ISSN 2278-3091
Volume 9, No.1.1, 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse7291.12020.pdf
https://doi.org/10.30534/ijatcse/2020/7291.12020

# The Influence of Urban Morphology on Ambient Air Temperature at Universiti Tun Hussein Onn Malaysia

**Nur Atikah Mohd Zinal[1], Norpadzlihatun Manap[2], Amnorzahira Amir[3], Mohd Yamani Yahya[4], Marcel Ignatius[5]**

[1]Department of Construction Management, Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia, atikahzinal@gmail.com
[2]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, padzliha@uthm.edu.my
[3]Department of Building, School of Design and Environment, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore

## ABSTRACT

Rapid development of Universiti Tun Hussein Onn Malaysia (UTHM) due to increase of demands for new facilities has caused changing of land surface area, natural landscape and paved surface of its surrounding. It creates many negative impacts to occupant and the environment such as reduced thermal comfort and increased energy usage for indoor cooling. The objective of this research is to assess how the urban heat island (UHI) parameter variation of urban morphology, namely pavement percentage (PAVE); building percentage (BDG); average ratio of building height compared to built area (AvgHT); sky view factor (SVF) and green plot ratio (GnPR), can affect the various levels of air temperature of a reference area, namely minimum temperature ($T_{min}$); average temperature ($T_{avg}$) and maximum temperature ($T_{max}$), by using Screening Tools of Estate Environment Evaluation (STEVE). In order to achieve this objective, a total of six stations considering different urban morphologies in UTHM are evaluated. The results are analyzed to understand which of the urban morphology type gives more impact to the ambient air temperature. Results have shown that GnPR, which related to the present of greenery, have the most significant impact on reducing air temperature by up to 0.2 °C to 0.5 °C. This study is the first and most comprehensive outdoor temperature monitoring in urban space at UTHM which gives a better understanding on implication of urban heat island.

**Key words :** air temperature; Universiti Tun Hussein Onn Malaysia (UTHM); Screening Tools of Estate Environment Evaluation (STEVE); building height, pavement; greenery

## 1. INTRODUCTION

Malaysia is going towards having megacities with higher urban density, narrower urban corridors and more high-rise buildings. Based on previous research, 70 to 80 percent increase of population in Malaysia were seen every 10 years and it is expected to increase to 90 percent of population at year 2020 [2]. In the context of rapid population growth and urbanization in recent years, the demands for housing, commercial development and industries tend to transform urban area landscape and surrounding environment to become high building dense city. This created many urban environmental issues. One of them is urban heat island (UHI) phenomenon which alters urban climate to be warmer compared to surrounding rural areas. This issue is because of diminishing of green area, low wind velocity due to high building density and change of street surface coating materials [4].
Supported by Wong *et al.* (2011), urban heat island (UHI) is defined as the phenomena which air temperature is higher in dense urban area than surrounding rural area. High temperature causes serious impact on the thermal comfort at outdoor area and also increases the indoor temperature of building that affects the demands of energy use for indoor cooling. A study by Kolokotroni et al (2007) measured of air temperature data and building energy simulation at 24 difference locations within London UHI found that urban cooling load is up to 25% higher than the rural load over the year and also reduce the level of health of the occupant due to the changing body adaptation of the indoor and outdoor temperature, which is “hot” to “cold” and “cold” to “hot”, intensely.

Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat which is located at suburban area in Johor is a public university in Malaysia and it is still in development progress. UTHM main campus land area is only about 38 hectares or 380000 square meters during its initiation. This area was further expanded to 100 hectares in phase 1 and 99 hectares in phase 2 of developments since 2007 to 2017 and the total land area is 199 hectares. Through this transformation of UTHM, the land use area has totally changed and produced different surrounding area. In the rapid development of this campus with changes of land surface area, natural landscape and paved surface, it provides positive and negative impact to human and the environment.

