirectly related to climate change due to their contribution to the greenhouse effect and hence leads to global warming. Thermal remote sensing measurement, weather stations network observation and numerical simulation model are several methods used to monitor the UHI event. However, a numerical method can give a greater control over modelling in regards to time and resources. This research aims to study the effects of natural environment on the air temperature distribution within a small urban setting. The examined scenarios were investigated using micro scale numerical model, ENVI-Met Ver. 4.3. The accuracy of the base model is validated by field measurements. The analysis revealed an important reduction of air temperature through shading effect of trees and leaves' evapotranspiration. The influence of greenspace and waterbodies on urban microclimate were significantly important to reduce ambient temperature in urbanized areas. This study provides evidence that the microclimate and outdoor thermal conditions in Section 7, Shah Alam city are greatly affected by different urban surface properties. The outcome of the study provides valuable insight for urban designers and planners making a right decision during the designing process through assessment and visualization the relevant impact of these phenomena on the urban environment for mitigating urban heat island effect. This results also contribute an understanding on the possibilities for the transformation of existing urban spaces towards a more liveable and sustainable future.

Keywords: Urban Heat Island, Urban Microclimate, Numerical Simulation, ENVI-Met.

1. Introduction

An increase in urbanization has been observed during the twentieth century. In Malaysia, the proportion of urban population increased to 32.6 % in 2010 compared with 62.0 % in 2000. Apart from Wilayah Persekutuan Kuala Lumpur and Wilayah Persekutuan Putrajaya with 100 % level in urbanisation, the other states with high level of urbanisation were Selangor and Pulau Pinang with 91.4 % and 90.8 % respectively (Department of Statistics Malaysia, 2011). In 2015, 74.71 percent of Malaysia's total population lived in urban areas and cities (World Bank, 2017).

The growth of the urban population in a short span of time in urban area has created various problems including high cost of living, crime, social problem, environmental deterioration, unemployment and poverty (Siwar et al., 2016). One of the major environmental impacts of rapid urbanization is the Urban Heat Island effect (Zhang, Li, & Wu, 2017; Xu et al., 2017; (Sodoudi, Shahmohamadi, Vollack, Cubasch, & Che-Ani, 2014). This event occurs when the air temperature over urban areas is significantly higher than over surrounding rural areas due to increased amounts of anthropogenic heat, heat absorbing land cover, air pollution, and the reduction of green spaces as urban areas develop (Paolo & Giovanni, 2018). Urban design geometry was identified as one of the leading factor of UHI issue (Abutaleb et al., 2015). This climatic phenomenon can affect communities by increasing heat-related illness and mortality, increase summertime peak energy demand, air conditioning costs, air pollution and greenhouse gas emissions, thereby contributing to global warming effect.

Since, the issue of urban heat island has received considerable critical scrutiny around the world. Therefore, the understanding the drivers of urban thermal issues is crucial for adaptive mitigation strategy which in turn has strong implications for a sustainable built environment. The architects, urban designers, and decision makers play an important role in this aspect to ensure that planning and development can meet present needs without comprising the ability of future generations. Various research studies were conducted to identify UHI matter in different urban sizes such as in mesoscale, local scale and micro scale. The urban climatology is mostly focused on micro scale UHI where the air temperature covered around less than 100 m from ground surfaces (Wang & Zhou, 2017). Several methods are commonly used to monitor the UHI effect such as from satellite remote sensing measurement (Zaeemdar & Baycan, 2018), fixed weather stations network (Puansurin, K., Wongtragoon, U., Singchan, B.,Suwanmaneepong, 2018) (Azevedo, Chapman, & Muller, 2016) and numerical simulation model (Maleki & Mahdavi, 2016).

Remote sensing can offer high spatial resolution thermal imagery to study the spatial and temporal pattern of UHI across entire urban regions over time through land surface temperature (LST) measurements. However, the observed LST is depends on spatial resolution because of the different land cover types. This technique can provide a qualitative measure of the distribution of UHI at a given moment which prescribed by time of satellite overpass. It also restricted to atmospheric condition, required only clear or mostly clear skies and the limited to the viewing of the sensors. Even though, it is possible to estimate air temperatures from surface temperature data, but the measurements are less reliable than direct measurements. This is due to the imagery data ignores land cover characteristics on a community or micro scale. The LST also neglects the contribution from the surface of exterior building walls. Here is a serious deficiency for the consideration of urban solar heat absorption and reflection, which not relevant for large cities with high density of high-rise buildings.

The other approach is from meteorological data that have been collected from fixed local weather station. The UHI effect can be analysed by comparing the thermal data series of an urban area with those corresponding to a nearby rural area. However, in the absence and non-uniform distribution of ground weather stations may give some limitation to investigate UHI event effectively (Abutaleb et al., 2015). Therefore, a better conceptual access is needed to understand the role and effects of UHI in cities and to consider in urban design guidelines and implementation measures especially in micro scale environment. Numerical simulation approach was capable to give a greater control over modelling in regards to time and resources. It also can give a great impact on urban climate modelling and simulation by providing realistic input data and powerful visual presentation tools. This method was identified as an easy way to observe how does the natural environment features in urban areas influence to the formation of UHI intensity. Since, a primary concern of urban information is always related with the temporal dimension. By all means, the design planner can solve problems which not only with present data but also with past and future data.

