The Study of Vegetation Effects on Reduction of Urban Heat Island in Dubai

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Abstract:
Rapid urbanization in the past 100 years has resulted in many environmental issues in large cities. Urban Heat Island which is the condition of excess heat in city centers is one of these environmental issues. Dubai which has developed tremendously in the past decade also suffers from condition of urban heat island. This research aims to study the effects of vegetation on reduction of urban heat island in dense and old neighborhoods of Dubai. Computer simulation was selected as the major methodology in this research and ENVI-met software was utilized as the main simulation tool. The investigations in this research were performed in two parts; Part One focused on identifying the most effective strategies of applying greenery in a simplified urban condition. In Part Two, these strategies were applied on two urban blocks in Dubai to measure their effectiveness on real conditions. The results from both parts of the research showed that application of trees with medium density is the most effective strategy in tackling excess heat in urban areas. Also, it was concluded that both grass and green roofs have negligible effects on reducing surface temperatures in the urban areas. Based on the results, it is suggested to apply the medium density trees in compacted forms around the built up structures in newly designed urban areas. In terms of the pre-existing urban areas, the best strategy is to utilize available empty plots such as parking lots to insert compacted forms of medium density trees in addition to planting along the wide pedestrian and vehicular paths.

Key words, Vegetation, Urban heat island, Envimet, Dubai

1. Inroduction

Rapid urbanization has caused number of negative consequences in different parts of the world. This research focuses on one of these consequeances as a phenomenon known as Urban Heat Island. This phenomenon can be defined as a temperature variance where an urban area (normally located at the heart of the city) features an island of warmer air and surface temperature compared to a suburban or rural area which features a sea of cooler air and surface temperature. There are two sources of heat gain in urban areas; sun and anthropogenic sources. Urban areas gain heat from the sun through solar radiation while getting heat from anthropogenic sources through people, machinery and buildings. The mitigation strategies of UHI are directly related to the causes of this phenomenon and they mainly deal with alteration of building materials and increasing evaporation by adding greenery. These mitigation strategies could be categorized under three main groups:

- Cool roofs and pavements
- Green roofs
- Urban Vegetation and greenery

All these strategies aim to focus on controlling the absorption of the heat and its release to the environment in order to establish a balance between heating and cooling of the urban fabric.

2. Litreture Review

The body of research on urban heat island could be divided into three categories; (1) Studies on causes of urban heat island in different cities, (2) Studies on measurement and modeling of the extent of urban heat island in different cities, (3) Studies on application, analysis and the effectiveness of mitigation strategies, for the purpose of this research only the last caterogy of research body was reviewed based on four different áreas listed below:

- Studies on the mitigation effects of Small scale application of greenery
- Studies on the mitigation effects of Large scale application of greenery
- Studies on the mitigation effects of Green roofs
- Studies on the mitigation effects of Vertical greenery

Zhanga, et al. (2010) studied the relationship between surface temperature and NDVI (Normalized Difference Vegetation Index, a numerical indicator used to study vegetation cover on the land from satellite data) in the city of Beijing, China. In this study it was concluded that the distribution of vegetation cover is low in center and high in the edges of the study area while the distribution of the temperature was opposite to vegetation cover, low at the edges and high in center; this observation revealed the significant negative relationship between vegetation cover and surface temperature. In terms of large scale application of greenery, Caoa , et al (2010) studied the role of urban parks characteristics such as size, shape and land use in the amount of Park Cooling Intensity; a parameter that measures the ability of a park to create a cooler environment within the urban fabric. The results of this study showed that large parks had significantly lower temperatures than the rest of the city during summer and spring however this temperature difference was lower during autumn; therefore with increasing the park size, the PCI factor increased considerably for summer and spring. On the other hand, Wong and Jusuf (2008) studied the effect of implementing green roof on reduction of ambient air temperature in National University of Singapore. This study concluded that grass and trees roof cover significantly result in cooler conditions; however this effect is considerably increased when roof garden strategy is combined with improving the amount of greenery on site.In terms of vertical greenery, Alexandri and Jones (2008) in their study of the impact of the characteristics of vertical greenery and street canyon on the microclimate showed that the amount of vegetation placed on the building envelope plays an important role on the cooling effect in urban areas.

3. Research Importance, Aims, Objectives & Methodology

One of the most important concerns which were raised by the authorities after the massive developments in Dubai, was Urban Heat Island phenomenon. Dubai municipality conducted an aerial thermal survey of the city in December 2009 (Zacarias,2011); the air born thermal images of Dubai showcased the existence of urban heat island in the city. Dense areas which belong to the older fabric of the city such as Deira and Bur Dubai as well as the industrial areas of Al Qouz were identified to be the hot spots within the city (Zacarias, 2011). Figure 1 shows a thermal image snapped from Deira and Bur Dubai area; the grey circles in the figure point out the hot spots in these areas. According to Figure 1, building dominated clusters with narrow roads have tremendously higher temperatures than the rest of the áreas. The objective

of this research is to test the effects of the vegetation on reduction of excess heat in urban areas of Dubai showcasing UHI; these effects would be tested in terms of type and composition of the greenery.