On this research, the Screening Tools of Estate Environment Evaluation (STEVE) is used to predict and monitor the ambient temperature that can help to reduce the negative impact of new building development that diminishes green area. This paper is aiming to assess how the urban heat island (UHI) parameter variation of urban morphology such as pavement percentage (PAVE), building percentage (BDG), average ratio of building height compare to the built area (AvgHT), sky view factor (SVF) and green plot ratio (GnPR) can affect the level of air temperature minimum ($T_{min}$), average ($T_{avg}$) and maximum ($T_{max}$) of reference area by using STEVE.

This study is the first and most comprehensive outdoor temperature monitoring and detecting in urban space in UTHM. Most of previous studies that have been conducted are about the outdoor and indoor thermal comfort. The result of this study can help to provide a better understanding of the general outdoor temperature of building and urban climate condition in building design and development especially in UTHM. This study may also have significant impact on the understanding of the temperature in urban space. The urban climatic simulation tool can be used by the urban designer, architect and planner in UTHM to produce building design in urban spaces. The urban design strategies suggested in this study can be adopted by urban architect and planner to design green and sustainable building development in UTHM and other relevant areas. The findings of this research helps to improve the people's comfort, reduce the energy consumption and other negative impact in the urban area to provide UTHM campus. From the result of this research, it can recommend land coverings formulae that can be used to decrease air temperature and help to bring a better impact for the other wider land areas such as the city of Kuala Lumpur.

## 2. LITERATURE REVIEW

The development is extremely changing the use of land and natural landscapes with building and paved surfaces. The natural landscape is replaced with the development and then reduces the vegetation. In daytime, the skies are clear of cloud and the urban surface is heated by solar radiation. The temperature in the urban area tend to warm faster than rural area because of the changes of natural landscape [9],[10],[11],[12],[13],[15].

In the build environment at micro scale, the surrounding condition especially on building and vegetation, it greatly influences the incident of solar radiation received by earth surface. This is determined by the open surface which is called as the Sky View Factor (SVF). The SVF is the percentage of a point's field of view that occupied by the trees, building, pavement and other landscape object. The urban canyon with a large aspect ratio will have small percentage of SVF, thus for the flat field with no obstructed horizon will have a large SVF [1]. Many researchers identified that SVF is one of the UHI problem sources, the lower SVF, the higher urban temperature (Figure 1). It is because the building emit greater amounts of long wave radiation than the cool sky, therefore an urban canopy with a small SVF will yield a larger net of long wave (L*). The larger the L* rate, the radiation will reduce and maintain a warm Urban Canopy Layer [14].

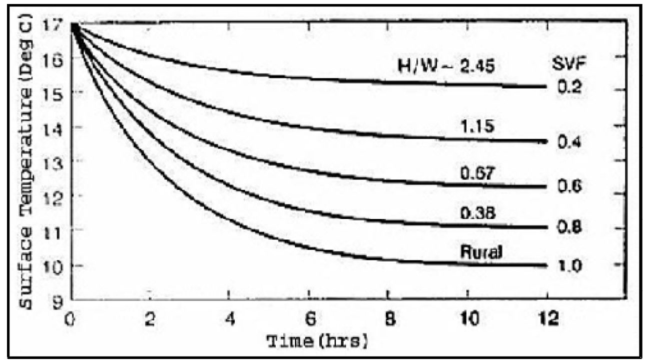


**Figure 1:** Modeled nocturnal cooling of surface temperatures

Urban heat island (UHI) phenomenon is a condition which the air temperature in urban areas are higher than their surrounding due to the greater area of asphalt roads and concrete buildings, which more heat absorbed and retained while the heat reflection ratio are decreasing. A development of temperature prediction model could be an effective tool for simulating and quantifying the temperature reduction in any strategies or mitigation methods.