2. Study Area and Climatic Condition

This study was conducted in Shah Alam city, which has a population of 723,890. It is situated within the district of Petaling and a portion of the district of Klang in the state of Selangor. The specific location of the study area is located at Section 7 Commercial Centre, Shah Alam and apart of I-City Shah Alam theme park, as shown in Figure 1. The size of site's area for this research study was 1km².

Figure 1. View of the Selected Study Area

The selection of this study area was due to the rapid changes development, which has resulted in change of urban environment conditions. The existing landscape features also consist of build and natural environment, high building density and the higher temperatures recorded in the selected central area compared to the city rural area. Thus, this selected space is appropriate for the research study whereby to investigate how does urban properties of natural environment given a significant impact on the microclimate condition on this particular area. As with other cities across Peninsular Malaysia, Shah Alam experiences a tropical rainforest climate. The temperatures are consistent throughout the year with an average high temperature of 31.9 °C and an average low temperature of 23.2 °C. The city is warmest in the month of March, and experiences heavy rains and showers during the month of November as the northeast monsoon moves in from October to March.

3. Research Methodology

The research was organised systematically into four (4) main phase, as shown in Figure 2. In first phase, it involves determination of the study area, considering what types of data are appropriate, equipment necessary, methods applied and the appropriate software to create a 3D model of urban microclimate and its capability on the analysis part. Next phase, consists of field measurement of current meteorological condition and obtained spatial and attribute information of urban properties in the study area. The domains pertaining to the base model was developed via digitizing of an orthophoto, data extraction from Open Street Map (OSM), field measurement of current site conditions and detail survey data such as building and tree height. These data gathered were used in the development of a computer simulation programme in the third phase. All information setups in ENVI-Met was used in simulating the current environment as its base model. The reconstruction of 3D models as depicted in Figure 3. This main model was validated to provide a reliable simulation output by comparing with the field measurement results.

There are sixteen (16) points was identified which randomly distributed within the study area as shown in Figure 4. A tinytag device was used to measure the air temperature for all these points. Next, several modifications were made to the original base model to simulate three (3) different hypothetical scenario conditions such as add more tress, without greenspace and without waterbodies, as shown in Table 1. These simulation output results from each proposed scenarios were compared with base model to analyze the effect of natural environment on the microclimate of the study area. In the final phase, the urban planning guidelines recommendations were highlighted.

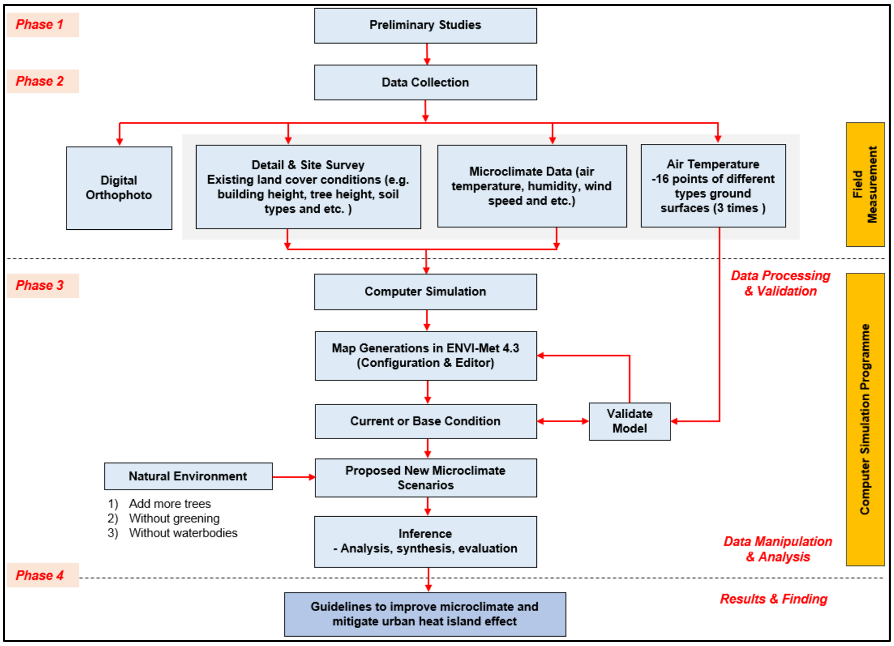
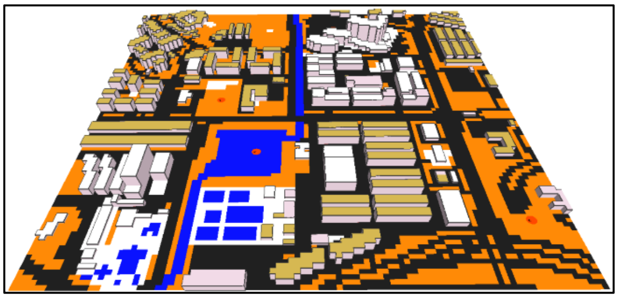
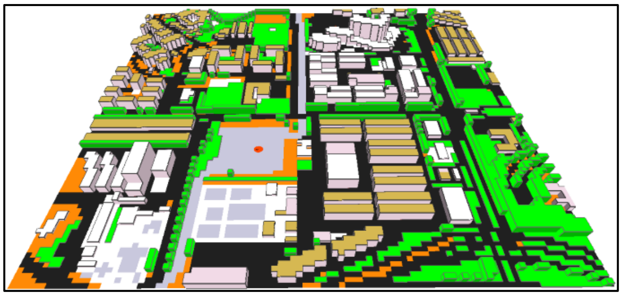


