Study on Effect of Greenery in Campus Area

Steve Kardinal Jusuf, Wong Nyuk Hien, Aung Aung La Win, Htun Kyaw Thu, To Syatia Negara, Wu Xuchao

Department of Building, National University of Singapore, Singapore

ABSTRACT: Urban environment quality becomes worsen in every year. There is a fact that the urban air temperature is gradually raising in all cities and some effective measures are needed to mitigate it. Planting of vegetation is one of the main strategies to mitigate the Urban Heat Island (UHI) effect. Large urban parks can extend the positive effects to the surrounding built environment. National University of Singapore (NUS) complex can be considered as a "city" in a smaller scale. The greenery area along Kent Ridge Road seems like the "rural" area, with a cooler ambient temperature. Some methodologies were employed in this study, such as field measurement and computer simulations. Field measurement was used to get the real temperature distribution across the campus and finally, computer simulation was used to predict some scenarios of different conditions.

Keywords: Effect of greenery, campus area, field measurement, computer simulation.

1. INTRODUCTION

1.1. Background

Planting of vegetation is one of the main strategies to mitigate the Urban Heat Island (UHI) effect. A single tree can already moderate the climate well. But its impacts are limited only to the microclimate [1]. Large urban parks can extend the positive effects to the surrounding built environment. The built environment, which is close to the park, has a lower temperature of average 1.3°C [2]. Thus, the more parks are built in an urban area, the lower the urban temperature will be. However, a country like Singapore, which has limited land area, especially in downtown area, that strategy may not be suitable. Another strategy that may be used is using rooftop greenery. The green plants could protect the hard roof surface from solar radiation, thus it would not emit long wave radiation to the surrounding environment at night and reduce the effect of UHI.

1.2. Object of Study

National University of Singapore (NUS) complex can be considered as a "city" in a smaller scale. The greenery area along Kent Ridge Road seems like the "rural" area, with a cooler ambient temperature. It is believed that the dense greenery area makes the ambient temperature in NUS cooler. It is observed that some open spaces are left with only grass cover the soil. There is an idea to grow trees in these areas, which logically will give a lower ambient temperature. It is also observed that many buildings in NUS are constructed with flat roof. There is a great potential to apply the rooftop greenery in these areas. The advantages, firstly, it will give a lower heat gain to the building, which leads to a lower cooling load. Secondly, if it is combined with the improvement on the open spaces, it will give a lower ambient temperature which indirectly leads also to a lower cooling load of buildings and psychologically, provides outdoor thermal comfort for the people.

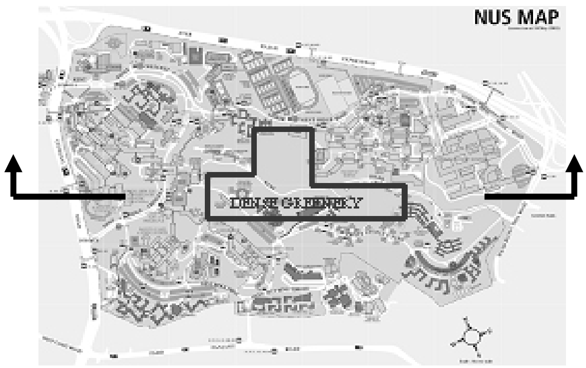


Figure 1: NUS Map

1.3. Objectives

This research has the following objectives:

a. To identify the hotspot area in NUS environment
b. To study the importance of dense greenery area for the microclimate of NUS environment.
c. To study the energy saving of a building as the result of lowering ambient temperature due to improvement of the greenery area.

2. METHODOLOGY

2.1 Field Measurement

The major instrument in this study is HOBO RH & Temperature sensors (operating range -20°C to +70°C, RH accuracy ±5%), which is used together with solar cover. The HOBO sensors were configured at an interval of every 10 minutes and installed on light posts at about 3m above the ground. The field measurements were conducted on 10th – 24th September 2005.