Based on previous study, urban morphology is the major factor that influences thermal behaviour in a city and creates the UHI impact. Wong *et al.*, (2011) summarized that local climate condition and urban morphology affected air temperature within urban canopy layer which changed the intensity of urban heat island (UHI) and later have impact on outdoor thermal comfort and urban energy usage.

Effective climatic responsive urban planning can be achieved by careful consideration on urban morphology parameter of urban corridor width, building height, urban surface materials, sky view factor (SVF) and vegetation that could help to improve urban environment quality. Wong & Jusuf (2002) stated that greenery has positive impact to the environment and it is necessary to consider greenery as an important element in any contemporary urban planning. Moreover, sustainable development of urban planning can help to improve the greenery condition in planning urban environment.

Another study done by Jusuf *et al.* (2007) revealed that land use planning can help in determining the environment quality by identifying land use type which have the most influence to the increase of ambient temperature in urban area. The different land use type give a different impact of UHI. Therefore, with appropriate land use planning, it could help to mitigate the UHI impact. Wong, Jusuf & Tan (2011) stated that prediction models can give good help in mitigation strategies, evaluating urban air temperature, improve weather forecasting and improve air quality. Additionally, trees and vegetation progressively help to cool urban climates through shading and evapotranspiration. The leaves and branches of the tree reduce the amount of solar radiation that reaches the area below of the canopy under a tree or plant. Thus, the amount of sunlight transmitted through the canopy varies based on plant species. In hot climate day, generally 10 to 30 percent of the sun's energy reaches the area below the tree, with the remainder of the sun's energy is being absorbed by leaves and used for photosynthesis and some of the sunlight reflected back into the atmosphere [16].

With the rise of current issues relating to poor planning of urban development in many cities, prediction models came to be an important tool of UHI mitigation strategies, especially by using various configurations of urban morphology. Hence, this research focus to study on how various urban morphology parameters contribute to the increasing of air temperature, and how prediction model can help non-science designer and planner to mitigate urban heat island impact for future sustainable development planning.

## 3. METHODOLOGY

### 3.1. Identification Of Landscape And Building In Case Study (Universiti Tun Husseion Onn Malaysia)

In order to determine the characteristic landscape and building in UTHM, site survey is done by observation and monitoring the background of the influence area of this research. The background data survey includes landscape, greenery, building and pavement arrangement. This data will be applied in 3D models of Sketch Up design as shown in figure 3.Universiti Tun Hussein Onn Malaysia (UTHM) main campus that located at Parit Raja, Batu Pahat is selected as the case study. UTHM main campus is still under process of development due the increasing number of its students.

This university is about 12 km from Parit Raja town and it is approximately about 199 hectares in size, which can be considered as a small-scale city. UTHM consists of educational buildings as well as high-rise and low-rise residential buildings in an urban city that includes sport facilities, transportation and administration offices. Most of the greenery in UTHM can be categorized as less dense. There are roadside trees and tree plantings between buildings with a certain distance about 3-10 meters and open grassland areas. A few places in UTHM can be categorized as having a sparse greenery condition, where only several trees are planted, surrounded by large pavement/concrete surface. The trees provide less thermal benefit which is mainly for aesthetical purpose.

Figure 2 shows the aerial view of the study area. The study area is focused on building in Universiti Tun Hussein Onn Malaysia (UTHM) on building of Faculty Technology and Business Management (FPTP), Faculty of Technical Education and Vocational (FPTV), Faculty of Civil and Environmental Engineering (FKAAS), Faculty Electrical and Electronic Engineering (FKEE) and Faculty of Computer Science and Information Technology (FSKTM) and also the Perpustakaan Tunku Tun Aminah (library) area.


**Figure 2:** Study area of this research

After determining the study area of this research, their three dimensional (3D) models will be formed for simulations. These 3D models were drawn using Google Sketchup program and STEVE plugin.