Figure 2. Research Methodology

Figure 3. 3D View of Base Condition Model in ENVI-Met

Figure 4. Measuring Points of Air Temperature for Validation Model
(Data source: JUPEM, 2017)

Table 1. The Examined Scenarios

The examined scenarios	Description of scenarios
S1 – Add Tree	 Trees were added into base condition scenario, replace the pavement, grass and bare land with different tree species types and height of tree. Two types of trees were added in this scenario, which are coded as SM and A9 in ENVI-Met system database profile.
S2 – Without Greenspace	 The green area coverage in urban area of the selected site area was removed and remained with the existing soil.
S3 – Without Waterbodies	 The waterbodies features were replaced with concrete pavement used/ dirty which coded as PP in ENVI-Met database profiles.

4. Results and Analysis

4.1. Validation of ENVI-Met Model

The different value of air temperature (ºC) between simulation model and field air temperature measurement in three (3) different time series were compared and shown in Table 2. The minimum and maximum value at 9.00, 12.00 pm and 3.00 pm are 0.23 and 1.74, 0.05 and 2.75, 0.189 and 2.80 respectively. The Root Mean Square Error (RMSE) for each set of air temperature data at 9.00 am, 12.00 pm and 3.00 pm were 1.082, 1.296 and 1.643 respectively. RMSE summarizes the magnitude of the average difference between observation and prediction, is necessary in model acceptance (Sule

Zango, Yaik Wah, Hooi Chyee, & Dalandi, 2018). Since, the RMSE results for each different time are nearly to 1.0, these show the observed data points are close to the model's predicted values.

Table 2. Different Air Temperature between Simulation Model and Observed Data

Time	Different Air Temperature (°C)		RMSE
	Min	Max	
9.00 am	0.23	1.74	1.082
12.00 pm	0.05	2.75	1.296
3.00 pm	0.189	2.80	1.643

4.2. The Effects of Natural Environment on Air Temperatures

4.2.1. Scenario: Add More Trees

The Figure 5 depicts 2D maps of difference air temperature distribution at six (6) different hours at 9.00 am, 12.00 pm, 3.00 pm, 6.00 pm, 9.00 pm and 12.00 am on 19 and 20 November 2017 respectively. The average temperature difference for this scenario was tabulated in Table 3, at 9.00 am to 12.00 am. The influence of shading tree with height 20 meter very dense coded as SM and distinct crown layer and height 12 meter with crown width 9 meter (A9) showed a significant effect that could reduce air temperatures by leaves' evapotranspiration, especially in the afternoon and evening. Once evaporated into the air, the moisture can spread throughout nearby environment, hence making the atmosphere cooler as well as to improve comfort by decreasing the amount of solar radiation on pedestrians (Wu, Kong, Wang, Sun, & Chen, 2016).

The effect typically reaches its peak when evaporation levels are highest at 3.00 pm, but still significant lowering air temperatures at 12.00 pm until 6.00 pm. However, the difference of air temperature map at 3.00 pm shows the temperature slightly increase at the upper left corner location, approximately around 0.3 to 0.6 ºC. These warmer areas were represented by orange tones which indicates the heat gain after running the simulation. Based on this hourly map, the location of abovementioned area actually increased the heat load, perhaps by blocking winds. The trapped heat reduces urban air flow at near surface due to tall buildings that are densely crowded over there. This condition may keep the surface air warm from the still warm urban surfaces and therefore forming the warmer air temperatures within that period of time. However, this effect was slightly reducing up to 0.6 ºC at midnight. This finding further support the idea of Ragheb, El-Darwish & Ahmed (2016) , where the constructing height, technique flow, wind direction, geometry of buildings and their surroundings are the factors could induce the wind speed.