The whole campus was divided into 3 groups of areas with respect to their different greenery and building distribution conditions. First group is the dense greenery along the Kent Ridge Road. Second is less dense greenery and third, sparse dense greenery. These HOBO meters were deployed in locations as shown in figure 2 and Table 1.

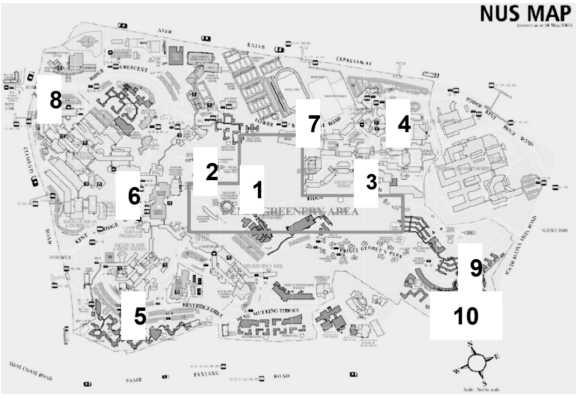


Figure 2: Points of measurement

Table 1: Measurement location grouping and numbering

Group	Location Number*	Landmark Nearby
Dense Greenery (Kent Ridge Road)	1	Water Tank
	2	Acoustical Lab
	3	Bioinformatics Center
Less Dense Greenery	4	Faculty of Medicine Carpark
	5	Temasek Hall
	6	Computer Center
	7	Sports Field
Sparse Greenery	8	PGP Road
	9	Engineering Auditorium
	10	PGP Canteen

*The initial numbering was rearranged to facilitate better presentation.

2.2 ENVI-MET Simulation

ENVI-MET was used to simulate the interaction of surface-air-plants in a three dimensional model [3, 4, 5]. A base model was constructed based on the map and building information provided by Office of Estate and Development. Parametric variations were also made to get predictions in different conditions. Three scenarios were designed, besides the current condition: replacing the dense greenery along Kent Ridge Road with buildings, removing all the greenery in NUS environment and converting the grasslands into vertically denser plantation. Then, the variations of ambient temperature in these scenarios from the base case are recorded and analyzed.

Basic settings were employed in this simulation, as follows:

1. Temperature: 303 K.
2. Wind speed (at 10 m above ground): 1.6 m/s
3. Wind direction: South to North
4. RH: 84%
5. Roughness length in 10m: 0.1
6. Total simulation: 24 hours

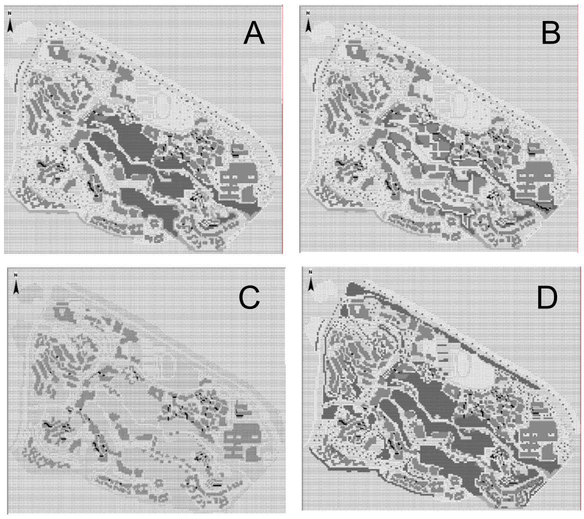


Figure 3: Four scenarios in ENVI-met simulation:
A. Current condition, B. Replacing dense trees with buildings, C. Removing all greenery, D. Adding more trees

2.3 TAS Simulation

To explore the energy consumption of NUS building, TAS, was employed. TAS is software, which simulate the dynamic thermal performance of buildings and their systems [6, 7]

Engineering building (EA), 7 storey high and 2000 m^2 footprint areas was chosen as the building model. This simulation was run to see and compare the energy consumption for cooling load of two models.