### 3.2. Input Weather Conditions Used for Simulations

The weather data that is used for the following building simulations were obtained from meteorological station in UTHM [18]. For the Climate Predictors in the model, this study is using the weather data on 2$^{nd}$ August 2018 from the meteorological station data obtained at Faculty of Engineering Electrical and Electronic (FKEE). This data is used as the background climate data of the influence area and used to set in STEVE (Table 2).

**Table 1:** Reference of climate background temperature of influence area

| Terms | Day ($^0$C) | Night ($^0$C) |
|---|---|---|
| $T_{min}$ | 23.80 | 24.40 |
| $T_{max}$ | 32.30 | 25.45 |
| $T_{avg}$ | 28.05 | 24.92 |

a. $T_{avg}$ = 26.49 $^0$C

b. $SOLAR_{total}$ = 6832 W/m$^2$

c. $SOLAR_{max}$ = 976 W/m$^2$

Figure 3 shows the workflow that is used to integrate between micro-climate and built environment in an urban area. This is used to simulate the prediction models focused on predicting outdoor conditions impacting the surrounding conditions. This tool is deemed to be more presentable and informative for non-scientist users such as urban planners and architects. At this stage, STEVE prediction models will be embedded as a plug in for Sketch Up, which further improved the inter-operability experience for planners, since the software been well acknowledged as common 3D model software in the industry. Hence, the required urban area model can be easily obtained as data input for models calculation.

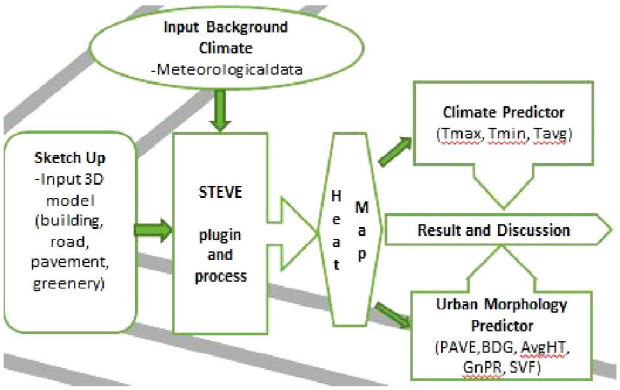


**Figure 3**:Workflow of STEVE tool process

Figure 4 shows the 3D models from Sketch Up that requires input on building shape with enclosed top and bottom building envelope, roads and pavement, and the greenery (trees, shrub and turf). About six stations of the reference areas are selected for the plugin to run the analysis. These background climate parameters are obtained from the weather station, which characterizes the microclimate condition in the study area.

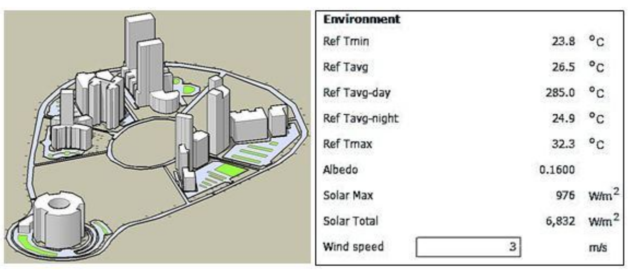


**Figure 4:** (Left) the 3D model within Sketch Up comprises of buildings, roads, and turf (Right) Input dialog box for background climate

## 4. RESULT & DISCUSSION

### 4.1 Varying The Building Density (BDG %) And Pavement Area (PAVE%)

The results from STEVE are used to assess the ambient air temperature of all stations which affected by the different urban morphology. Table 2 and figure 5 show the results of varying BDG% and PAVE% parameter impacting the ambient air temperature of $T_{min}$, $T_{max}$ and $T_{avg}$ for the study area.