The capability of the trees to provide shade and absorb carbon dioxide can be an alternative way of rising albedo for improving the thermal environment. The vegetation cooling potential have the greatest impact on sunny summer afternoons. On the other hand, few variables were identified influence shading potential and the quality and quantity of shading. It was determined by species of tree, foliar condition, canopy volume, shape of crown, foliation period, leaf area, tree location and its orientation with respect to a building (Abdel Aziz, 2014). In addition, it also depends on the size of selected urban area and the amount of trees covered on that area. The consideration on these variables can play a significant role in energy conservation. It was considered of the practical strategy on mitigating high local temperature through tree shading and evapotranspiration (Rui et al., 2019). Previous study has indicated that the spatial arrangement and tree locations can strongly influence its cooling effect on outdoor microclimates. Zhao, Sailor, & Wentz (2018) suggest that an equal interval two trees arrangement can improve microclimate and human thermal comfort followed by clustered tree layout without canopy overlap.

Table 3. Different Air Temperature between Add More Tress and Base Condition

Date	Time	Average Temperature (ºC)
19-Nov-17	9.00 am	- 0.23
19-Nov-17	12.00 pm	- 0.42
19-Nov-17	3.00 pm	- 0.73
19-Nov-17	6.00 pm	- 0.67
19-Nov-17	9.00 pm	- 0.35
20-Nov-17	12.00 am	- 0.24