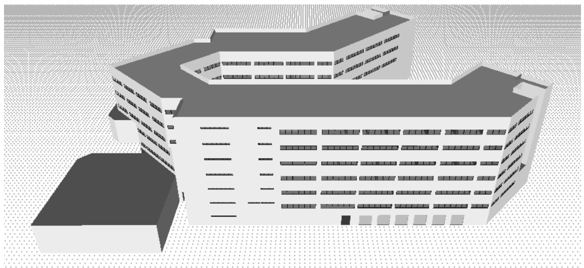


Figure 4: Engineering building model

First model is the EA building's cooling load simulation due to the difference of ambient temperature condition in the different locations. In this model, there are two scenarios, without internal load and with internal load.

Basic setting for both scenarios:

1. Air conditioning was on 08.00 AM – 22.00 PM (extended office hour)
2. Temperature and RH were input using the field measurement result on 15th September 2005
3. Thermostat setting:
   a. Temperature upper limit: 24 deg C and lower limit: 21 deg C
   b. Humidity upper limit: 70% and lower limit: 60%

In the first scenario, the internal heat load was omitted to get the energy saving with only considering the ambient temperature heat load. In the second scenario, some general assumptions were made in terms of internal load of the building, as follows:

1. Lighting gain 15 W/m^2
2. Occupant's sensible heat and latent heat 15 W/m^2
3. Equipment sensible gain 20 W/m^2

The ***second model*** is the EA building's cooling load simulation due to application of different types of rooftop greenery. Three different types of rooftop garden were simulated, 100% turfing, 100% shrubs and 100% trees. The R-values are 0.84 m^{2}K/W, 2.216 m^{2}K/W and 1.429 m^{2}K/W, respectively [8]. In this model, the basic setting is the same as first model. And there is only one scenario, the internal heat load was omitted to get the energy saving from different rooftop application.

3. FINDINGS AND DISCUSSIONS

3.1 Field measurement

A typical day on 15th September was chosen as a representation of typical day in Singapore. Figure 5 shows the temperature difference among different locations. The lines representing sparse greenery areas are clustered on the top, with maximum temperatures reaching 33°C or even higher. On the contrary, the "cool spots" lines are mostly at the bottom. As can be seen in the graph, the peak temperature difference between location 1 (Kent Ridge Road-Water Tank) and location 10 (inside PGP Residence) can be as high as 4°C at around 13:00. When the time approaches midnight, the temperature difference between these two locations is about 3°C. This is almost the same time condition when temperature difference induced by UHI effect can be quantified. The difference of 3°C within a community-scale environment is believed to be large.

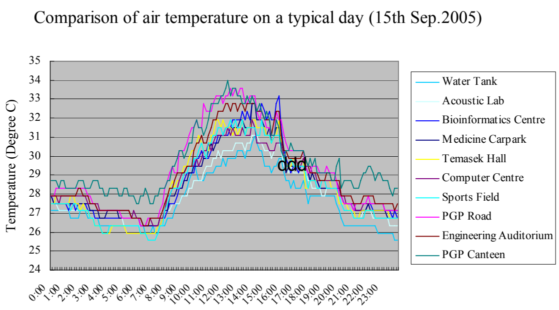


Figure 5: Comparison of air temperature on a typical day (15th Sep.2005)

Considering the dominant role solar radiation plays in air temperature and the possible UHI effect, daytime and night-time data were analyzed separately. In this study, daytime is defined as from 7am to 7pm, and the balance is night-time. In Singapore, the daytime defined here is approximately coincident with the solar radiation availability on sunny days. The averages, minimums, and maximums of air temperature during the whole measurement period are plotted on figure 6 and 7.

As the average temperature is concerned, the pattern is very obvious. There are fluctuations within some groups, especially in figure 7, but the dominant trend, from low to high temperature is unchanged. The daytime average temperature ranges from 27.4°C to 29.6°C, and it ranges from 25.6°C to 27.4°C during night-time. It is about 2°C difference.

