Simulation Study of Thermal Effects of Vegetation Covered Sand dune mounds within the Landscape around Urban Structures in the UAE

دراسة عن التأثير الحراري للغطاء النباتي للجبال الكثبية الرملية ضمن منطقة الهياكل الحضرية في دولة الإمارات العربية المتحدة

By

Dana Al-Yaqoob

Student ID 100030

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Professor Bassam Abu-Hijleh

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Abstract

Urbanization is one of the many factors that have caused numerous environmental concerns around the world. Such issues that are the root subject of concern is Urban Heat Island effect, a condition that describes the overheating of cities. Dubai is just one of many cities that have had a rapid growth in development, leading to the condition of urban heat island. This research topic aims to study the effects of vegetation in the shape of sand dune formations to help reduce effects of urban heat island in Dubai, as well as, link back to the cities original typography.

Computer simulation was chosen as the major methodology in this research and ENVI-met software was applied as the main simulation tool. The investigations in this research were performed by testing the vegetation dune-like mounds on a selected site against three different base cases to compare the overall effect of surface temperatures around urban areas in Dubai.

The results of the research showed that application of trees in a natural and diverse arrangement while still having a mix of different vegetation types around the urban areas is the most effective strategy in tackling excess heat in urban areas. Also, increase in edge compactness and shape complexity of vegetation can decrease surface temperatures and progress the exchanges between vegetation and built-up areas. On the other hand, it was concluded that grass has the least effects on reducing surface temperatures in the urban areas. When designing, the landscape should try to mesh with the existing surroundings, linking back to the area's historic characteristics for additional visual benefits. Based on the results, it is recommended to apply high trees with wide canopies to create best shading and reduction in temperatures. Other suggestions can be guided towards including trees and shrubs along roads, pedestrian paths, and even within parking lots. As a general rule it is suggested to aspire to diminishing the hard surfaces such as concrete and asphalt, as much as possible.

ملخص

التحضر، احدى العديد من العوامل التي تسببت في العديد من الاهتمامات البيئية في جميع أنحاء العالم. مثل هذه القضايا التي هي موضع للقلق في جزيرة الحرارة الحضرية ، دبي واحدة من العديد من المدن التي كان لها النمو السريع في مجال التنمية، مما أدى إلى حالة من جزيرة الحرارة الحضرية. هذا الموضوع يهدف البحث إلى دراسة تأثير النباتات في شكل تشكيلات الكثبان الرملية للمساعدة في الحد من المنضوين جزيرة الحرارة الحضرية في دبي، وكذلك، ربط عودة إلى الطباعة مدن الأصلية.

وقد تم اختيار محاكاة الكمبيوتر والمنهجية الرئيسية في هذا البحث، وطبق
كأداة محاكاة رئيسية.ENVI- metالبرامج
وأجريت التحقيقات في هذه الدراسة عن طريق اختبار الحالات قاعدة مختلفة للمقارنة بين التأثير العام لدرجات الحرارة السطحية في جميع أنحاء المناطق الحضرية في دبي.

وأظهرت نتيجة البحث أن تطبيق الأشجار في ترتيب الطبيعية ومتنوع في حين لا تزال لديها مزيج من أنواع النباتات المختلفة في جميع أنحاء المناطق الحضرية هي الاستراتيجية الأكثر فعالية في التعامل مع وصول الحرارة في المناطق الحضرية. أيضا، زيادة في الاكتناز حافة وتعقيد شكل من النباتات التي يمكن أن المراسيم درجات الحرارة السطحية والتقدم تبادل بين الغطاء النباتي والمناطق المبنية من ناحية أخرى فقد خلص إلى أن العشب يحتوي على الأقل على الحد من تأثيرات درجات الحرارة السطحية في المناطق الحضرية. عند تصميم، وينبغي أن المشهد في محاولة لتنسجم مع البيئة المحيطة القائمة، وربط العودة إلى خصائص المنطقة التاريخية لالمرئي الفوائد الإضافية. الأخرى على أساس النتائج، فمن المستحسن أن تطبق الأشجار العالية مع الستائر واسعة لخلق أفضل التظليل وتخفيض في درجات الحرارة. ويمكن الاسترشاد بما في ذلك اقتراحات أخرى من أجل الأشجار والشجيرات على طول نحو، ممرات المشاة، وحتى داخل ساحات وقوف السيارات. كقاعدة عامة يقترح على التطلع إلى التقليل من سطح صلب مثل الخرسانة والأسفلت، قدر الإمكان.

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Words fail to express my appreciation to my best friend, soul mate, and a true gift from God, Mr. Saoud AlNuaimi. Thank you for standing by me through all hardships and for pushing me to always be my best.

Last but never the least; I thank my family for all the support and efforts, especially my mother and father for bringing me to this point in my life.

I dedicate this dissertation to all of you.

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Chapter 1: Introduction

1.1 Sustainability:

In the past years, the fast track lifestyles the world is driven by, as well as, the increase in the development technologies being used that aim at easier standards of living; go hand in hand with many present day issues and impacts to the world and to future generations to come. The constant increase in population growths leading to a surplus of resource demands and supplies is an evident global factor being faced in our day an age. It is no surprise that people ignore negative side effects from their actions for their everyday existence. Lack of knowledge of these negative impacts, effects of modern day lifestyles and bad habits is harming our surroundings. These are just a few common obstacles that are needed to be overcome, so as to obtain and decrease the setbacks being faced.

Furthermore, the lack of incentive with the common majority of political and economic mind sets of the present day mans profit based outlook to living, causes problematic implications. Thus, resulting in ignoring the depletion of natural resources combined with the never ending need for energy consumption. Even more, to keep up with the boundless evolution of modernization and developmental needs, many effects are concurred. Carbon footprints and emission increases, urban heat island effects, global warming, deforestation, desertification and so forth are just a few examples of the staggering negative influences being caused. All of this has some bearings on the diminishing losses to the natural environment with the escalated reliance on the built environment. Building construction plays an enormous ingredient in the impressions shaping imminent exhaustion of our ecosystem. Many countries around the world face similar issues; however, The United Arab Emirates has become one of top countries with the greatest carbon footprint levels. Sustainability is an approach to a solution to such concerns. As stated by the Royal institute of chartered surveyors (2007):

> The most commonly accepted definition of sustainable development is from the 1987 UN Brundtland Commission Report: [Development] which meets the needs of the present without compromising the ability of future generations to meet their own needs. (p. 5)

Many countries around the world face the same issues and concerns, however, most developed countries have investigated, tested solutions, even implemented many sustainable methods to try and overcome these negative future outcomes. Developing countries on the other hand, are still adapting and attempting to follow in their footsteps. In the Middle East, the subject of sustainability has arisen around the past couple of years and such methods of sustainability, even renewable energy incorporation and conservation, has become an important subject of discussion and study. Many factors and problems lead to the need for countries and globally for solutions at decreasing these negative impacts that have arisen, plaguing future generations to come. The United Arab Emirates (UAE) has been thriving to excel at extenuating the negative effects of climate change on the environment. It has introduced various proposals to contribute to the international agenda for the mitigation of the outcomes on climate change. An important stride towards the direction at bettering the current situation taken by Abu Dhabi, the capital of UAE, is the commencement of the Estidama Program, which is an enterprise developed by the Abu Dhabi Urban Planning Council that aims for sustainable development. (Abu Dhabi Urban Planning Council, 2010).One of the most energy consuming sectors in the UAE is the construction sector. It was revealed that the construction industry consumes 40% of the overall electricity of the country, therefore making this a major concern as specialists are hunting for solutions to minimize energy consumption. (Abu Dhabi Urban Planning Council, 2010).

Furthermore, according to a United Nations report (UNCCD, 2004) more than one billion people worldwide are affected by drought and desertification. These people, which amount to approximately one quarter of the planet, are facing major problems such as soil degradation and vegetation loss, leading to corrosion of land used for growing crops and eventually to continual food uncertainty. Biodiversity and sustainable use are words connected with human beings and linked to the wellbeing of mankind. Most living systems are based on the unpredictability and complexity of organisms that comprise the biodiversity of regions and the world as a whole. However, this biodiversity, which has demonstrated through the past, to be vital to the constant and sustainable life of all living communities, has been seriously put through a great deal of damage and destruction. Due to the result of the fast growing industrial revolution, and the ever-increasing demand on food and raw materials as a natural consequence of human population increase and exploitation of technologies, the damage to biodiversity has been very rapid and complex. Two meetings were held in Saudi Arabia and Dubai to deal with similar issues of desertification, conservation and biodiversity in which introduction to detailed work was taken out in this regard (Al-Eisawi, 1996, 2003)

Urban Heat Island (UHI) is considered as one of the major problems in the 21st century posed to human beings as a result of urbanization and industrialization of human civilization. The large amount of heat generated from urban structures, as they consume and re-radiate solar radiations, and from the anthropogenic heat sources are the main causes of UHI. When there are two heat sources that increase the temperatures of an urban area as compared to its surroundings, is known as Urban Heat Island Intensity (UHII). The problem is even worse in cities or metropolitan areas with large population and extensive economic activities. The estimated three billion people living in the urban areas in the world are directly exposed to the problem, which will be increased significantly in the near future. Due to the severity of the problem, vast research effort has been dedicated and a wide range of literature is available for the subject. The literature available in this area includes the latest research approaches, concepts, methodologies, latest investigation tools and mitigation measures. A study by Memon, Leung, and Chunho (2007) was carried out to review and summarize this research area through an investigation of the most important feature of UHI. It was concluded that the heat re-radiated by the urban structures plays the most important role, which should be investigated in details to study urban heating, especially the UHI. It was also concluded, that the future research should be focused on design and planning parameters for reducing the effects of urban heat island and ultimately living in a better environment.