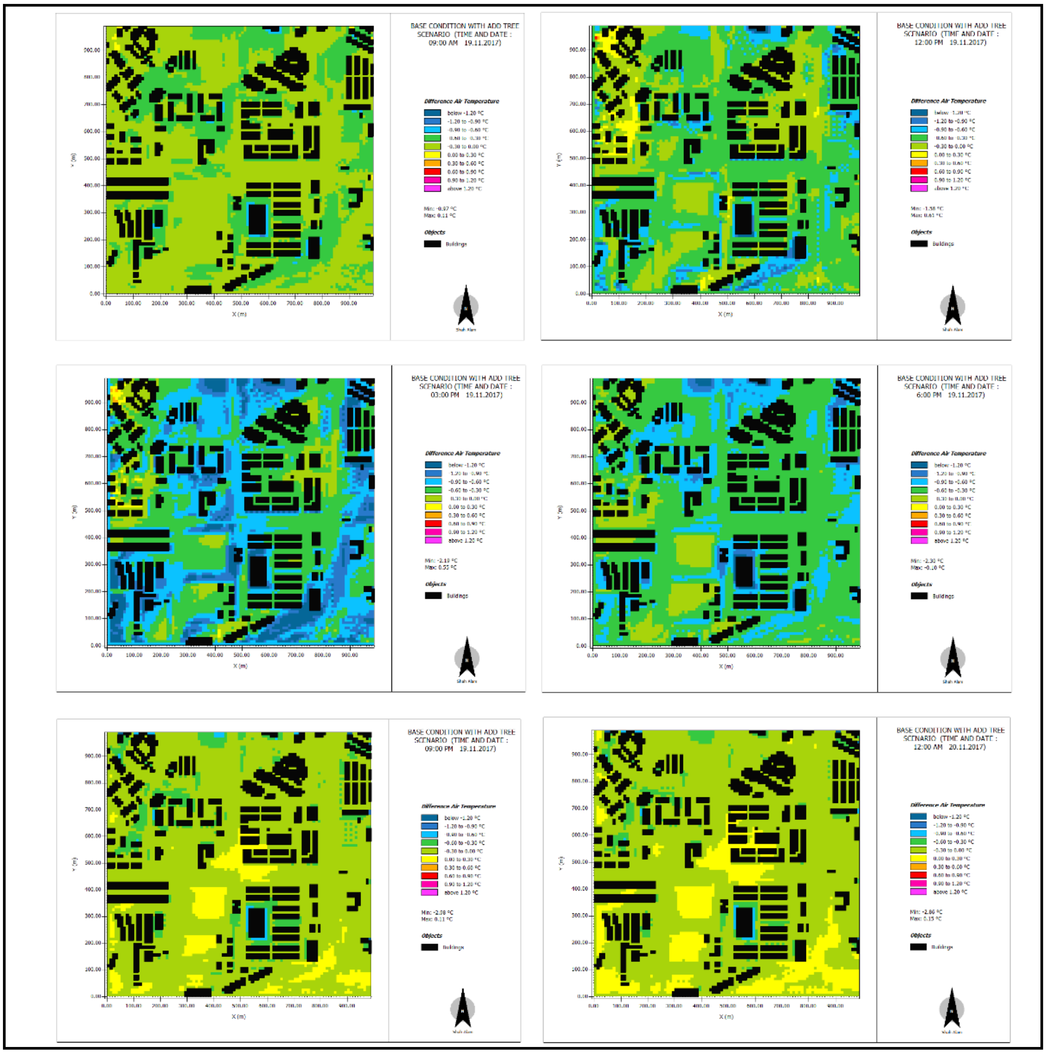


Figure 5. 2D Maps of Difference Air Temperature after Adding More Trees

4.2.2. Scenario: Without Greenspace

The spatial distribution map of air temperature after running 24 hours simulation were depicted in Figure 6 at 7.00 am, 3.00 pm and 11.00 pm respectively. By referring to these map, there were no effect on microclimate in the morning and night, at 7.00 am and 11.00 pm. The average difference temperature between this scenario and base condition is shown in Table 4. However, this effect of without greenspace more influence air temperatures in the surrounding area in the evening, at 3.00 pm. As seen at this hour, the size of the air temperatures distribution was growing to be larger and hotter than the base condition. Additionally, Figure 7 depicted the difference of air temperature map between without greenspace scenario with base condition model at 3.00 pm. The orange, red, light and dark pink colour on the map indicates the heat gain after the modification of removing greenspace area. This means, the effects of greenspace on urban microclimate was significantly important to reduce ambient temperatures at urbanized areas. This finding is consistent with the previous study that green space and landscape configuration should be incorporated into urban planning to reduce the influence of urban heat island (Cao, Huang, Liu, Zhai, & Wu, 2019).

However, the increment of air temperature only concentrated on the area which previously covered with urban trees. The green colour on the map portrayed the reduction of air temperature range from 0 to 0.3 ºC, which potentially influence from the availability of waterbodies that existed within the study area which enhances evaporation. This may help to cool the aforementioned places indirectly. The other possible reason is due to the changes of wind direction and speed, effect from removing trees and this bring cool air to heat places, hence cooling the surrounding area.

Table 4. Different Air Temperature between Without Greenspace and Base Condition

Date	**Time**	**Average Temperature (ºC)**
19-Nov-17	7.00 am	0.01
19-Nov-17	3.00 pm	0.17
19-Nov-17	11.00 pm	0.05

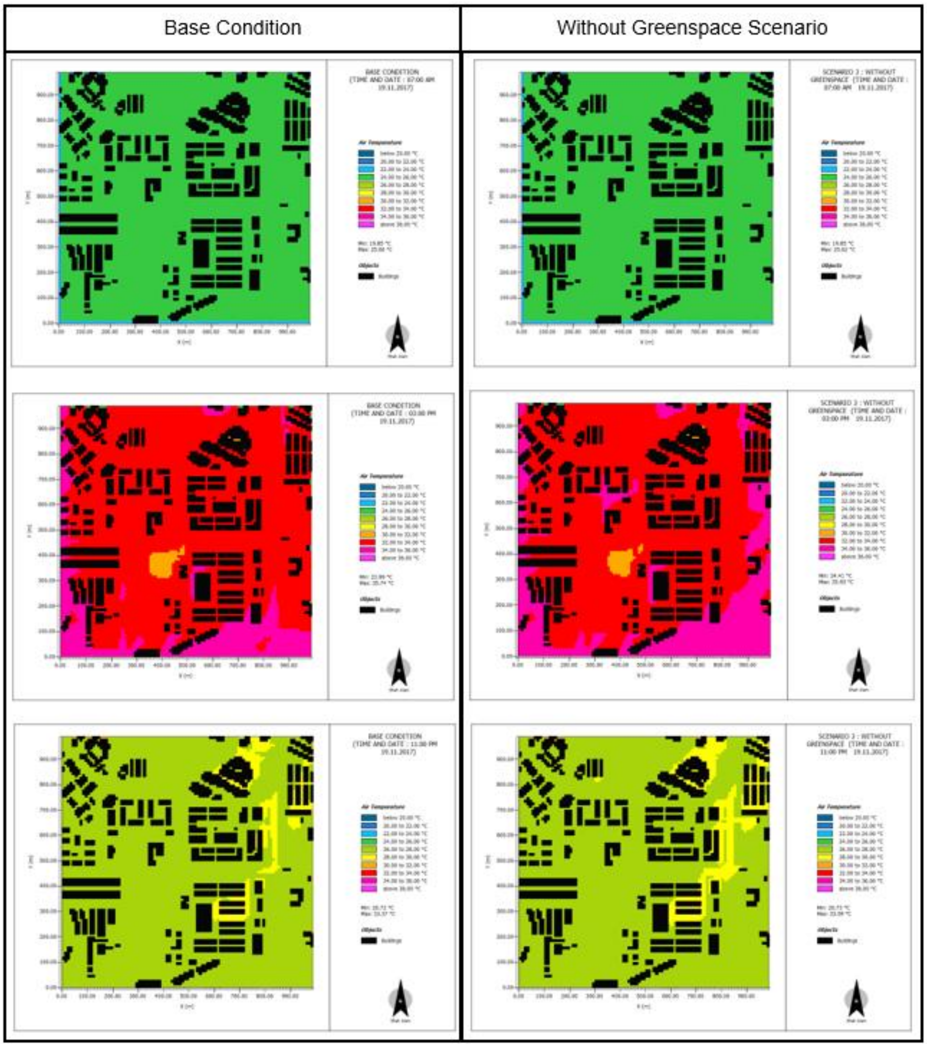


Figure 6. 2D Map of Air Temperature for Base Condition and Without Greenspace at 7.00 am, 3.00 pm and 11.00 pm