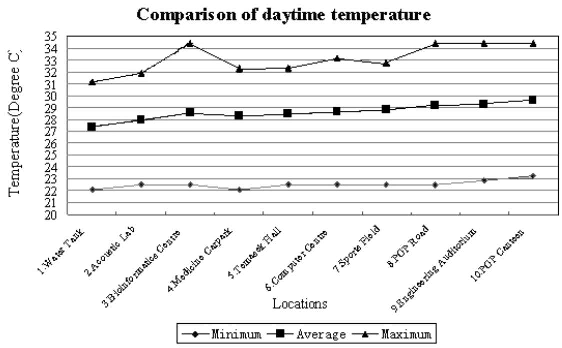


Figure 6: Comparison of daytime temperature

In figure 6, it can be perceived that temperature difference of daytime maximum among different locations is very significant. It has a peak of 3.3°C, which is the difference between location 1 (Kent Ridge Road-Water Tank) and location 10 (inside PGP Residence). In the tropics like Singapore, the maximum temperature is of special importance, since it determines the sizing of air-conditioning systems. It is also worth taking notice of the night-time minimum temperature on figure 7. The line is generally very even, but goes up to nearly 23°C at location 10(inside PGP Residence). This verifies the hypothesis that the heat accumulated in the day is hard to dissipate during night-time due to large concentration of buildings and sparse plantation in PGP.

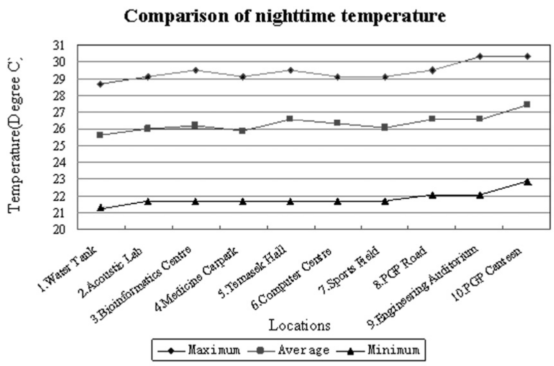


Figure 7: Comparison of night time temperature

Location 3 (Kent Ridge Road-Bioinformatics) is an eye-catching lump on the line for maximum daytime temperature, see figure 6. It also deviates a bit from the normal trend on other lines, but not so evident. Further investigation was done after preliminary data analysis in an effort to find out whether it's an outlier. It was initially chosen to represent dense greenery areas due to its location at the east end of Kent Ridge Road. There is a large construction site in close vicinity. The anthropogenic heat from the workers, trucks, and construction machinery is likely to have substantial influence on its vicinity. Moreover, the whole construction site is bare soil without any green coverage. These two factors may well account for the abnormal temperature of location 3 (Kent Ridge Road-Bioinformatics).

On a whole, the field data measurement has achieved the targeted objectives. The presumed temperature difference throughout the NUS campus was quantified. Through elaborate selection of locations according to their green conditions, the relationship between air temperature and greenery was verified.

3.2 ENVI-MET Simulation

Day time

Figure 8 shows temperature profiles throughout NUS environment for 4 different conditions at 13.00 hours. In condition (A), it can be observed that the presence of dense greenery area in centre region and moderate greenery area around the campus clearly contribute to NUS low ambient temperature. This can be illustrated by “cool areas” indicated by blue and green colour in the centre region. However, areas near faculty of engineering, University Cultural Centre and University Sport Centre have been generally high in temperature. This is due to lack of greenery, higher building density and particularly presence of pavement at sport field. In contrast, it is clearly observed that the presence of “cooler areas” has disappeared due to removal of all greenery areas in NUS as shown in condition (B). The areas have become much hotter in general as indicated by yellow and red colour representation. It is noted that ENVI-Met simulation model assumes that the source of water in the soil is non-depleting. In reality, this is not the case, the water will become dry at some time and hence the temperature in condition (B) would be even higher. From Figure 9 (B) it can be seen that there is no cooling effect to NUS environment after removal of greenery.