As in another paper Mirzaei and Haghighat (2010) discuss Urban Heat Island (UHI) having significant impacts on the buildings energy consumption and outdoor air quality (OAQ). Various approaches, including observation and simulation techniques, have been proposed to understand the causes of UHI formation and to find the corresponding mitigation strategies. However, the causes of UHI are not the same in different climates or city features. Thus, general conclusion cannot be made based on limited monitoring data. With recent progress in computational tools, simulation methods have been used to study UHI. These approaches, however, are also not able to cover all the phenomena that simultaneously contribute to the formation of UHI. The short comings are mostly attributed to the weakness of the theories and computational cost. They present a review of the techniques used to study UHI. The abilities and limitations of each approach for the investigation of UHI mitigation and prediction are discussed. Treatment of important parameters including latent, sensible, storage, and anthropogenic heat in addition to treatment of radiation, effect of trees and pond, and boundary condition to simulate UHI is also presented. Finally, a conclusion is discussed for the application of integration approach as a future opportunity.

Onishi et al. (2010) stated Artificial urban land uses such as commercial and residential buildings, roads, and parking lots covered by impervious surfaces can contribute to the formation of urban heat islands (UHIs), whereas vegetation such as trees, grass, and shrubs can mitigate UHIs. Considering the increasing area of parking lots with little vegetation cover in Nagoya, Japan, this study evaluated the potential for UHI mitigation of greening parking lots in Nagoya. The relationships between land surface temperature (LST) and land use/land cover (LULC) in different seasons were analyzed using multivariate linear regression models. Potential UHI mitigation was then simulated for two scenarios: (1) grass is planted on the surface of each parking lot with coverage from 10 to 100% at an interval of 10% and (2) parking lots are covered by 30% trees and 70% grass. The results show that different LULC types play different roles in different seasons and times. On average, both scenarios slightly reduced the LST for the whole study area in spring or summer. However, for an individual parking lot, the maximum LST decrease was 7.26 ◦C in summer. This research can help us understand the roles of vegetation cover and provide practical guidelines for planning parking lots to mitigate UHIs.

Zhang, Wu, and Chen (2010) report, brightness temperature (Tb) and normalized difference vegetation index (NDVI) were quantitatively derived from Landsat TM images of Beijing City. Feature profiles of Tb and NDVI were drawn in the directions of NE-SW and NW-SE using the technologies of RS and GIS. Laws of spatial distribution of the relationships between Tb and NDVI were discussed. The following conclusions are drawn. (1) There is a significant negative correlation between Tb and NDVI. (2) The less distance between the other profiles and the central profile is, the stronger the negative correlation between Tb and NDVI is. (3) The relationship between Tb and NDVI is affected by the complexity of underlying surface land use structures. The more complex the land use structure is, the stronger the relationship between Tb and NDVI of feature profile is. The spatial correlations between vegetation and temperature are effectively revealed in this paper and thus certain scientific supports for Beijing's urban and Greenland planning in the future could be provided.

1.2 Definition of Urban Heat Island Effect

Many of the problems concurred are linked even sometimes having a lot of similar impacts and causes. Here are two serious problems that relate to the papers investigations and are mainly focused and touched upon:

1.2.1 *The Urban Heat Island (UHI) Effect*

UHI definition that relates to this paper is stated by Kolokotroni (2006) indicating that urban heat island effect is instigated by micro-climatic variance which is caused by “man-made” interference and alteration of urban surfaces.

1.2.2 *Causes*

UHI formations main cause is the substitution of natural surfaces by built surfaces, through urbanization. Natural surfaces are often made up of vegetation and moisture-trapping soils. Vegetation intercepts radiation and produces shade that also contributes to reduce urban heat release. Thus when vegetation is replaced with urban walls and surfaces, it hinders the process of reducing heat emissions (Memon, Leung & Chunho 2007).

1.2.3 *Impacts*

- Increased energy consumption: Higher temperatures in summer increase energy demand for cooling and add pressure to the electricity grid during peak periods of demand.
- Elevated emissions of air pollutants and greenhouse gases: Increasing energy demand generally results in greater emissions of air pollutants and greenhouse gas emissions from power plants.
- Compromised human health and comfort: Warmer days and nights, along with higher air pollution levels, can contribute to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality.
- Impaired water quality: Hot pavement and rooftop surfaces transfer their excess heat to storm water, which then drains into storm sewers and raises water temperatures as it is released into streams, rivers, ponds, and lakes. Rapid temperature changes can be stressful to aquatic ecosystems (Akbari 2005; Berdahl and Bretz. 1997).

1.2.4 *Mitigation strategies*

- Increasing tree and vegetative cover;
- Creating green roofs (also called "rooftop gardens" or "eco-roofs");
- Installing cool, mainly reflective roofs
- Using cool pavements.

Clearly we see Without Vegetation Urban heat island effects would worsen and be harder to control, hence bringing about other concerns that cause the loss of vegetation, such as desertification and so forth. Therefore, it is clearly evident that our current living conditions have many side effects that have a domino effect on each other, and unmistakable threats presently being faced by the Middle East and many other countries. If these implications begin to encroach more and more all over further parts of the world it will become an irreversible pandemic danger. By realizing the risk at an earlier stage presently, the attempt at a reversal to this dilemma still stands for hope. If not entirely reversible, then at least, it is a step in the right direction to put a standstill to turning into an epidemic that is even more infectious. The reality of the situation is that the human race stands to gain more than loose by seeking and applying solutions to these problems. For if not, then what awaits our children is a sandy grave yard that will be dug out by our own hands for the future generations to come. The first starting point than is by investigating the benefits of bringing back vegetation to the surroundings and exploiting our natural habitats, to benefit the outcomes in the process.

1.3 Natural Phenomenon

The Arabian Desert encompasses almost the entire Arabian Peninsula, blanketing the area in sandy territory and seasonal winds. Encompassing over 1,447,7955 square miles (2,330,000 sq km), the Arabian Desert contains Rub'al-Khali, one of the world's largest continuous bodies of sand (New World Encyclopedia, 2008). UAE, Oman, Saudi Arabia, Bahrain, Iraq, etc. are some of the many countries that share these vast desert sands, linking back to its historical battle against the inhospitable landscape. Still, the Arabian Desert served as a passage for many from the Middle East to North Africa and beyond. Dubai in its self is surrounded by deserts, but the constant structural urban growth being seen at our present day and age has overtaken most of the countries historical natural horizon. Through these constructed progressions comes many benefits, however the negatives, as seen by many, surpass the destruction of the countries environmental heritage. By linking back to desert life and re-introducing such environmental ecology and geology of deserts and even trying to find a balance between old and new technologies creating a link between our growing modern structures and the natural existing environment surrounding it can try to reach some kind of unity. Hence, this will help bring back a balance to the rigidity of our present day skyline and the neighboring local habitation. In this report the investigation will compose of attempting to bridge between environmental benefits and economical obstacles by blending natures urban form into the built environment, thus, having coinciding opposite habitats blending into one co-existing system. The United Arab Emirates energy consumption rates have swelled notably during the present and past years. Lack of suitable shading devices, greenery as well as, lack of consideration towards better design strategies for decreasing energy consumption are one of the leading cause in that dramatic increase. Therefore, finding a half way point with potential decrease of energy consumption both hand in hand at a micro and macro level are essential.

1.3.1 Sand Dune Formation

A sand dune needs the following three things to form:

1. A large amount of loose sand in an area with little vegetation
2. A wind or breeze to move the grains of sand
3. An obstacle that causes the sand to lose momentum and settle. This obstacle could be as small as a rock or as big as a tree.

Where these three variables mentioned above begin to merge, a sand dune forms. As the wind picks up the sand, the sand travels but generally only about an inch or two above the ground. Once it's in motion, sand will continue to move until an obstacle causes it to stop. The heaviest grains settle against the obstacle, and a small ridge or bump forms. Because the obstacle breaks the force of the wind, the lighter grains deposit themselves on the other side of the obstacle. Eventually, the surface facing the wind crests, and the lighter grains of sand cascade down the other side, or the slip face. This is how a sand dune may actually move over time, it rolls along, and maintaining its shape as it goes as seen in Figure 1.1 (Mangimeli n.d; Ronca n.d.).

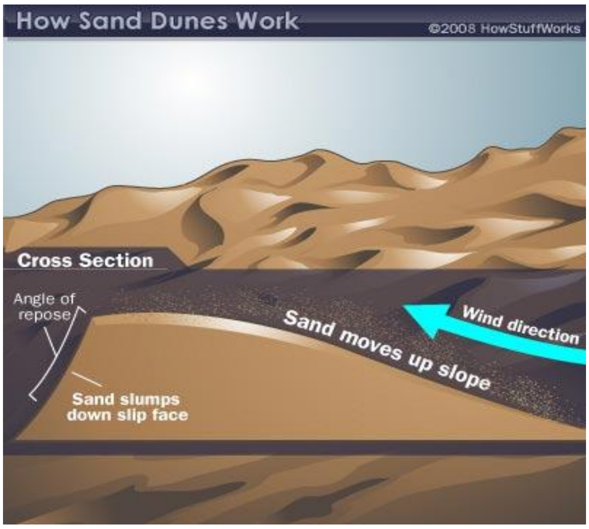


Figure 1.1 - Sand Dune Formation (Mangimeli n.d; Ronca n.d.)

1.3.2 Shifting slip face/side

How and why does a sand dune crest? As the wind moves sand up to the top of the sand pile, the pile becomes so steep it begins to collapse under its own weight, and the sand avalanches down the slip face. The pile stops collapsing when the slip face reaches the right angle of steepness for the dune to remain stable. This angle, which scientists call the angle of repose, is usually about 30 to 34 degrees.

After enough sand builds up around an obstacle, the dune itself becomes the obstacle, and it continues to grow. Depending on the speed and direction of the wind and the weight of the local sand, dunes will develop into a different shapes and sizes. Stronger winds tend to make taller dunes; gentler winds tend to spread them out. If the direction of the wind generally is the same over the years, dunes gradually shift in that direction. Any vegetation that crops up will stabilize the dune and prevent it from shifting (Mangimeli n.d; Ronca n.d.).