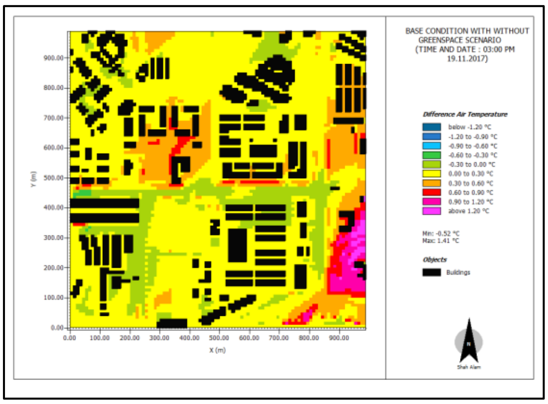


Figure 7. Different Air Temperature Map After Removing Greenspaces at 3.00 pm

4.2.3. Scenario: without Waterbodies

Under this scenario, all the waterbodies surface in the study area was removed and replaced with concrete pavement material. The image view after run the simulation were shown in Figure 8 and Figure 9 at 3.00 pm and 11.00 pm respectively. The effects of air temperature were no significance different in the morning and less effect at night but have a significant higher effect in the afternoon after the replacement of waterbodies features. These warmer areas were depicted by orange, red and pink color on map where the maximum difference value of air temperature between both scenarios was 2.38 ºC at 3.00 pm. Meanwhile, the distribution of air temperature was slowly decrease at night with the maximum value was 0.88 ºC at 11.00 pm on 19 November 2017. The average temperature difference at 3.00 pm and 11.00 pm are 0.22 and 0.13 ºC.

Based on Figure 8 the direction of this warmer air temperature distribution was influences by wind speed and wind direction and these heat disseminations gradually lost when the distance was approximately reach to 300 meter from the outer boundary of concreate pavement for the area less than 0.021 km^2 or 20956 m^2. The higher difference air temperature was found in the centre of the concreate pavement, the area where the lake region was removed. The air temperature increment occurred between these scenarios with a maximum difference up to 2.38 ºC. The average of air temperature rising recorded at this hour, 3.00 pm was 0.22 ºC. The encounter of difference wind direction over the concrete pavement at atmospheric level caused the air temperature trapped and still for period of time and hence getting hotter since the wind speed was low on that particular areas.

Besides, the replacement linear shapes of waterbodies such as river with 18-meter width to concreate pavement material could increase air temperature up to 1.2 ºC. However, the effect of rising heat on the surrounding environment will disappear when the distance away 50 meter from the outer boundary of concreate pavement was also follow the wind direction and wind speed. Based on this finding, the distribution size of this warmer air temperature affect nearby environment was highly depend on the area size of the concrete pavement itself. The big size of waterbodies replacement with concrete pavement, the more heat can take place in surrounding environment together with wind speed and direction influences. Further support for this finding was found from Masiero & Cristina Lucas de Souza (2015), that the waterbodies play a great role to control thermal quality of the urban air rising humidity levels and having direct force on its surroundings.

Based on these results, it can be concluded that the decentralized distribution of concreate pavement after replaced to waterbodies on the microclimate environment in urban area can give more significant effect in increasing air temperature than the concentrated distribution. This finding is in agreement with Zeng, Zhou & Li (2017) findings which showed that the water scale has a significant effect on the microclimate of the waterfront environment which is gainful to alter temperature and humidity in microclimate. They found that the air cooling effect of the water increases with the increase of the water area, and the water area size of the 400 m^2 and 1600 m^2 can be reduced air temperature by 0.2 ℃ and 0.39 ℃ respectively. Therefore, the size, shape and the distribution of the waterbodies over the urban areas play their important role on cooling the ambient temperature in the surrounding areas. Hence, this natural feature of waterbodies in urban environment should be preserve from any future development to mitigate UHI effect.