In condition (C) most of the dense greenery areas in the centre region have been replaced with buildings where the rest of greenery in NUS was kept unaltered. It is observed that the centre region of NUS has experienced increase in temperature and cooling effect of central greenery areas to NUS environment has considerably decreased. Generally, in comparison with current condition, the areas have now become hotter as indicated by more yellow, orange and red colour. Figure 9 (C) also shows that the cooling effect generated by dense greenery in central region has been reduced. The increase of temperature especially in the central region is due to high building density and reduction of plants which eventually contribute to the reduction of cooling effects of the greenery to the surrounding areas.

In contrast, by adding denser greenery to NUS environment, it is clearly observed that NUS environment has now become much cooler than current condition as represented Figure 8 (D) and (A). The “hot spots” which initially occur near Faculty of Engineering, University Cultural Centre and sport centre have now become much cooler as a result of cooling effects of much denser greenery in centre region of NUS and other areas.

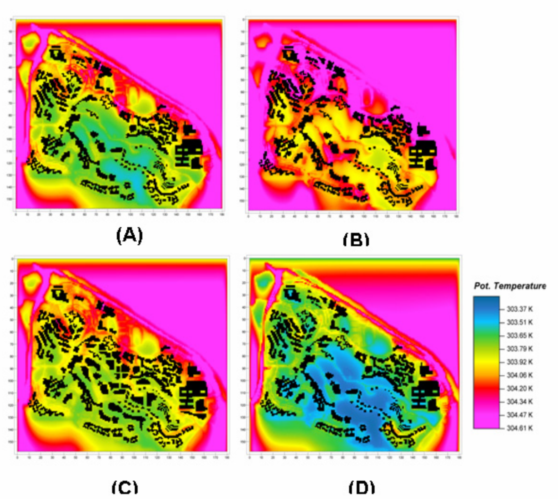


Figure 8: Day time result – Site Plan:
A. Current condition, B. Replacing dense trees with buildings, C. Removing all greenery, D. Adding more trees

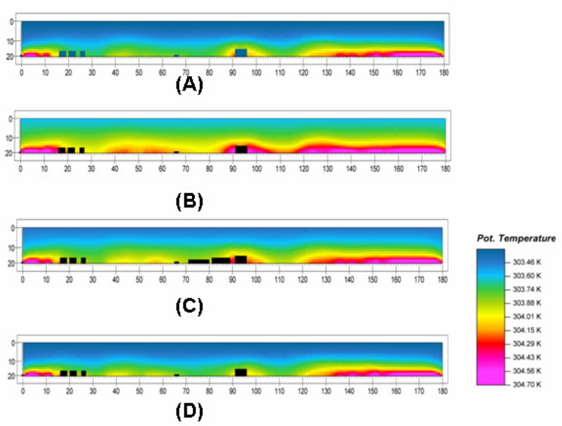


Figure 9: Day time result – Section (refer to arrow in figure 1):
A. Current condition, B. Replacing dense trees with buildings, C. Removing all greenery, D. Adding more trees

Night Time

Temperature profiles and vertical temperature distributions at 00.00 hours for 4 different conditions in NUS environment are shown in Figure 10 and 11 respectively. By comparing all 4 conditions, it can be observed that the presence of greenery is very important in keeping low ambient temperature in NUS environment. Without greenery, it is clearly seen in condition (B) that during night time areas with high building density, such as: Faculty of Art and Social Sciences, Faculty of Engineering, Faculty of Science and Prince George’s Park residence are much hotter than the surrounding areas. This is due to the fact that the heat stored in the buildings during daytime start to radiate back to the environment and thus making the surrounding areas much hotter at night time. However, with the presence of greenery, the cooling effects produced by plants are able to neutralize this heat and even keep the areas cooler as shown in condition (A).