Computer simulation is selected as the main study approach in this research; the methodology of this research consists of three stages of software validation, modeling and simulation as well as data analysis and conclusion. The main computer simulation tool which was selected in this research is ENVI-met V3.1 due to the capabilities of this software in modeling greenery and urban simulations.

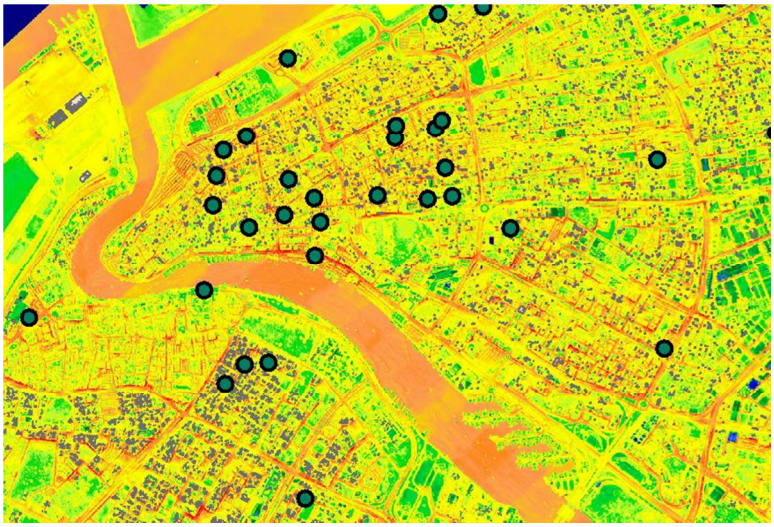

Figure 1 Thermal map of surface showcasing urban heat island in Dubai, snap shot of Deira and Bur Dubai area; the bold circles indicate the urban hotspots. (Zacarias, 2011)

In order to validate the Envi-met software, thermal images of Dubai were acquired from the Dubai municipality environmental studies section. An urban block was selected and modeled in EnviMet under similar conditions as the real termal survey. Figure 2 shows the modeled area and its actual and simulated thermal image. Comparison of both images shows similar thermal trends validating the software. Based on the verifications of previous studies and validation process that was done in this research, it could be concluded that the simulation of microclimates of urban areas in Dubai by using the ENVI-met software could be promising and would yield into results close to the real conditions.

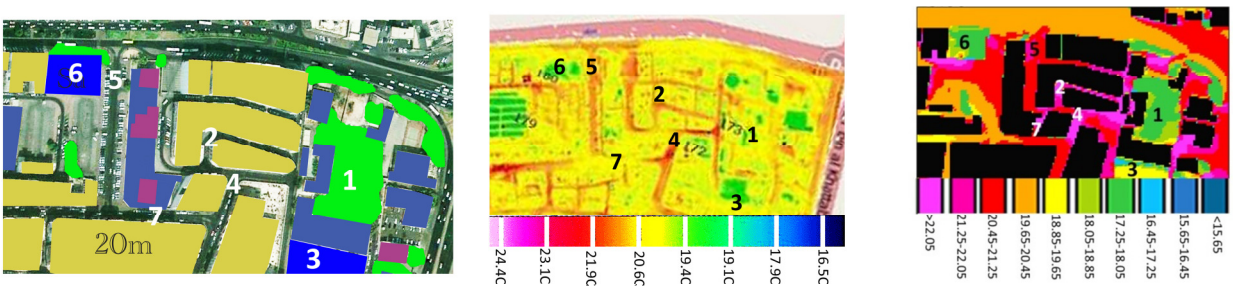

Figure 2 selected urban block with actual and simulated thermal image

Part One: Model Setup, Resutls and Discussion

The investigations of the effect of greenery in this research are done in two parts. In Part one the most effective greenery strategies are identified; the tests in this part of the research are performed on simplified conditions. Part Two of the research utilizes the results of Part One in order to investigate the effects of greenery in reduction of urban heat island in real urban areas of Dubai. In Part One, the heat reduction capabilities of formal composition of green urban fabric, including grass, trees and green roof are investigated. Also, several variables have been defined based on ENVIMET input variables. Wind speed, wind direction, average temperature and relative humidity are fixed variables that depend on simulation day and time setup. In addition, variables such as building density, albedo value of walls and roofs, heat transmission values of walls and roofs and the inside temperature of the buildings are also kept fixed in all simulations. Beside considering the fixed variables, it is important to note that all the simulations in this research are run in both cold and hot seasons in Dubai; therefore 21st of July has been selected to represent summer and 21st of January has been selected to represent winter conditions. The effects of different configurations are compared based on hourly average surface temperature.