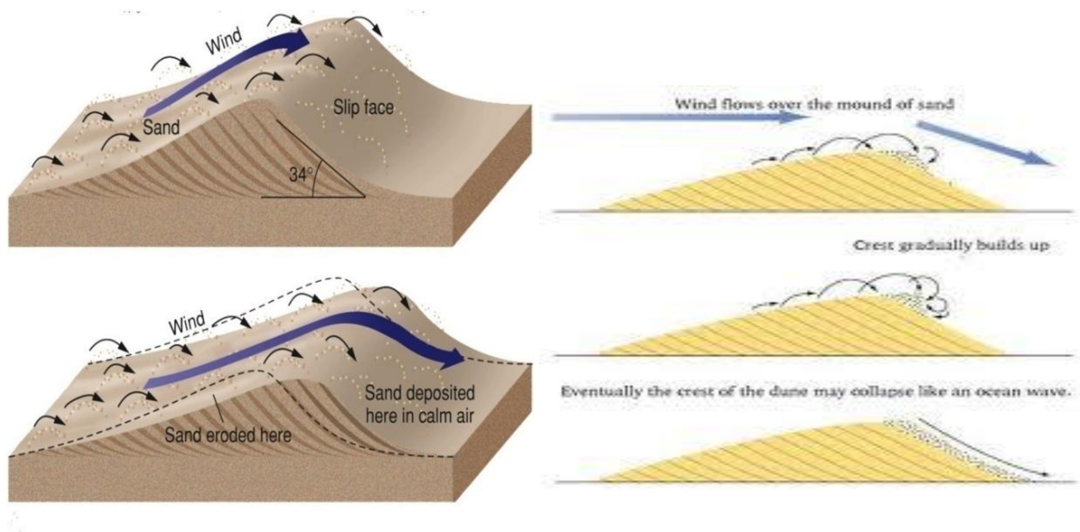


Figure 1.2 Slip face/side (Mangimeli n.d; Ronca n.d.)

1.4 Types of Sand Dunes

Sand dunes develop into all shapes and sizes. By using satellite and aerial photography of the world's deserts, the United States Geological Survey (USGS) (2007) and Geological Survey Professionals (1979) have identified five types of sand dunes:

The Crescent dune, also called the *Barchan*, is the most common type of sand dune. As its name suggests, this dune is shaped like a crescent moon with points at each end, U-shaped dune that has its "horns" or tips pointing downwind or away from the wind and it is usually wider than it is long. Crescentic dunes form when winds blow from one direction (Figure 1.3).

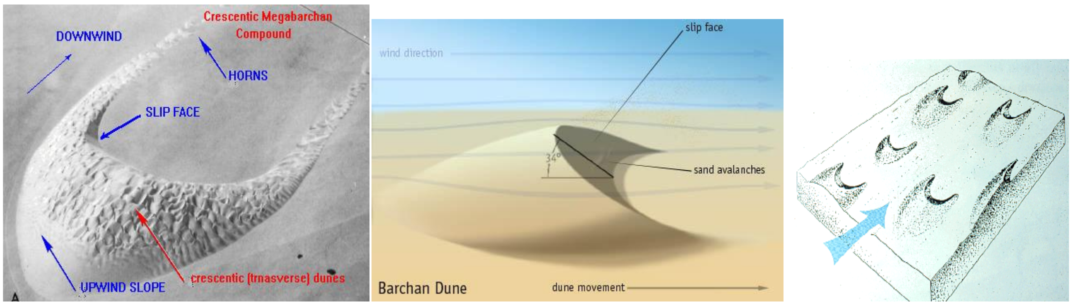


Figure 1.3 Barchan Dune: cresent shaped with "horns" pointing downwind (Sand Dunes. n.d.)

The Parabolic dune is U-shaped, but differs from the crescentic dune because its crests point upward, with elongated arms that follow behind and its tips point into the wind. A parabolic dune's trailing arms are typically anchored by vegetation. The longest known parabolic dune has a trailing arm nearly 7.5 miles (12 kilometers) long.

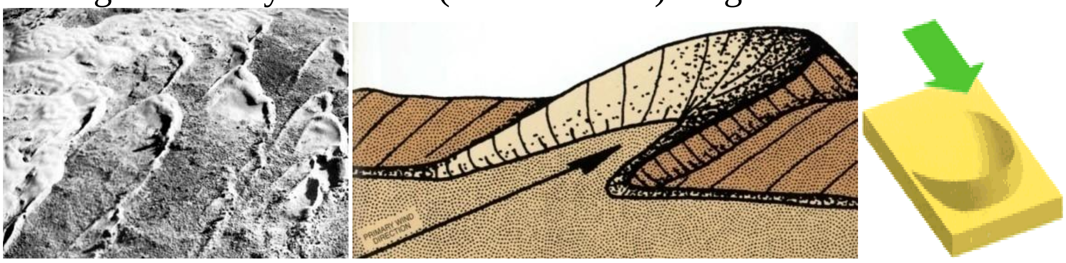


Figure 1.4 Parabolic Dune: with a crescentic form opposite that of the barchans (i.e. with horns pointed upwind) (Sand Dunes. n.d.)

The Linear (Seif) or Longitudinal dune seen in Figure 1.5, is straighter than the crescentic dune with ridges as its prominent feature. Unlike crescentic dunes, linear dunes are longer than they are wide; in fact, some are more than 100 miles (about 160 kilometers) long. The ridges are long and snakelike, and these dunes usually occur in parallel sets separated by other sand, gravel or rocky corridors.

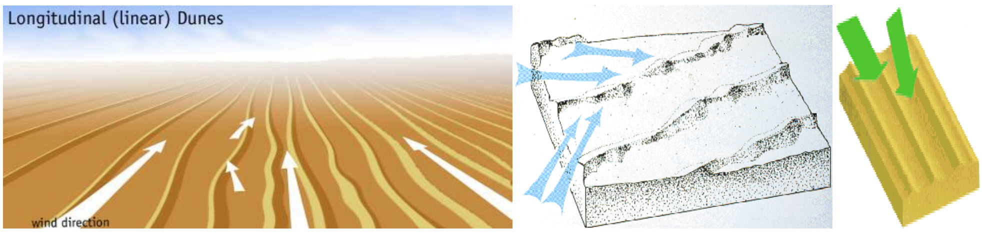


Figure 1.5 Longitudinal Dune: linear dune that moves parallel to the wind(Sand Dunes. n.d.)

A Transverse or Barchanoid ridge dune also forms where sand supply is great. This dune is a ridge of sand that forms perpendicular to the direction of the wind. The slip face of a transverse dune is often very steep. A group of transverse dunes resembles sand ripples on a large scale as shown in Figure 1.6.

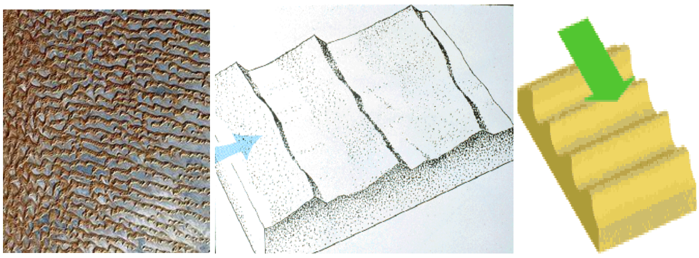


Figure 1.6 Transverse Dune: linear dune that moves perpendicular to the wind (Sand Dunes. n.d.)

The Star dune has arms that radiate out from a center pyramid-shaped mound, hence the descriptive name (Figure 1.7). Star dunes grow upward instead of outward and are a result of multidirectional winds. They're among the tallest sand dunes on Earth, some star dunes are more than 1,600 feet (500 meters) tall.

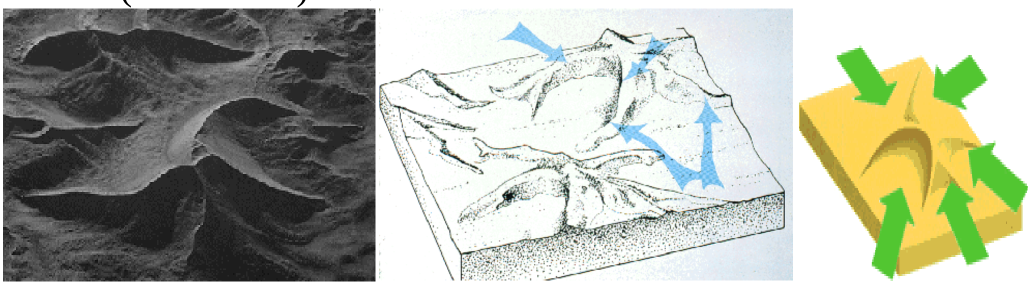


Figure 1.7 Star Dune: dune that forms when there are a number of dominant wind directions (Sand Dunes. n.d.)

1.5 Project Mitigation Strategy

The concept of this project is derived from the natural surrounding milieu of Dubai's Deserts, specifically the sand dune. Integrating the various types of sand dune formations and shapes, within an urban context or in simpler terms as a structural landscape, alleviates the linkage between the natural scenery with the built setting. Further, assimilating sand dunes as vegetation around the site and/or forms symbolically represents an innate shading tool that will help avert and redirect unwanted harmful sun rays while still allowing natural lighting within the space. The sand dune is created by wind thus should be an added mechanism to direct wind flow around the vicinity, and vegetation helps cool wind thus escalating the benefits of the innate combination of both and amplifying the views of the occupant throughout the development. Thus, by shaping the vegetation around existing urban forms in the shape of sand dune formations within computer simulated software and testing them against base cases such as where the same site is tested once without any vegetation and again with just low cut grass. We can then compare the simulation results obtained, to get a better understanding of the effects of such future implementations in reality.

1.6 Dissertation Outline

This research paper is divided into the following chapters:

Chapter one is an introduction and overview of the topic of sustainability and a focus on two problems concurred such as Urban Heat Island effect, including desertification and its definitions. The chapter also underlines the significance of understanding such phenomenon and justifying effects on the environment and human comfort. Then a brief background of sand dune formations is explained as the natural phenomena that will be investigated along with vegetation.