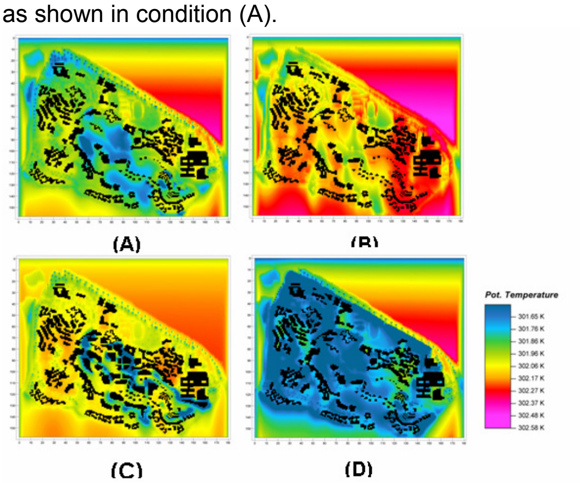


Figure 10: Night time result – Site Plan: A. Current condition, B. Replacing dense trees with buildings, C. Removing all greenery, D. Adding more trees

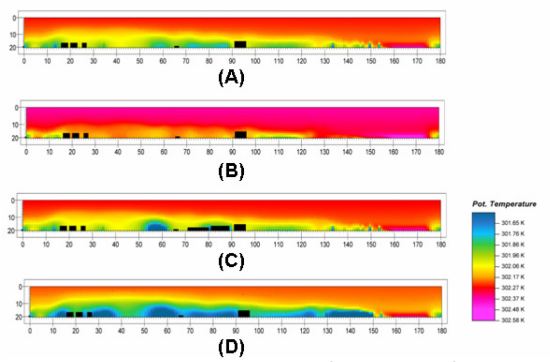


Figure 11: Night time result – Section (Refer to arrow in figure 1): A. Current condition, B. Replacing dense trees with buildings, C. Removing all greenery, D. Adding more trees

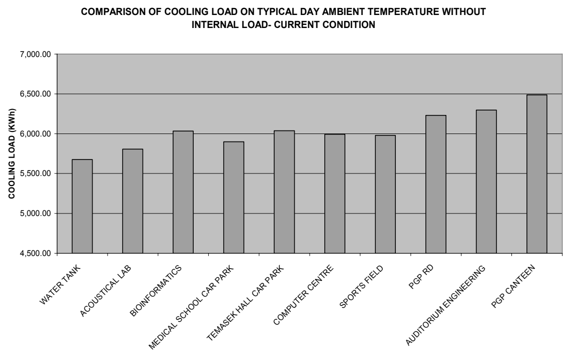
Furthermore, the comparison also shows that the cooling effects of the greenery areas on NUS environment are affected by building density as indicated by condition (C). The higher the building plot ratio the less pronounced the cooling effects will be. This observation is clearly seen during night time, where the heat stored in the concrete mass in buildings start to be released to the environment. It is noticed that cooling effects still exist in the centre region of NUS due to dense greenery; however, the effect is not so prevailing to NUS environment as compared to the heat radiated by buildings.

In contrast with condition (C), it is observed in condition (D) that by adding much denser plants to NUS environment, the cooling effects generated are much more prevail than the heat by buildings. Whole NUS environment has substantially become much cooler as indicated by blue colour representation. Cooling height to NUS environment can be seen in vertical temperature distribution as shown in Figure 11 (D).

3.3 TAS Simulation

The calculated result of energy consumption for current condition is presented in the below. The average ambient temperature on 15th September 2005 was input to the weather data. In the Kent Ridge Road –Water Tank is 27.65 deg C and in the PGP complex is 29.76°C. Thus, the difference is 2.11°C.

In the first model – first scenario, the internal heat load was omitted to see the impact of ambient temperature condition to the cooling load. The simulated result is presented below.