After defining the parameter under assement and variables, five different tests were designed and modeled .Each of these tests utilizes a certain composition of greenery; Table 1 shows each test and its corresponding variable under assessment. Trees, grass and green roof are three different types of greenery that are applied in individual configurations.

Table 1 Group of tests and their corresponding variables, investigating parameter 1.

Test	P1
P1-1	Trees and green roof
P1-2	Grass and green roof
P1-3	Trees and grass
P1-4	Grass Only
P1-5	Trees without Grass

Figure 3 shows a comparison of the average hourly surface temperatures of a summer and winter day for all the tests in Table 1 plus the base test. At first glance, all configurations in both summer and winter fall below the base test, proving the positive effect of applying any type of greenery including grass, trees or green roof in reduction of surface temperatures in urban areas. In addition, different configurations depict diverse behaviors particularly from 9:00 to 17:00 due to the fact that solar radiation increases in these hours of the day. The comparison of summer and winter during peak hours shows that individual configurations may behave differently during each season. For example P1-1 (trees and green roof) results in the least surface temperature during the summer while the same configuration results in the

highest surface temperature during the winter. Also, the graphs suggest that the cooling effects of greenery are higher during summer compared to winter.

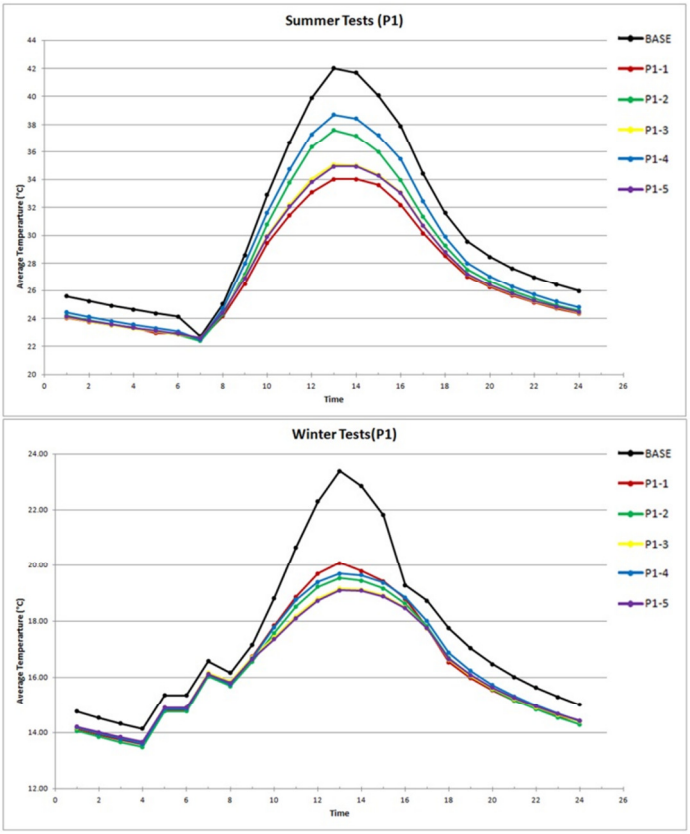

Figure 3 Average hourly surface temperatures for tests investigating Composition of Green Fabric vs. Grey Fabric (P1). 5.3

Among all the configurations, P1-4 which employs only grass has the highest surface temperature in summer and second highest during winter.The poor performance of grass is related to its lack of complexity in terms of density and variability of foliage.Therefore, P1-3 (trees and grass) and P1-5 (Trees without grass) result in reasonably low surface temperatures in both seasons compared to other configurations. As a result, presence of trees has the most tremendous effects in decreasing the surface temperatures specifically during hot season; this conclusion corresponds to results of Caoa , et al (2010) and Chang, et al. (2007) who suggest that trees have the best cooling effects compared to other forms of greenery.