Chapter two will be a broad discussion on the Literature review of several scientific papers discussing a variety of factors influencing and instigating Urban Heat Island effects and the impacts of vegetation within urban ecology and its benefits of implementation to its surroundings.

Chapter three reviews the methodology section where literature review papers are examined based on their methodologies and evaluated. The different methodologies pertained to their limitations and advantages will be studied to thus select the most suitable one for this dissertation and research parameters. Software selection and site selection are also determined in this section.

Chapter four will illustrate the computer model set-up and validation procedure. The chapter will portray the baseline model and the course on how the set up of the model scales were made and chosen.

Chapter five will summarize the results and present a broad discussion. The findings will be discussed and compared to recognize the advantages and disadvantages of each scenario.

Chapter six will provide a conclusion based on the results as well as highlighting the recognized issues contributing to these results. Further studies and future recommendations will also be suggested.

Chapter 2: Literature review

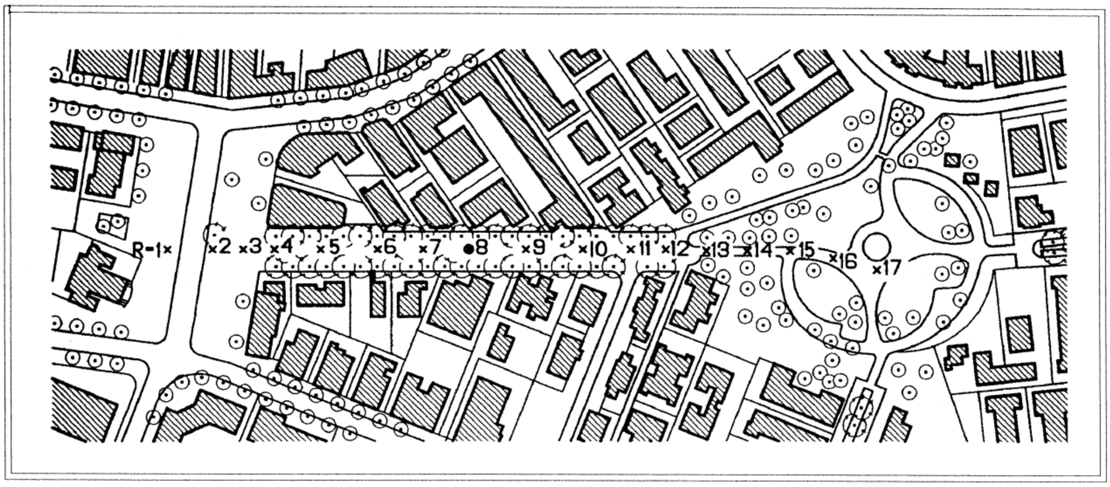
2.1 Background

This Chapter will highlight the main scientific papers that have addressed the Urban Heat Island effects occurring around the globe, as well as, a discussion on mitigated effects of vegetation in battling such problems. In this section the reviewed papers will be presented depending on some of the major factors that have affected such outcomes and their impacted results. Many Countries have developed and evolved into a forest of urban structures with rich collection of buildings and structures of various architectural styles. It is such iconic buildings that increase tourism and population in the countries, however, in this hot climate many urban structures and expansion of tall constructions with little thought on environmental aspects to both the occupiers of the buildings themselves as well as the natives of the country. The Urban heat Island effect is just one of many examples of such constructional effects and impacts these structures has to surroundings. Increase in vegetation, incorporation of open spaces, adaptive vegetation as shading devices are all ways at reducing these environmental effects. In this section a focus on these integrating an environmental Concept derived from nature will be the basis of discussion. The investigation will compose of attempting to bridge between environmental benefits and economical obstacles by blending natures urban form, such as sand dunes and vegetation into the built environment, thus having coinciding opposite habitats blending into one co-existing system. By looking at natural phenomena in the countries we reside in we can try to examine the benefits of interrelating and blending the urban structures with the natural forms. In this section specifically we will be looking at research papers discussing vegetation being investigated within the urban forests we live in today and its impact.

2.2 Vegetation Introduction

Greenery has demonstrated to be the most vital factor in mending the microclimate due to its various benefits. Examining the concept of improving the thermal environment by having more greenery has been overly exasperated. Hoffman and Bar (2000) declared that vegetation can decrease the air temperature and its effect is unlimited to its surrounding built environment called the 'background effect'. The background effect can reach to 1.3 degrees Celsius. The microclimate of a site adjacent to an urban park is much cooler than that adjacent to an urban area since the effect of the surrounding sites extends beyond its limits. The background effect varies between 100m from small green areas to 2 km from bigger green areas such as parks. Therefore the advantages of vegetation are considered to be various not only on a local scale but on a wider level.

Vegetation integrates several characteristics that assist in plummeting the air temperature. Trees offer shading that has a significant effect on the heat absorption levels of the shaded surfaces. A cooling effect on the site can be achieved by supplying trees, manmade or shading elements.



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HAYELED AVENUE

* The X's denote the observation points (spaced at about 20 m)
x R = Reference point
● 8 = The point of maximum cooling effect at noon

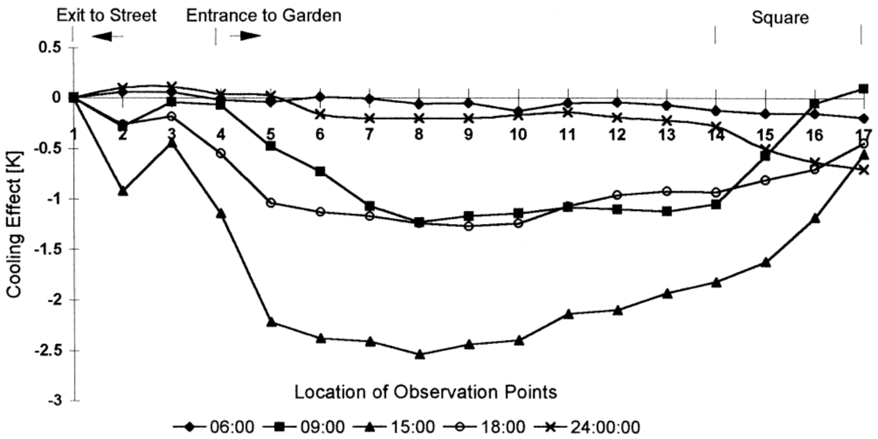

Fig. 2.1 The daily cooling effects along the Hayeled avenue site wKx _averages for the days of measurement. (Hoffman and Bar, 2000)

Hoffman and Bar (2003) proved that 80% of the cooling effect provided within 11 sites in Tel-Aviv urban complex was due to the shading effect obtained by trees. During daytime, trees reduce the penetration of solar radiation due to shade and dwindling of the thermal gains.

2.3 Vegetation and Configuration

In Contrast to the Urban Heat Island effect there is a cooling effect due to vegetation in parks and open spaces that has been known as 'park cooling island'. Drops on the air temperature have been observed during hot summer days in areas with greenery (Hoffman and Bar, 2000; Dimoudi and Nikolopoulou, 2003). This trend has demonstrated to be of vast importance depending upon the types and allocation of the vegetation, microclimate and the topographic character of the site.

Zhoua et al. (2011) examined the consequence of land cover arrangement, exploring the effects of both the structure and arrangement of land cover elements on Land surface temperatures (LST) in Baltimore, USA. It was found that the structure of land cover element is more important in determining LST than their arrangement. The land cover element that most considerably affects the extent of LST is the percent cover of buildings. In contrast, percent cover of vegetation is the most important factor mitigating UHI effects. However, the arrangement of land cover features also matters. Holding structure constant, LST can be significantly increased or decreased by different spatial arrangements of land cover features. These results imply that the impact of urbanization on UHI can be mitigated not only by balancing the relative amounts of various land cover elements, but also by optimizing their spatial arrangement. Edge compactness is a very important arrangement variable that affects LST. Given a fixed structure of land cover elements, an increase in edge compactness of vegetation considerably reduces the degree of LST. In addition, LST commonly reduces with the increase of shape complexity and changeability of vegetation. Increase in edge compactness and shape complexity of vegetation can amplify shade, provided by vegetation, for surrounding areas and thus, decrease LST. In addition, higher edge density and increased shape complexity of vegetation can improve the exchanges between vegetation and built-up areas and thus ease energy exchange between land cover elements, resulting in a lower mean LST (Zhoua et al. 2011).

Table 2
Pearson correlation coefficients between LST and variables of composition and configuration of land cover features. For example, the cell value of 0.41, as highlighted, is the correlation coefficient between LST and the largest patch index of building. We only included the configuration variables for building, pavement, CV and FV in this study.

		Land cover features					
		Building	Pave	CV	FV	Bare soil	Water
Composition	Percent cover	0.57**	0.55**	−0.47**	−0.25**	−0.02	−0.10**
Configuration	Largest patch index	**0.41****	0.55**	−0.45**	−0.22**		
	Patch density	0.16**	0.04	0.31**	0.20**		
	Edge density	0.42**	0.49**	−0.30**	−0.18**		
	Mean patch size	0.20**	0.17**	−0.24**	−0.10**		
	Standard deviation of patch size	0.18**	0.14**	−0.22**	−0.16**		
	Mean shape index	0.14**	0.16**	−0.30**	−0.22**		
	Standard. deviation of shape index	0.14**	0.16**	−0.34**	−0.24**		
	Mean nearest neighbor distance	0.07**	0.09**	−0.32**	−0.13**		
	Standard deviation of nearest neighbor distance	0.05*	−0.12**	−0.26**	−0.17**		
	Cohesion index	0.24**	0.17**	−0.14**	−0.17**		

* Correlation is significant at the 0.05 level (two-tailed).
** Correlation is significant at the 0.01 level (two-tailed).

Fig. 2.2 Pearson correlation coefficients between LST and variables of composition and configuration of land cover features. (Zhoua et al.,2011)

Land surface temperature is also expected to lessen with an increase of the average and variability of bordering neighbor distance among vegetation. This proposes that an regularly spread, rather than clustered, pattern of vegetation can further decrease LST. This may be because, given a fixed percent cover of vegetation, an even distribution can provide more shade for surrounding non-vegetated areas and enhance the interactions between vegetation and other land cover features than had the vegetation been clustered.