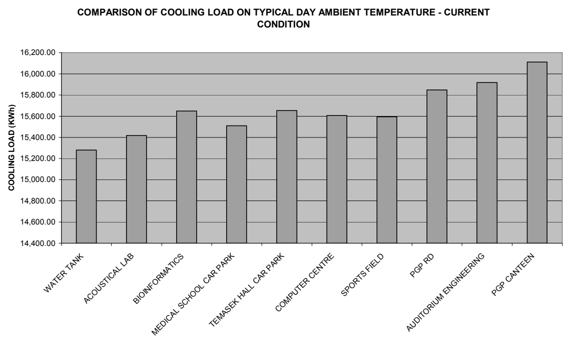


Greenery Condition	Places	Cooling Load (KWh)	Increase of Energy Usage (Compared with Kent Ridge Road-Water Tank)
SPARSE GREENERY	PGP Inside	6,486.62	14.30%
	Auditorium Engineeering	6,298.47	10.98%
	PGP Road	6,229.32	9.76%
LESS DENSE GREENERY	SPORTS FIELD	5,981.50	5.40%
	COMPUTER CENTRE	5,993.55	5.61%
	TEMASEK HALL CAR PARK	6,038.81	6.41%
	MEDICAL SCHOOL CAR PARK	5,899.49	3.95%
DENSE GREENERY	BIOINFORMATICS	6,034.02	6.32%
	ACOUSTICAL LAB	5,808.25	2.34%
	WATER TANK	5,675.24	0%

Figure 12: Cooling load in 10 points of different location with current condition

It is clearly seen that the ambient temperature has a significant effect to cooling load of the building. Building with the PGP ambient temperature has 14.30% higher cooling load than the building in Kent Ridge Rd – Water Tank area.

In the first model – second scenario, the internal heat load was included.

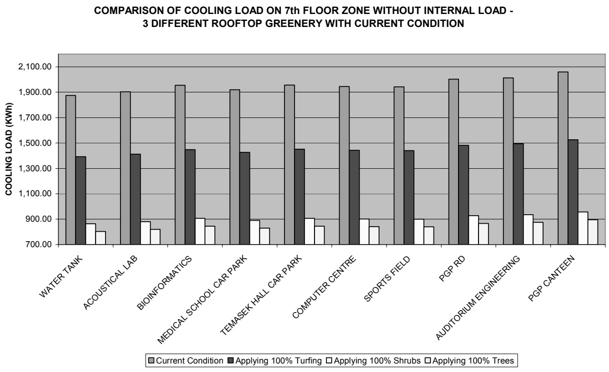


Greenery Condition	Places	Cooling Load (KWh)	Increase of Energy Usage (Compared with Kent Ridge Road-Water Tank)
SPARSE GREENERY	PGP Inside	16,110.88	5.43%
	Auditorium Engineeering	15,918.85	4.17%
	PGP Road	15,848.51	3.71%
LESS DENSE GREENERY	SPORTS FIELD	15,594.81	2.05%
	COMPUTER CENTRE	15,606.87	2.13%
	TEMASEK HALL CAR PARK	15,652.94	2.43%
	MEDICAL SCHOOL CAR PARK	15,510.44	1.50%
DENSE GREENERY	BIOINFORMATICS	15,648.66	2.41%
	ACOUSTICAL LAB	15,417.03	0.89%
	WATER TANK	15,280.88	0%

Figure 13: Cooling load in 10 points of different location with current condition

The lowest cooling load, 15,280.88 KWh was the building along the Kent Ridge Road - Water Tank area and the highest, 16,110.88 KWh is the building in PGP area. The difference of cooling load is about 5.4%. The cooling loads of the other locations are within the range, follows the ambient temperature condition of each location. Transforming the PGP condition become similar as the Kent Ridge Road condition may be difficult to achieve. However, by adding more trees to be similar as in the less dense greenery area may cut the cooling load difference of 50%, become only about 2.5%.