**Table 2:** Result of the UHI parameter (BDG%, PAVE%) and the ambient air temperature ($T_{min}$, $T_{max}$, $T_{avg}$)

| UHI Para-meter | Group A | | Group B | | Group C | |
|---|---|---|---|---|---|---|
| | Lib. | FKEE | FPTV | FKAAS | FPTP | FSKTM |
| BDG % | 64.40 | 44.00 | 35.53 | 31.98 | 16.47 | 15.68 |
| PAVE % | 21.91 | 26.57 | 4.20 | 7.56 | 8.45 | 9.80 |
| $T_{max}$ (˚C) | 32.60 | 32.70 | 32.10 | 32.70 | 32.10 | 32.70 |
| $T_{min}$ (˚C) | 24.10 | 24.20 | 23.90 | 23.90 | 23.40 | 23.80 |
| $T_{avg}$ (˚C) | 27.20 | 27.10 | 26.90 | 27.00 | 26.80 | 25.70 |

The higher PAVE% means they have more pavement areas such as road around the vicinity. Figure 6 shows the comparison result of the station due to the different percentage of the BDG% and PAVE% of the study area. The couple comparison station is set as Group A (library and FKEE), Group B (FPTP and FSKTM) and Group C (FPTV and FKAAS) which is their calculation STEVE results are having a close rate.

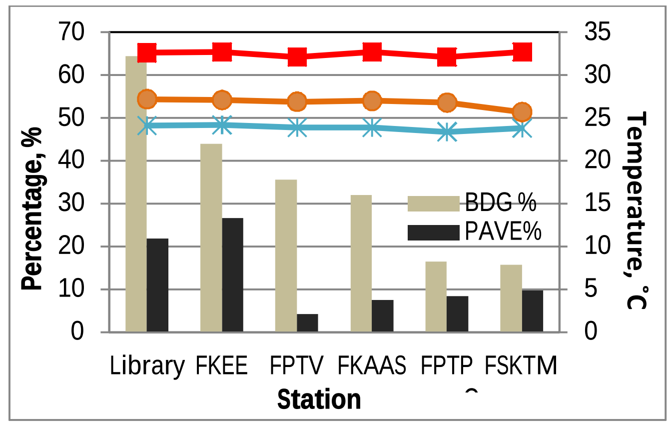


**Figure 5:** BDG% and PAVE% versus the ambient air temperature ($T_{min}$, $T_{max}$ and $T_{avg}$)

Based on figure 5, for the couple comparison of Group A which is between library station and FKEE's station, the library station has the higher value of the BDG% at 64.40% than FKEE's station at 44.00%. However, the FKEE's station has a higher value of the PAVE% at 26.57% than library station at 21.91%. Followed on this result, the temperature data of the library station for $T_{max}$ and $T_{min}$ is lower than FKEE's station. The $T_{max}$; $T_{min}$ for library station is 32.60 $^0$C; 24.10 $^0$C and for FKEE's station is 32.70 $^0$C; 24.20 $^0$C.

For the Group B, the comparison station is between FPTV's station and FKAAS's station. On this group, the FPTV's station has higher value of BDG% at 37.53% than FKAAS's station at 31.98%, but then for the PAVE%, FPTV's station has lower value at 4.20% and 7.56% for FKAAS's station. Referred on that result, the $T_{max}$; $T_{min}$ value for FKAAS's station is at 32.70 $^0$C; 24.20 $^0$C and for the FPTV's station is at 32.10 $^0$C; 23.40 $^0$C. This shows that FPTV's station has lower temperature than the FKAAS's station

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Group C discusses the FPTP's station and FSKTM's station which is the BDG%; PAVE% for the FPTP's station is at 16.47%; 8.45% and 15.68%; 9.80% for the FSKTM's station. From the result of the BDG% and PAVE% of both of these stations, the $T_{max}$;$T_{min}$ for the FPTP's station is 32.10 $^0$C; 23.40 $^0$C and for the FSKTM's station is at 32.70 $^0$C; 23.80 $^0$C. The calculation result show there is likely a reduction of 0.10 $^0$C to 0.6 $^0$C on the $T_{min}$ and $T_{max}$ due to the lower of the PAVE%.