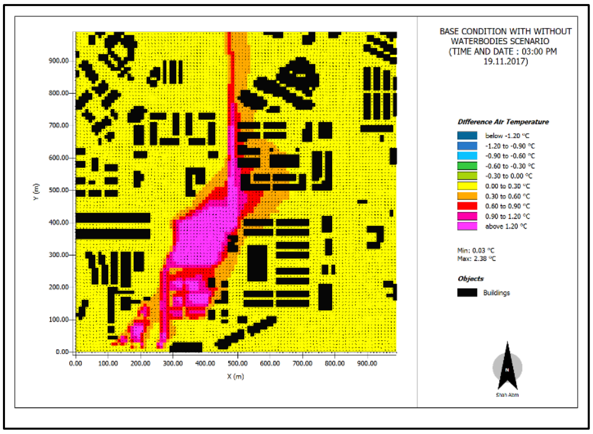


Figure 8. Different Air Temperature Map after Removing Waterbodies at 3.00 pm

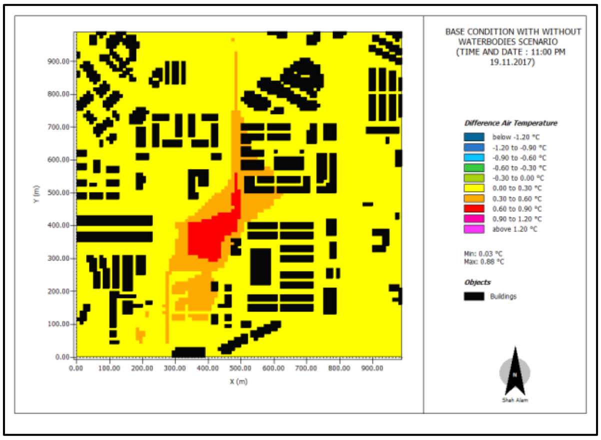


Figure 9. Different Air Temperature Map after Removing Waterbodies at 11.00 pm

5. Conclusion and Recommendation

It can be concluding that, the numerical simulation modelling was identified as an effective tool to evaluate the effect of natural environment and recommend urban planning strategies on UHI mitigation. This is due to the capability of this method that have a greater control over modelling in regards to time and resources. Thus, make it advisable for any planning process. Even so, the precision of ENVI-Met output results highly depends on the accuracy of input data and the carefulness of digitizing the components of the urban space. Therefore, field measurement approach and high resolution image orthophoto used are important to produce a precise model of the study site microclimate condition.

The potential cooling of shading trees, greenspace area and the existence of the waterbodies plays a significant impact on microclimate condition in urbanized areas. The shading of trees has the greatest impact reducing the ambient air temperature especially on sunny summer afternoons. However, the benefits of shading trees can be achieved through the consideration of the quality and quantity of shading whereby determined by species of tree, foliar condition, canopy volume, shape of crown, foliation period, leaf area, tree location and its orientation with respect to a building. It also depends on the size of selected urban area and the amount of trees covered on that area. The tree arrangement plays a significant effect to mitigate extreme heat especially in residential environment area.

Furthermore, the effect of without greenspace more influence air temperatures in the surrounding area in the evening. However, the increment of air temperature only concentrated on the area which previously covered with urban trees. But in certain places, the reduction of air temperature ranges from 0 ºC to 0.3 ºC, which potentially influence from the availability of waterbodies within the study area. The other possible reason is due to the changes of wind direction and speed, effect from removing trees and this bring cool air to heat places, hence cooling the surrounding area.

Besides, the effect of the waterbodies in reducing air temperatures was depend on the distance from the waterbodies itself. The size, shape and the spatial distribution of waterbodies in urban area may also influence the change of air temperature. Unconcentrated waterbodies more influence to increasing air temperatures compare with concentrated distribution. Furthermore, the influence of the waterbodies is still measurable several meters downwind of the waterbodies together with the wind speed and wind direction influences. The heat dissemination gradually lost when the distance was approximately reach to 300 meter from the outer boundary of waterbodies for the area less than 0.021 km^2 or 20956 m^2. The replacement linear shapes of waterbodies such as river with 18-meter width could increase air temperature up to 1.2 ºC. However, the effect of rising heat on the surrounding environment will disappear when the distance away 50 meter from the outer boundary of river together with the wind direction and wind speed.

Further studies should consider the highly detailed and accurate of the 3D model development of urban spaces from Lidar data. This Lidar point data not only represent the bare earth elevation model but also represent man-made object likes building, tress and ground. The other climatic parameters such as wind speed and direction need to be explored together with air temperature since it can play a significant impact on microclimate changes. Besides, it was also recommended to set the programme run for 48 hours and notice that the simulation starting time should fix to 6.00 am. This is due to the slow physical process and the interaction of thermal behaviour at the sunrise time which can take place completely after run the first 24h cycle. By doing this, all of the environmental components were more stable and the calculation of the model more accurate in the second 24h cycle to achieve numerical stability. Finally, the exploration and development of on urban properties characteristic (vegetation database, physical soil structure and profile information) should be considered according to Malaysia context, to ensure the result of simulation more accurate and reliable.

References

Abdel Aziz, D. M. (2014). Effects of Tree Shading on Building's Energy Consumption. *Journal of Architectural Engineering Technology*, *03*(04). https://doi.org/10.4172/2168-9717.1000135

Abutaleb, K., Ngie, A., Darwish, A., Ahmed, M., Arafat, S., & Ahmed, F. (2015). Assessment of Urban Heat Island Using Remotely Sensed Imagery over Greater Cairo , Egypt. *Advances in Remote Sensing*, *4*(March), 35–47.