Humans not only configure landscape during their activities, but their view of nature is affected by the structure in the landscape. Crow, Brown, and De Young (2005) explore two communities; the first one is Riverside which was designed as an urban forest of naturalistic groupings of trees and vegetation with curvilinear streets. In contrast, the adjacent community of Berwyn had a very trimmed and edged look. Riverside occupants stated obtaining greater advantage from the visual and nature-related quality of the urban forest than did Berwyn occupants. Berwyn residents ranked highest for social atmosphere for the community. Regardless of differences between the two communities, residents appreciated the green residential environment provided by vegetation. However, the more varied urban landscape established to be more rewarding to the inhabitants of these two communities.

Fig. 2.3. The structure of the urban landscape is determined largely by the patterns created by the individual lots and the road network. The irregular lots and curvilinear streets in Riverside (top) differed markedly from the rectangular grid in Berwyn (bottom). (Crow, Brown, and De Young , 2005)

Stabler, Martin and Brazel (2005) look at spatial arrangements of land use, plant density, and microclimate in the Phoenix metropolitan area, a mixed desert, agricultural, and urban area. The results of the data show in summary, that urban plant cover is a transformer of microclimate in Phoenix and validates the use of greenery to reduce urban heating. Confirmation was acquired from this study of a dissimilar mix of microclimates correlated to socioeconomic land use, as well as, an urban to rural decrease in temperature. Not related with an increased concentration of urban forest cover at the urban border as is more characteristic of urban areas in such climates. The study suggests that urban microclimates are more a product of vegetation concentrations intermingling with other factors of the urban basics such as parking lots and buildings. More thorough assessments of differences in land surface cover category and their outcome on urban heating is required, and approaches of urban greening to lessen UHI consequences in desert cities also need to be compensated against the necessity to conserve water resources.

On the other hand, some research focus on characteristics of urban parks. Cao et al. (2010) studied urban parks and the role of their characteristic effects bases on their size, shape and land use. In this study Remote sensing images (ASTER LST and IKONOS) were used to study park cooling intensity (PCI) which is the temperature difference between the inside and outside of a park. The outcome showed that large parks had notably lower temperatures than the rest of the city during summer and spring however these temperature dissimilarities was lower during autumn; hence with enlarging the park size, the PCI factor increased significantly for summer and spring.

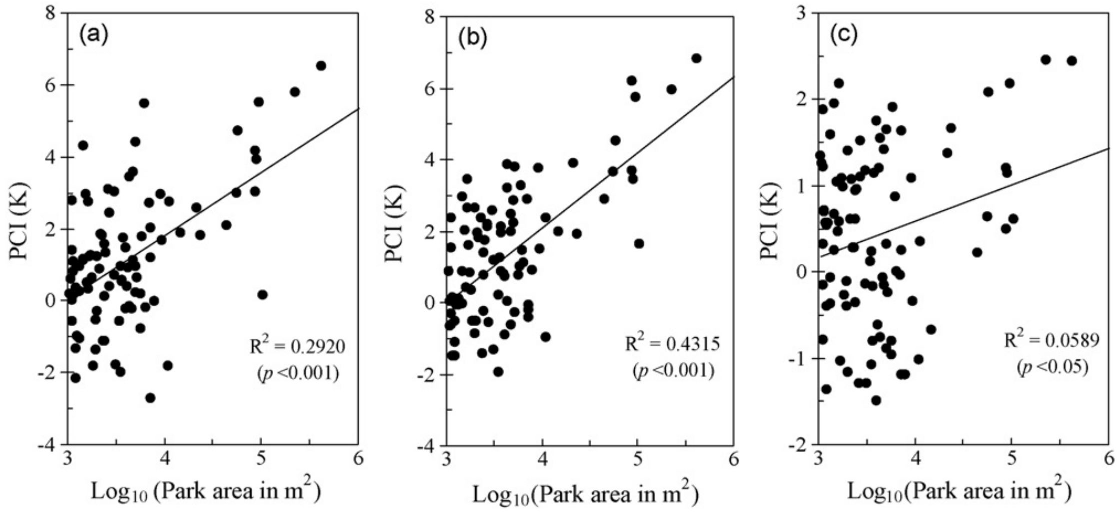

Fig. 2.4 Relationship between PCI intensity and park size in (a) spring, (b) summer, and (c) autumn (n = 92). The solid lines are linear regression lines. (Cao et al., 2010)

Nevertheless the results also exposed the connection between PCI and size is non-linear and intricate which can only explain 60% of PCI occurrence. Another observation showed the PCI is negatively influenced by grass and positively influenced by shrubs and trees. The negative upshot of the grass cover was due to its adverse state of growth ensuing in immense areas of bare soil. It was also concluded that the compactness of the park has positive effect on PCI. The park characteristics (size, land use and shape) and the non-linear appearance of park vegetation and shape index (PVSI) may help improve cooling loads. (Cao et al. 2010).

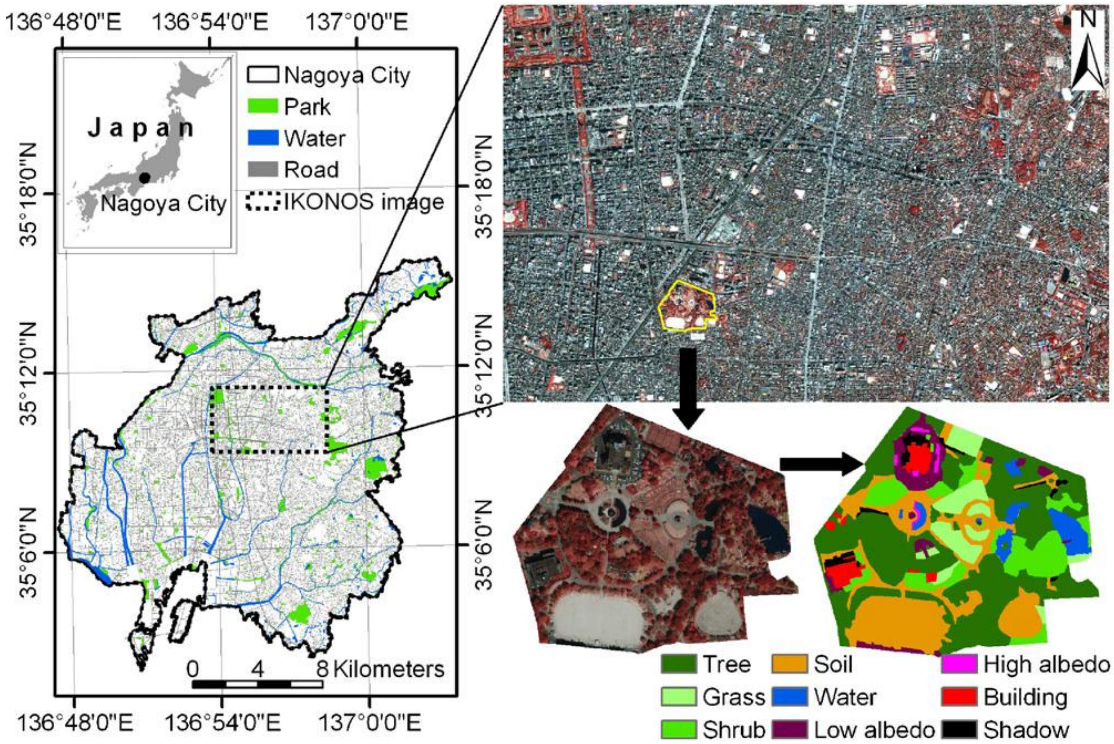

Fig. 2.5 Location of Nagoya in Japan and the IKONOS image. The IKONOS image is displayed by false color with RGB composition of band 4 (near infrared), band 3 (red) and band 2 (green). The parks areas were extracted and then manually classified into 9 land-use types of tree, grass, shrub, soil, water, low albedo surface, high albedo surface and shadow. Here shows an example of Tsurumai Park with park size of 22.7 ha. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.) (Stabler, Martin, and Brazel, 2005)

2.4 Vegetation in Microclimates

Looking at the study Cited in Dimoudi and Nikolopoulou (2002) the main aim for the project is to extend basic limitations that explain the microclimate and environmental presentation of diverse urban surfaces. The Centre for Renewable Energy Sources within the team's role was to illustrate basic factors for the use of vegetation in the urban context, which can ultimately be used without regard of site-explicit features for different climatic backgrounds and urban surfaces. Of specific significance is the result of vegetation on microclimate: thermal effects, as well as on solar and daylight admission. These affect the microclimate of the present open spaces as well as the energy use of the neighboring buildings for heating, cooling and lighting, through shading, the sum of evaporation and plant transpiration, etc. Simple parametric studies were analyzed, to distinguish the thermal impression of vegetation in the urban environment. The results demonstrated it is obvious that vegetation can significantly encroach on the thermal microclimate in the urban areas. This influences the area within the park as well as the neighboring area, mostly at the leeward side of the green area. The functioning region of the park is plotted against the decrease of air temperature that is observed within the park and at the street at the leeward side of it, from the use of vegetation. This temperature difference is acquired from the ensuing air temperature in the region under concern and the ambient air that was applied as an input to the model, i.e. 25 °C. It is obvious that the area of vegetation greatly affects air temperature within the park area. More exclusively, the results appear to imply that an average temperature drop can be likely for every 100 m2 of vegetation added. More prominently, though, this consequence continues outside the limits of the park, at the leeward side of it, reducing air temperature at the adjacent street. This is also established by the parametric runs implemented with a 45° wind direction where the utmost temperature decline of all was found at the leeward region of the park. The results evidently reveal the valuable effects of vegetation to the microclimate of the street at the leeward side of the park. Therefore, the higher the ratio of green to built area the greater the air temperature decrease is to be likely in the area.