### 4.2 Varying The Average Height (Avght)

Table 3 and figure 6 show the analysis results of UHI varying parameter of the AvgHT and SVF due to the ambient air temperature of $T_{min}$, $T_{max}$ and $T_{avg}$. The result of the sky view factor (SVF) is influenced by the different surrounding building height. The higher of the building height, the lower the sky view factor result.

**Table 3:** Result of the UHI parameter (AvgHT; SVF) and the ambient air temperature ($T_{min}$; $T_{max}$; $T_{avg}$)

| Para-meter | Lib. | FPTP | FPTV | FKAAS | FKEE | FSKTM |
|---|---|---|---|---|---|---|
| AvgHT (m) | 18.00 | 23.00 | 24.00 | 15.00 | 19.00 | 17.00 |
| SVF | 0.50 | 0.21 | 0.16 | 0.73 | 0.45 | 0.69 |
| $T_{max}$ (˚C) | 32.60 | 32.10 | 32.10 | 32.70 | 32.70 | 32.70 |
| $T_{min}$ (˚C) | 24.10 | 23.40 | 23.90 | 23.90 | 24.20 | 23.80 |
| $T_{avg}$ (˚C) | 27.20 | 26.80 | 26.90 | 27.00 | 27.10 | 25.70 |

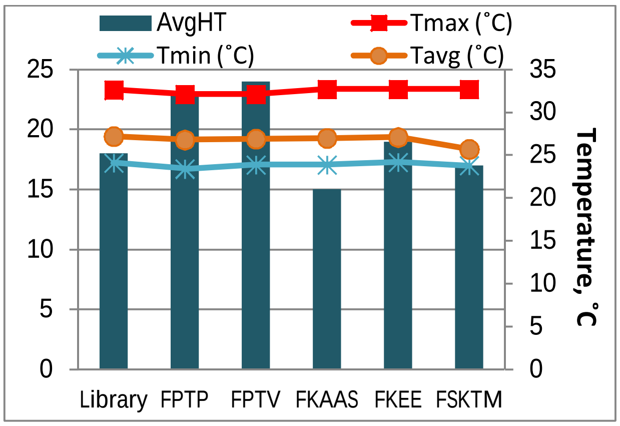


**Figure 6:** AvgHT (m) versus the ambient air temperature ($T_{min}$, $T_{max}$ and $T_{avg}$)

Figure 6 shows the highest surrounding building (AvgHT) on the station of FPTP and FPTV is having the lowest temperature at 32.10 $^0$C for $T_{max}$ as compared to other station which for the library at 32.60 $^0$C and FKAAS, FKEE and FSKTM at 32.70 $^0$C. The one possible reason studied based on the result on table 5 and figure 6 is the increase of the surrounding building height reduces the sky value factor (SVF), which provides more shading to its surrounding environment. If only the building height is being considered, a taller building seems to give more benefits to its surrounding environment.

### 4.3 Varying The Green Plot Ratio (Gnpr)

Table 4 and figure 7 show the analysis UHI parameter to the ambient air temperature of $T_{min}$, $T_{max}$ and $T_{avg}$. The GnPR value is referred as the greenery condition on the surrounding area.

**Table 4**: Result of the UHI parameter (GnPR) and the ambient air temperature ($T_{min}$; $T_{max}$; $T_{avg}$)

| Para-meter | Lib. | FPTP | FPTV | FKAAS | FKEE | FSKTM |
|---|---|---|---|---|---|---|
| GnPR | 0.449 | 1.700 | 1.357 | 1.397 | 0.577 | 1.643 |
| $T_{max}$ (˚C) | 32.60 | 32.10 | 32.10 | 32.70 | 32.70 | 32.70 |
| $T_{min}$ (˚C) | 24.10 | 23.40 | 23.90 | 23.90 | 24.20 | 23.80 |
| $T_{avg}$ (˚C) | 27.20 | 26.80 | 26.90 | 27.00 | 27.10 | 25.70 |