Azevedo, J. A., Chapman, L., & Muller, C. L. (2016). Quantifying the daytime and night-time urban heat Island in Birmingham, UK: A comparison of satellite derived land surface temperature and high resolution air temperature observations. *Remote Sensing*, *8*(2). https://doi.org/10.3390/rs8020153

Cao, W., Huang, L., Liu, L., Zhai, J., & Wu, D. (2019). Overestimating Impacts of Urbanization on Regional Temperatures in Developing Megacity: Beijing as an Example. *Advances in Meteorology*, *2019*, 1–15. https://doi.org/10.1155/2019/3985715

Department of Statistics Malaysia. (2011). *Population Distribution and Basic Demographic Characteristic Report 2010*. Retrieved from https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=117&bul_id=MDMxdHZjWTk1SjFzTzNkRXYzcVZjdz09&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09

Maleki, A., & Mahdavi, A. (2016). Evaluation of Urban Heat Islands mitigation strategies using 3dimentional urban micro-climate model envi-met. *Asian Journal of Civil Engineering*, *17*(3), 357–371.

Masiero, É., & Cristina Lucas de Souza, L. (2015). Among Winds, Water Bodies and Urban Elements. In *9th International Conference on Urban Climate jointly with 12th Symposium on the Urban Environment*.

Paolo, M., & Giovanni, M. (2018). Monitoring Urban Heat Island through Google Earth Engine at large scale : potentialities and diffculties in the case of different cities in the United States. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (Vol. XLII, pp. 2–4).

Puansurin, K., Wongtragoon, U., Singchan, B.,Suwanmaneepong, S. (2018). The study of participatory monitoring of air quality and urban heat , case study Udon Thani province , Thailand. *International Journal of Agricultural Technology*, *14*(7), 1693–1708.

Ragheb, A. A., El-Darwish, I. I., & Ahmed, S. (2016). Microclimate and human comfort considerations in planning a historic urban quarter. *International Journal of Sustainable Built Environment*, *5*(1), 156–167. https://doi.org/10.1016/j.ijsbe.2016.03.003

Rui, L., Buccolieri, R., Gao, Z., Gatto, E., & Ding, W. (2019). Study of the effect of green quantity and structure on thermal comfort and air quality in an urban-like residential district by ENVI-met modelling. In Building Simulation (Vol. 12, No. 2, pp. 183-194). Tsinghua University Press.

Siwar, C., Ahmed, F., Bashawir, A., & Mia, M. S. (2016). Urbanization and Urban Poverty in Malaysia: Consequences and Vulnerability. *Journal of Applied Sciences*, *16*(4), 154–160. https://doi.org/10.3923/jas.2016.154.160

Sodoudi, S., Shahmohamadi, P., Vollack, K., Cubasch, U., & Che-Ani, A. I. (2014). Mitigating the Urban Heat Island Effect in Megacity Tehran. *Advances in Meteorology*, *2014*, 1–19. https://doi.org/10.1155/2014/547974

Sule Zango, M., Yaik Wah, L., Hooi Chyee, D., & Dalandi, A. (2018). Validation of Envi-met Software Using Measured and Predicted Air Temperatures in the Courtyard of Chinese Shophouse Malacca. ©*Journal of Applied Sciences & Environmental Sustainability*, *4*(9), 28–36.

Wang, Y., & Zhou, D. (2017). Simulation Study of Urban Residential Development and Urban Climate Change in Xi'an, China. In *Procedia Engineering*. https://doi.org/10.1016/j.proeng.2017.04.201

World Bank. (2017). Urban population in Malaysia from 2005 to 2017. Retrieved from https://www.statista.com/statistics/603362/malaysia-urban-population/

Wu, Z., Kong, F., Wang, Y., Sun, R., & Chen, L. (2016). The impact of greenspace on thermal comfort in a residential quarter of Beijing, China. *International Journal of Environmental Research and Public Health*, *13*(12). https://doi.org/10.3390/ijerph13121217

Xu, X., Cai, H., Qiao, Z., Wang, L., Jin, C., Ge, Y., … Xu, F. (2017). Impacts of park landscape structure on thermal environment using QuickBird and Landsat images. *Chinese Geographical Science*, *27*(5), 818–826. https://doi.org/10.1007/s11769-017-0910-x

Zaeemdar, S., & Baycan, T. (2018). Analysis of the Relationship between Urban Heat Island and Land Cover in Istanbul through Landsat 8 OLI. *Journal of Earth Science & Climatic Change*, *8*(11). https://doi.org/10.4172/2157-7617.1000423

Zeng, Z., Zhou, X., & Li, L. (2017). The Impact of Water on Microclimate in Lingnan Area. *10th International Symposium on Heating, Ventilation and Air Conditioning*, *205*, 2034–2040.

Zhang, X., Li, G., & Wu, D. (2017). Impact of rapid urbanization on urban heat island effect in a typical valley-city. In *2017 25th International Conference on Geoinformatics* (pp. 1–5). https://doi.org/10.1109/GEOINFORMATICS.2017.8090944

Zhao, Q., Sailor, D. J., & Wentz, E. A. (2018). Impact of tree locations and arrangements on outdoor microclimates and human thermal comfort in an urban residential environment. *Urban Forestry and Urban Greening*, *32*(April), 81–91. https://doi.org/10.1016/j.ufug.2018.03.022