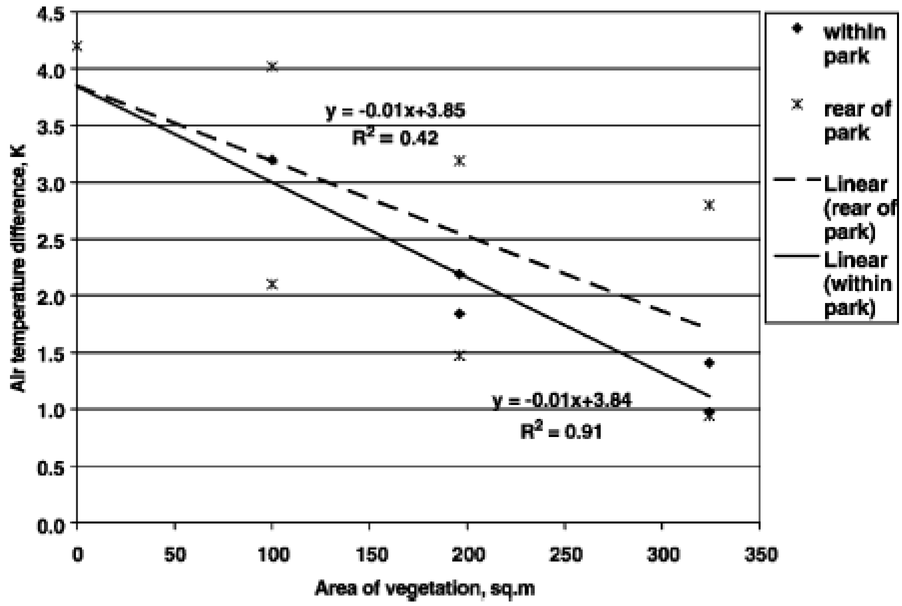

Fig. 2.6 Reduction of air temperature within the park and at the leeward side of it, from the use of vegetation. (Dimoudi and Nikolopoulou ,2002)

In another study, cited in Spangenberg et al. (2008) the paper investigates the microclimates of a park, a square and a street canyon. They were measured on a summer day in the city centre of São Paulo, Brazil. The effect of adding shading trees to the street canyon was simulated for the same day using the numerical model ENVI-met. The simulations showed that incorporating street trees in the urban canyon had a limited cooling effect on the air temperature (up to 1. 1°C), but led to a significant cooling of the street surface (up to 12°C) as well as a great reduction of the mean radiant temperature at pedestrian height (up to 24°C). Applying the simulation software ENVI-met to the climate of Thessaloniki, Greece, found small temperature decrease for tree-aligned streets (less than 1°C), but up to 20°C lower surface temperatures and more than 40°C lower mean radiant temperatures. In the hot dry climate of Ghardaia, Algeria, found that shading trees could improve the thermal comfort in streets considerably. In another simulation study of different greening scenarios using ENVI-met in Rio de Janeiro, Brazil, found that an increased amount of urban green (tree cover of 30% of the ground and 100% green roofs) could nearly re-create the comfortable conditions of a natural forest. This showed preliminary results from an ongoing study of the benefits of vegetation in the city of São Paulo, Brazil.

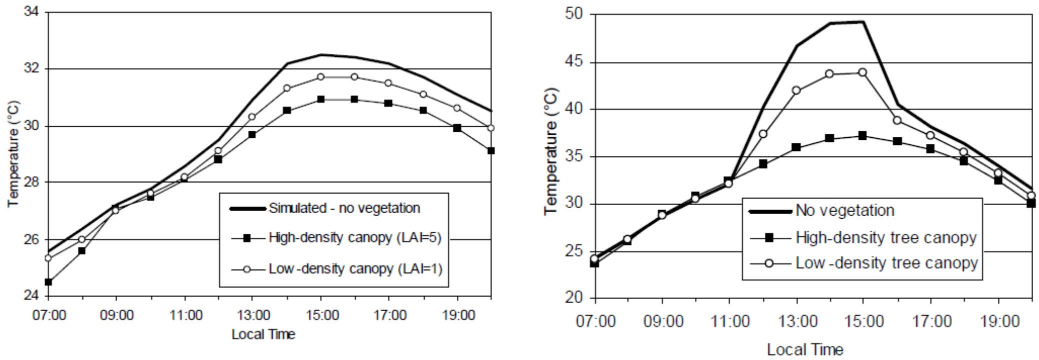

Fig. 2.7. a) Simulated air temperature for the street canyon without trees, with trees having a high-density canopy and with trees having a low-density canopy. b) Simulated street surface temperature for treeless street, street with high-density tree canopies and street with low-density tree canopies. (Spangenberg et al., 2008)

Sailor (1996) simulations were performed to investigate the effect of urban vegetation augmentation on cooling of urban spaces. Three dimensional simulations were done for 6 hypothetical cities at different latitudes and having various weather conditions. The hypothetical cities were made of arrays of 19x18 grid cells. The outer edges were considered as suburban land, while the core of the grid was divided to residential, urban, industrial, residential and commercial areas. As for the vegetation augmentation, it was assumed that vegetation can be greatly increased in residential areas, although realistically there might be some obstacles for that to be achieved (for example program costs, maintenance problems, and so forth). All residential cells had an increased vegetation factor by 0.15, while no vegetation augmentation was done on any of the other uses' cells. The average vegetation augmentation level throughout the whole city grid was less than 0.065. To check how the effects vary with the season, the simulations were carried out for a day from every month of the year. Degrees of temperature of heating and cooling days were calculated for each simulation done as an index of the effect of urban vegetation. The results of the simulation show that the temperature decreased by planting urban vegetation thus cooling the area. Adding vegetation by fraction of less than 0.065 showed an approximate decrease of 3–5% in summertime cooling loads in places with low-moderate humidity. This was caused by the indirect cooling impacts of vegetation. The energy saved by the shading of buildings was not included. In wintertime, the energy savings caused by vegetation was lower than in summertime, further proving the vast benefits of vegetation in urban environments.

Table 3. Total degree days (°C-day) before and after vegetation augmentation for different levels of surface moisture availability offsets

Annual degree days before and after vegetation augmentation	Moisture offset value		
	+ 0.00	+ 0.05	+ 0.15
CDD (before)	538.8	496.2	437.0
CDD (after)	529.1	489.2	431.2
% change in CDD	− 1.8	− 1.4	− 1.3
HDD (before)	996.8	1020.7	1055.6
HDD (after)	1002.6	1024.2	1060.6
% change in HDD	0.6	0.3	0.5

Fig 2.8 Total degree days (°C-day) before and after vegetation augmentation for different levels of surface moisture availability offsets. (Sailor, 1996)

Wong et al. (2007) took into account the effect of a green cluster on microclimate and energy savings on the campus of the National University of Singapore. Based on satellite images, the NUS campus was divided into 3 zones of dense greenery, medium greenery and sparse greenery; in each of the zones temperature and relative humidity were measured. Then ENVI-met software was used to simulate three different scenarios beside the current condition of these green areas. The first scenario replaced dense trees by buildings, second scenario they removed all greenery, and the last scenario they replaced grass with more trees. The ENVI-met simulation exposed higher air temperature with no cooling effect on surrounding buildings when greenery was removed.
What's more when they replaced the dense forest with buildings, higher temperatures resulted compared to the current condition. Alternatively, adding more greenery to the current condition increased the cooling effect significantly.

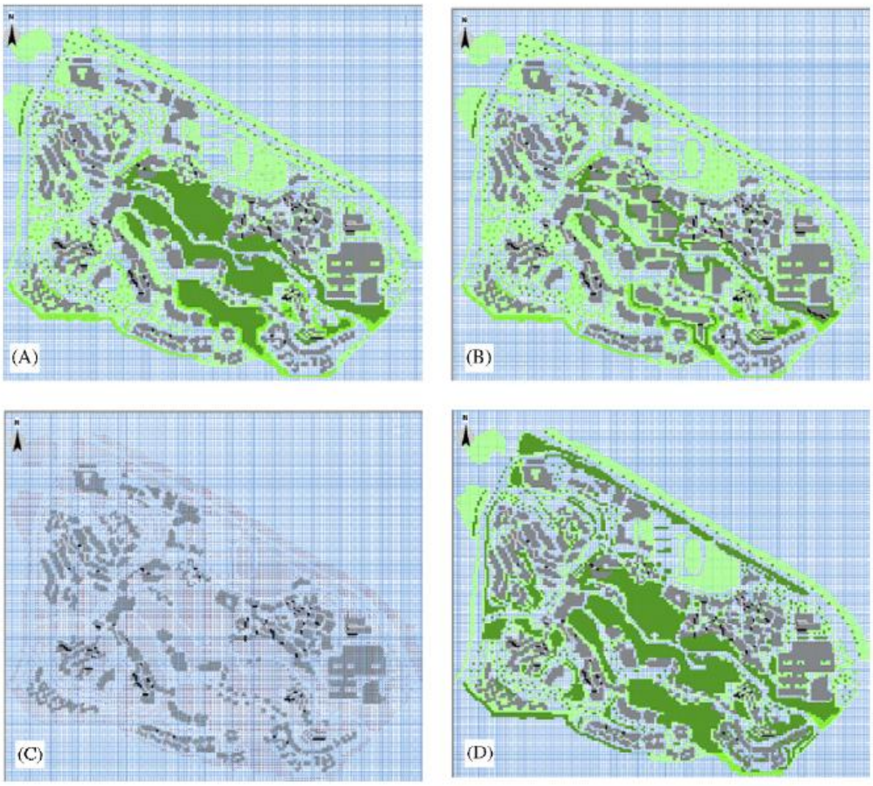

Fig 2.8 Four scenarios in ENVI-MET simulations (A) current condition; (B) replacing dense trees with buildings; (C) removing all greenery; and (D) adding more trees. (Wong et al., 2007)

2.5 Vegetation and Users

Many studies have immerged indicating that contact with nature impact people's health and psychological well-being both directly and in moderation. Gunnarsson and Ohrstrom (2007) conducted a questionnaire study in urban residential surroundings with elevated exposure to road-traffic noise to test the same theory. Out of 500 people, 367 lived in homes with contact to a quiet region and 133 had no contact with a quiet region. The present paper inspects and proves that apparent availability to close proximity of greenery affects a variety of aspects of the inhabitant's well-being. Among these aspects are the reduction of long-term noise annoyances and frequency of stress-related psychosocial symptoms, and hereby increasing the use of spaces outdoors giving an overall benefit from nature.