4. Part Two: Model Set up, Results and Discussion

This part of the research aims to test the effect of application of optimal strategies on pre-existing urban conditions in Dubai. As mentioned previously, a thermal survey of Dubai in December 2009 showcased existence of urban heat island in older fabric of the city, particularly areas of Deira and Bur Dubai. Therefore, an urban blocks from these two areas was selected for testing the effect of optimal strategies of formal composition of greenery in pre-existing dense urban areas. Each model is tested in 3 different configurations; existing situation without any alteration, addition of trees to all the empty areas as well as along the

roads & addition of green roof besides inserting trees in all the empty spots. Figure 4 showcases the results of three configurations that were tested on Area A (urban area away from Dubai Creek) during summer and winter. Based on the figures, inserting greenery in this area has a tremendous effect on reducing surface temperatures during both seasons. Different conditions showcase individual behavior specifically from 9:00 to 17:00 due to the abundance of solar radiation during these hours. Even though, the strategy of inserting both trees and green roofs seems to result in the lowest Surface temperatures, the configuration of inserting only trees is considered to be the best configuration. The fact that the case of Trees only, and Trees plus Green roof obtain close results indicates that green roofs have negligible effect on reducing surface temperatures in the urban areas.

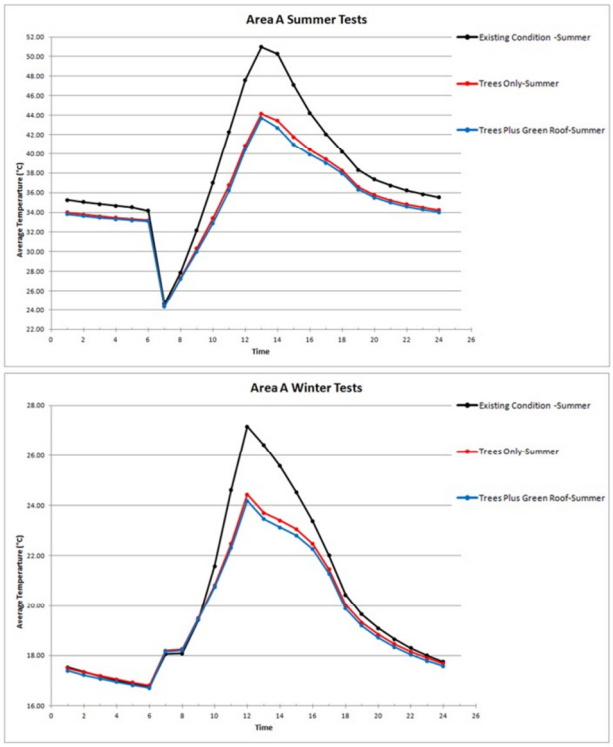

Figure 4 Average hourly surface temperatures for different tests investigating the effects of Optimal Strategies in Area A (area away from Dubai Creek).

Data analysis shows that all configurations showcase the maximum difference in value right after the noon time during 13:00 h. In order to see the distribution of temperatures during this peak hour, the map of surface temperatures for the existing condition and condition of adding trees only, for Area A are compared in figure 5. These thermal maps indicate the tremendous reduction of surface temperatures in areas directly adjacent to places where trees are inserted (a). Also in areas were no trees were inserted directly (b), there is evidence of reduction in surface temperature.

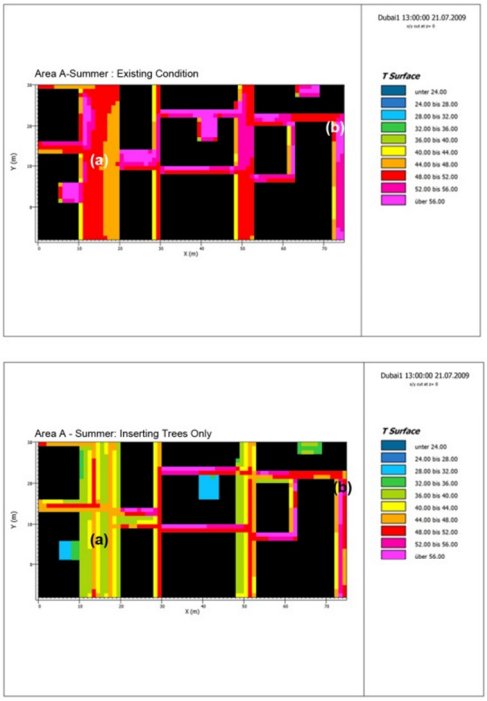

Figure 1 Thermal map of surface temperatures for different configurations in Area A at 13:00 on a summer day.

5. Conclusion

The results from both parts of the research revealed that in terms of composition of greenery, trees have the best contribution in reduction of surface temperatures in the urban areas of Dubai. On the other hand, grass has the least contribution in reduction of urban heat due to the lack of complexity and variation in foliage. Also green roofs were proved to perform poorly in reducing the surface temperatures in urban areas; this is due to the fact that the cooling effects of green roofs reduces by distance and therefore this effect is negligible on the overall temperature reduction in urban areas. It should be noted that this observation is only true at the macro scale and it does not contradict the other benefits of green roofs at the micro scale which were out of the scope of this research. The conclusion of this research signifies the importance of greenery in reducing excess heat and creating balanced microclimatic conditions in urban areas of Dubai.

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