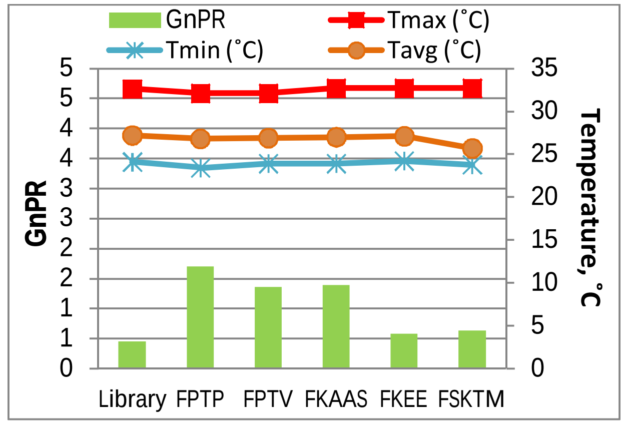


**Figure 7:** GnPR versus the ambient air temperature ($T_{min}$, $T_{max}$ and $T_{avg}$)

Result shows that the FPTP station has the lowest $T_{min}$ at 23.80 $^0$C, the $T_{avg}$ at 26.91 $^0$C and the $T_{max}$ at 32.40 $^0$C. The highest result of $T_{min}$ is at the library station at 24.70 $^0$C and $T_{avg}$ at 27.05 $^0$C. However, a higher result of $T_{max}$ is at FKEE station at 32.60 $^0$C that it might happened because of the FKEE station area is a new development area and the vegetation and greenery area are less than other stations. By referring to the result at figure 7 it shows that there is a likely reduction of 0.20 $^0$C on the $T_{min}$ with increase about 0.50 of GnPR value. A higher value of GnPR means there is more greenery at around the vicinity. The greenery provides cooling effect not only from its evapotranspiration process but also from its shading effect at the surrounding environment.

### 4.4 Varying All Four Variables Simultaneously (BDG%, PAVE%, Avght And Gnpr)

The result data from STEVE have been examined in order to assess the ambient air temperature around all the six station of the study area due to their difference of urban morphologies in each station. Table 5 shows the all variables parameter combined that could bring an effect to the result of $T_{max}$, $T_{min}$ and $T_{avg}$ of the base case model which are deviated from the background air temperature measured at FKEE meteorological station.

**Table 5:** Result of the UHI parameter and the ambient air temperature ($T_{min}$; $T_{max}$; $T_{avg}$)

| Para-meter | Lib. | FPTP | FPTV | FKAAS | FKEE | FSKTM |
|---|---|---|---|---|---|---|
| BDG% | 64.40 | 16.47 | 37.53 | 31.98 | 44.00 | 15.68 |
| PAVE% | 21.91 | 8.45 | 4.20 | 7.56 | 26.57 | 9.80 |
| AvhHT (m) | 18 | 23 | 24 | 15 | 19 | 17 |
| GnPR | 0.449 | 1.700 | 1.359 | 1.397 | 0.577 | 1.643 |
| SVF | 0.50 | 0.21 | 0.16 | 0.73 | 0.45 | 0.69 |
| $T_{max}$ (˚C) | 32.60 | 32.10 | 32.10 | 32.70 | 32.70 | 32.70 |
| $T_{min}$ (˚C) | 24.10 | 23.40 | 23.90 | 23.90 | 24.20 | 23.80 |
| $T_{avg}$ (˚C) | 27.20 | 26.80 | 26.90 | 27.00 | 27.10 | 25.70 |

Table 5 and figure 8 shows the comparison result of the station due to different values of the all variables of the UHI parameter (BDG%, PAVE%, AvgHT, GnPR and SVF) to the air temperature of all the six stations (library, FPTP, FPTV, FKAAS, FKEE and FSKTM).