Table 2
Questionnaire responses on demographic and personal variables and measured sound levels ($L_{Aeq, 24h}$, dB) at the exposed side of the dwelling for two green-area groups ("poorer" and "better" availability to green areas) in two noise conditions ("noise/quiet" and "noise/noise")

Variables	Noise/quiet condition			Noise/noise condition		
	Poorer green-area access	Better green-area access	p^a	Poorer green-area access	Better green-area access	p^a
Women (%)	55	56	0.80	58	63	0.62
Civil status (%)			0.65			0.72
Married or de facto	52	46		50	56	
Living alone	35	34		43	33	
Divorced	10	17		4	11	
Widow/widower	3	3		3	0	
Age group (%)			0.42			0.18
<30	24	18		30	18	
31–40	26	22		35	27	
41–50	18	19		14	13	
51–60	16	23		12	30	
61–70	10	9		5	7	
>71	6	9		4	7	
Occupation (%)			0.68			0.11
Employed	68	61		67	63	
Studying	12	12		20	8	
Unemployed	4	4		1	7	
Retired	14	19		9	17	
Other	2	4		3	7	
Time of residency (mean, S.D.)	8.6 (9.5)	10.4 (11.9)	0.11	7.0 (8.9)	9.4 (11.4)	0.22
Longstanding illness (%yes)	30	32	0.73	27	40	0.18
Sensitivity to noise (%rather/very sensitive)	36	32	0.09	44	43	0.25
Sound levels in $L_{Aeq, 24h}$ (dB) (mean, S.D.)	62.2 (1.9)	62.2 (1.6)	0.97	61.8 (2.0)	62.0 (1.9)	0.78

Values within parenthesis are standard deviations (S.D.).
[a] Differences between the two green-area groups were determined by χ^2-tests of percentage and by t-tests on mean scale values.

Fig 2.9 Questionnaire responses on demographic and personal variables and measured sound levels at the exposed side of the dwellings of two green areas. (Gunnarsson and Ohrstrom, 2007)

Picot (2004) reports on a study on the evolutionary impact of vegetation in a newly built square in Milan designed by Gregotti. The aim of the work is to evaluate the impact of vegetation growth on users' comfort. The methodology adopted involves: sets of field measures (air and radiant temperature, wind velocity and relative humidity); a simplified thermal comfort evaluation with the energy budget method COMFA; and a scenario for the vegetation growth. When trees become adult we can observe different phenomena. The shading effect under an aged tree canopy clearly shows a reduction of the absorbed radiation by users, generating an energy budget very close to comfort (under 50 W/m2) even with a high air temperature. In the case of points exposed to direct sunlight all day long, tree growth reveals two phenomena of the global radiation absorbed by a user: (1) reduction, by the tree screening effect, of absorption of the diffuse solar global radiation, and (2) increase, by the elevation of the objects viewed in the sky hemisphere, in absorption of the terrestrial radiation. The residential vegetation features in urban landscapes play an important role as indicators regarding urban biodiversity potential and cultural changing. They also include ornamental resources in the context to landscape appreciation for human environment.

Therefore, Acara, Acarb and Eroglub (2005) provide quantitative information on the distribution of plant species in urban residential landscape areas of Trabzon city (Turkey). In a total of 218 sampled areas, 274 plants species belonging to 70 families were surveyed with respect to residential use types of the city. The study results showed that among the species recorded in five residential type (traditional housing, detached housing, villa, apartment blocks and sites, mass housing for employees), non-native frequency of a total species are much and dominantly represent residential landscape structure. Additionally, the species richness and diversity is positively related to new urban development areas. But, it was clearly determined that the vegetation structure has tended to ornamental purposes different from traditional residential gardens including fruit and other benefiting species. Consequently, it can be evidence that the residential vegetation is ornamental plant resources to urban biodiversity and that the distribution of the species in urban landscapes follows necessities of city and human quality.

2.6 Urban heat island and Vegetation

Memon, Leung and Chunho (2007) state that Urban Heat Island (UHI) is thought to be one of the chief dilemmas of the 21st century posed to human beings as a product of urbanization and industrialization of human civilization. The large quantity of heat produced from urban forms, as they use and give out solar radiations, are the key reasons of UHI. The crisis worsens in cities with large population and widespread economic bustle. Due to the gravity of the crisis, immense research attempt has been devoted and a large variety of literature is offered for the topic. From their research, it was concluded that the heat given out by the urban forms plays the most important role. It was also deduced that the future research should be concentrated on design and planning parameters for decreasing the effects of urban heat island and in due course living in an improved environment.

In another study an attempt to assess the positive effects of vegetation with a multi-scale approach both from an urban and a building scale. However what is relevant to this studying was the results from monitoring the urban heat island in four areas of New York City. The results showed an average of 2 degree Celsius difference of temperatures between the most and the least vegetated areas, caused by the replacement of vegetation with man-made building materials (Susca, Gaffin & Dell’Osso 2011).

Mirzaei and Haghighat (2010) show Urban Heat Island (UHI) has major bearings on the buildings energy consumption and outdoor air quality

(OAQ). With latest growth in computational tools, simulation methods are now being used to study UHI. They exhibit an evaluation of the techniques used to study UHI and discuss the capabilities and confines of each approach to the investigation of UHI improvement and foretell. Handling of significant parameters including dormant, rational, storage, and heat caused by humans on top of presenting way of treating radiation, effect of trees and pond, and boundary state to simulate UHI. Finally, the use of vegetation integration approach as a future prospect is discussed.

Another study centers on using remote sensing for relative evaluation of exterior urban heat island (UHI) in 18 mega cities in both temperate and tropical climate zones. Spatial patterns of UHIs for each city were observed over its daily cycles and cyclic alterations. To expose connections of UHIs with exterior properties, UHI patterns were explored in relationship with urban vegetation covers and surface energy fluxes consequential from high-resolution Landsat data. This study supplies a widespread picture on the UHI phenomena with relation to vegetation covers in the Asian region. (Hung et al.2005)

Jung, Kardevan and Tokei (2004) focused their study on the feature of diverse non-natural materials and vegetation in Hungary. Artificial surfaces manipulate the urban climate mainly in summer. That result can play a vital part in shaping urban heat islands that establish the growing of vegetation as well. In order to recognize this characteristic better, vegetation in the centre of the city was investigated, however concentrating on a less build-up area. Planted areas in cities in relation to their environmental potential are not equal to areas out of the city in rustic surroundings. Pavements and paths can impinge on the inside environment of the canopy. This examination was an effort in uncovering and recognizing the effect of vegetation on the micro scales environmental setbacks among man-made conditions. Not only big cities need to monitor their urban climates but smaller cities with less build-up surfaces as well.

Weng, Lu and Schubring (2003) profess remote sensing of urban heat islands (UHIs) has conventionally used the Normalized Difference Vegetation Index (NDVI) as the sign of vegetation profusion to approximate the land surface temperature (LST) and vegetation relationship. Their study explores the validity of vegetation derived from a combination model as a different sign of vegetation profusion. This is established on assessment of a Landsat Enhanced Thematic Mapper Plus (ETM+) image of Indianapolis City, USA. The transformed ETM+ image was placed into three images (green vegetation, dry soil, and shade). Results revealed that LST contained a slightly stronger negative connection with the vegetation fraction than with NDVI for all land cover types across the spatial resolution (30 to 960 m). The spatial variability of texture in LST was positively connected with those in NDVI and in vegetation fraction.

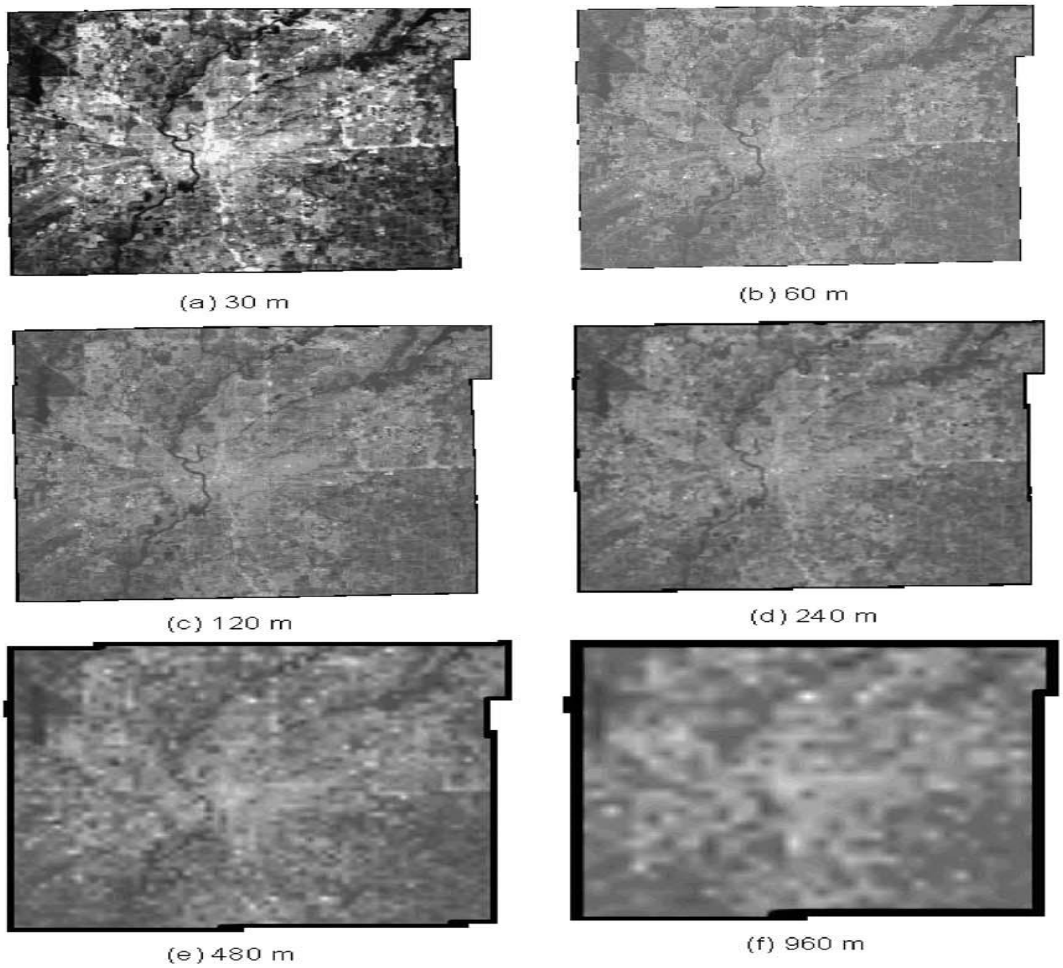

Fig. 2.10. Illustration of aggregated images of St. Present are an original image of 30-m resolution (a), and aggregated images at the resolutions of 60 (b), 120 (c), 240 (d), 480 (e), and 960 m (f). (Weng, Lu and Schubring, 2003)