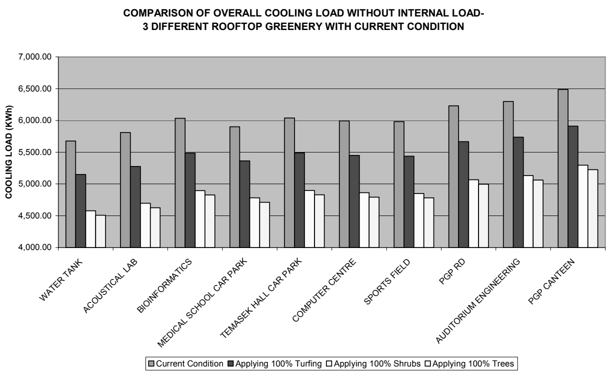
In the second model, the potential of rooftop garden application in NUS building was also simulated. The simulated result is shown in the figure below. The internal heat load was omitted to see the performance of different rooftop greenery. In this first simulation, there are two simulated cooling load values, the cooling load for the rooms below the roof (7th floor) and the overall value.



	Applying 100% Turfing	Applying 100% Shrubs	Applying 100% Trees
Energy Savings of Cooling Load Compared with Current Condition	25.82%	53.67%	56.78%

Figure 14: Comparison of 7th floor zone cooling load in 10 points of different location with different rooftop application – without internal heat load

By applying rooftop garden, it shows the potential of energy saving. The rooftop garden has the performance of energy savings 25.82%, 53.67% and 56.78%, for applying turfing, shrubs and trees respectively.



	Applying 100% Turfing	Applying 100% Shrubs	Applying 100% Trees
Energy Savings of Cooling Load Compared with Current Condition	9.05%	18.85%	20.01%

Figure 15: Comparison of overall cooling load in 10 points of different location with different rooftop application – without internal heat load

For the overall cooling load, energy savings may get 9.08%, 18.85% and 20.01%, for applying turfing, shrubs and trees respectively. These result shows that rooftop greenery has a performance to reduce the cooling load.

From these simulations, between applying shrubs and trees, the energy savings seems not too much different. Thus, the application of shrubs on the rooftop is more reasonable to be applied, because application of trees may have problem with the building structure in carrying the additional load.

5. CONCLUSION

This study has shown the importance of greenery area in keeping the NUS microclimate comfortable. Some improvements may be considered to put more trees in the less dense greenery and especially in the sparse green area. In the further research, a more comprehensive study can be done by looking into how far the cooling effect of the dense greenery area along Kent Ridge Road to the surrounding area.

ACKNOWLEDGEMENT

This project was supported by Department Building and Office of Estate and Development, National University of Singapore.

REFERENCES

[1] Jauregui, E. (1990/91). Influence of a large urban park on temperature and convective precipitation in tropical city. *Energy and Buildings*, 15-16, 457-463.

[2] Wong Nyuk Hien. (2002). *Study of Rooftop Gardens in Singapore.* Singapore: National University of Singapore.

[3] Bruse, M. (1999). The influences of local environmental design on microclimate (...), Ph.D Thesis University of Bochum, Bochum (in German)

[4] Bruse, M. (2004). ENVI-met 3.0: Updated Model Overview, http://www.envi-met.de/

[5] Bruse, M. and H. Fleer (1998). Simulating Surface-Plant Air Interactions Inside Urban Environments with a Three Dimensional Numerical Model, *Environmental Software and Modelling*, (13), S. 373–384

[6] Chen Yu & Wong Nyuk Hien. (2006). Thermal benefits of city parks. *Energy and Buildings*, 38, 10-120.

[7] B. Avissar, Potential effects of vegetation on the urban thermal environment, *Atmospheric Environment,* 30, 437–448.

[8] Wong Nyuk Hien, et al. (2003). Effects of rooftop garden on energy consumption of a commercial building in Singapore. *Energy and Buildings*, 35, 353-364.