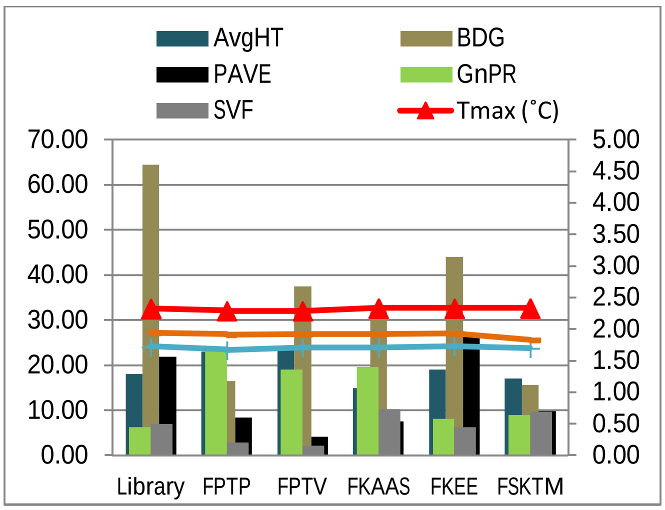


**Figure 8**: UHI parameter (BDG%, PAVE%, AvgHT, GnPR and SVF) versus the ambient air temperature ($T_{min}$; $T_{max}$; $T_{avg}$)

Figure 8 show that the combination of maximum AvgHT and maximum GnPR has the lower $T_{max}$, $T_{avg}$ and $T_{min}$ (FPTP's station). This is might due to the reason of the increase of building height reducing the SVF because of the the shading effect. On the result at FSKTM's station, they have a high GnPR but low BDG%, AvgHT and PAVE% than FKEE station. However, their $T_{max}$ result remains same which happened when FKEE has low SVF comes from the effect of height of the surrounding building. The high greenery and the lower sky view factor give positive impact to the environment by their shading effect. Referring to the library station, it has high density which is related to the value of BDG% and PAVE% that gives a negative impact due to increase of wall surface area and pavement since they have high result of $T_{max}$, $T_{min}$ and $T_{avg}$. For the station at FKAAS and FPTV, FPTV station has high of the BDG%, AvgHT but low PAVE% value than the FKAAS's station. The result shows that the FPTV's station has a low of $T_{max}$ and $T_{avg}$ than FKAAS's station. This might be because of one possible reason that a high PAVE% would increase the surrounding temperature.

## 5. CONCLUSION

In conclusion, by referring to the analysis results, the effect of surrounding density (BDG% and PAVE%) and building height (AvgHT) might have a positive impact to reduce the ambient temperature due its shading effect. When dense greenery is applied, the ambient temperature was found to be lower and this means that greenery could help to mitigate the UHI effect. It can be concluded that when the surrounding areas have maximum density, maximum height and maximum greenery, the ambient temperature could be lower due to shading effect and lower sky value factor. With previously mentioned features, STEVE is able to produce temperature and heat maps of urban areas by using UTHM as the main typology and climate reference. Planners can be well informed during the design process regarding the design impact on the microclimatic condition at the studied site. Such information is deemed necessary to ensure that the master plan and its surroundings do not suffer from unnecessary temperature increase which can worsen the urban heat island phenomena and the thermal comfortability. This mitigation approach at the early stage of design process can be proven beneficial especially to tackle the environmental issues earlier rather than at the latter stage. Furthermore, users are able to conduct benchmarking between various designs scenarios simultaneously and with the minimal time required to produce the heat maps, different stakeholders can further discuss the problems and analyse multiple master plan options, simultaneously.

## ACKNOWLEDGEMENT

Acknowledgments are given to Professor Wong Nyuk Hien from the National University of Singapore and the Center of Development and Maintenance (P3P) UTHM for all their support during the publication of this paper

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