Cao et al. (2010) state artificial urban land uses such as commercial and residential buildings, roads, and parking lots covered by impermeable surfaces can add to the creation of urban heat islands (UHIs), whereas vegetation such as trees, grass, and shrubs can alleviate UHIs. Bearing in mind the growing area of parking lots with little vegetation in Nagoya, Japan, this study assessed the prospective for UHI improvement of greening parking lots in Nagoya. The associations between land surface temperature (LST) and land use/land cover (LULC) in different seasons were studied using a number of random but related variable linear regression models. This research can help recognize the roles of vegetation cover and offer realistic strategies for planning parking lots and further urban areas to mitigate UHIs.

Urban heat islands (UHIs) phenomenon of changed temperatures that transpire in urban areas when compared to their rural surroundings. UHIs influence human well-being, human health and the city as an ecological position. UHIs can be measured with ground measurements of air temperatures or with remotely sensed land surface temperatures. Further, within these approaches, different indicators for measuring the UHIs are used. A relationship between the land surface and air temperatures was established. However, the results for the single indicators showed that the absolute values of the detected UHI in Leipzig depend on the selected indicator and the data set used. The main conclusion for future studies on UHIs is to use several UHI indicators in parallel to acknowledge the uncertainty of measuring the UHI using a single indicator and either ground measurements or remote sensing (Schwarz et al. 2012).

Wong and Yu (2005) Green areas in cities have been considered as potential measure in mitigating the urban heat island (UHI) effect. In this paper, a mobile survey using vehicles equipped with observation tubes and placed around the country was conducted to explore both the severity of UHI effect and cooling impacts of green areas at macro-level in Singapore.

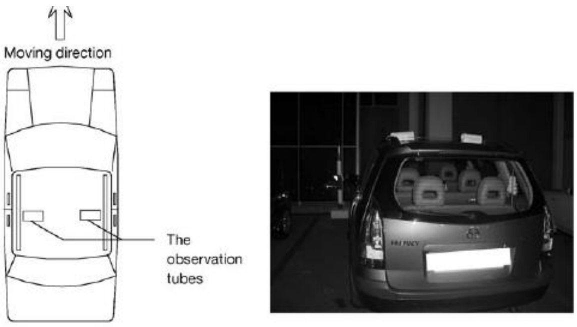

Fig. 2. Mobile surveys conducted by vehicles equipped with observation tubes.

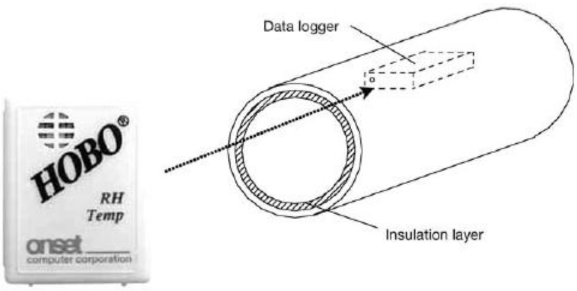

Fig. 3. The observation tube.

Fig. 2.11 Image of the vehicles equipped with observation tubes used to conduct the surveys. (Wong and Yu, 2005)

Island wide temperature distribution was mapped relying on data derived from the mobile survey. This study has indicated a strong correlation between the decrease of temperature and the appearance of large green areas in the city. Although there is no distinct borderline between ‘urban’ and ‘rural’ areas in Singapore, maximum temperature difference of 4.01 degree C was observed.

Table 2
The results of Tukey–Kramer test

Comparison	Absolute difference	Std. error of difference	Critical range	Results
West and Central regions	0.632857	0.09249415	0.357	Means are different
West and North regions	0.623824	0.11870494	0.4582	Means are different
West and Northeast regions	0.168333	0.13191974	0.5092	Means are not different
West and East regions	0.53625	0.10850113	0.4188	Means are different
Central and North regions	1.256681	0.10179238	0.3929	Means are different
Central and Northeast regions	0.80119	0.11693436	0.4514	Means are different
Central and East regions	0.096607	0.08968456	0.3462	Means are not different
North and Northeast regions	0.45549	0.13859776	0.535	Means are not different
North and East regions	1.160074	0.11652904	0.4498	Means are different
Northeast and East regions	0.704583	0.12996527	0.5017	Means are different

Level of significance = 0.05.

Fig. 2.12 Table of the results conducted in Turkey. (Wong and Yu, 2005)

2.7 Research Importance

Even though a lot of cities around the world have been taking on the issue of urban heat island for a long time, this phenomenon is considered to be new in some of the developing countries around the world. Most of the cities located in the Middle East have been developing at an incredible rate during the last decade; among these cities Dubai stands out in terms of development, in a short period of time. From the year 2000 to 2012 remarkable development has spread throughout Dubai. During this 12 year period, larger amount of built up areas has been added to the urban areas as compared to the vegetation present. Due to these harsh climatic issues to acquire the least amount of heat gains into a building would need to follow certain design considerations.

Dubai is known for its iconic buildings and surrounding desert sands which are main factors in the increase of tourism in the area. However, in this hot climate many urban structures and expansion of tall constructions with little thought on environmental aspects to both the occupiers of the buildings themselves as well as the demolition of the country's native landscape are just a few root causes to the problem. The Urban heat Island effect is one clear example of such constructional effects and impacts these structures has to surroundings. Increase in outdoor spaces and vegetation is a main aspect in reducing such effects as seen from the literature review. By focusing on implementing vegetation in the urban environment, as well as, integrating an environmental concept derived from the natural surroundings of Dubai, for example the sand dunes, the research topic is attempting to link back to the aesthetics of the historic scenery of the country and at the same time test the benefits to the thermal environment.

Chapter 3: Methodology

3.1 Methodology

The previous chapter looked at various criteria that impact and contributes to UHI effects and the advantages and disadvantages of vegetation in mitigating the problem. It is important to realize that many factors contribute to the domino effect resulting in UHI. Each of the factors interacts with each other and causes these phenomena to take place. Urban structures being built reflects heat, impacts circulation of wind in turn impacting the heat transfer and so forth. The implementation of vegetation helps reduce those impacts as seen in the reviewed literature. Testing different aspects nature within urban areas has had a variety of research methodologies that can be used.

3.2 Introduction

This section aims at presenting literature review of different research methodologies relevant to the topic discussed. A few that can be investigated are, field investigations, experimentation, observational methods, computer simulations, case studies, numerical methods and many others. Here we will look at the different methods used to help concur the methodology used to test the project topic, as well as emphasize the need for integrating nature with ecology.

3.2.1 Field Measurements

Field observation methods can yield good results as a product of using Landsat imagery to compare and analyze natural contours and vegetation satellite pictures. But the researcher will not have control of the conditions as in a lab since it is based on natural data that is constantly changing on a daily basis. In addition, the setup and usage of the apparatus is costly to acquire. It is important to realize that in most cases field research can be more effective when it comes to having all conditions known where in lab experiments most of the times a few conditions might be left out and might change results of the analysis significantly increasing chances of error. Other variable unknowns could be the chances of having faulty equipment which the researcher is unaware of increasing error. Finally, Field observations are good research methods when the objectives and the goals are unclear, are for analyzing vast areas and have more than one variable to explore at the same time. It can help collect data from real existing situations that are what naturally is happening at a specific duration of time. The drawbacks of this method are minimal.

Stablera, Martina and Brazelb (2005) used a Field Investigation with data collection and observation that looks at spatial arrangements of land use, plant density, and microclimate in the Phoenix metropolitan area, a mixed desert, agricultural, and urban area. Because Phoenix is in the Sonora Desert and facing arid climatic conditions, it was hypothesized that (1) urban land uses are connected to spatial changes in temperature and atmospheric moisture; (2) urban plant concentration impacted by land uses (3) the most important plant concentrations and coupled concealed heat fluxes would be the factor influencing microclimates; and (4) changes in spatial configuration of land use and plant concentration over time would control urban microclimates. To test these hypotheses, spatial configurations of microclimate settings, land use, and urban plant concentration resulting from a normalized differential vegetation index (NDVI) were considered along four intervals consisting of major arterial roadways within the Phoenix metropolitan area. These intervals pass through a wide variety of urban and suburban land uses and incorporated both the urban core and urban fringe. In addition, two of four historic intervals were studied to assess how land use adaptation over time affected NDVI and microclimate. Plant cover concentration along each interval was evaluated using a NDVI map produced from a Land sat thematic mapper. The results of the data show in summary, that urban plant cover is a transformer of microclimate in Phoenix, a desert metropolis, and validates the use of greenery to reduce urban heating. Confirmation was acquired from this study of a dissimilar mix of microclimates correlated to socioeconomic land use, as well as, an urban to rural decrease in temp. Not related with an increased concentration of urban forest cover at the urban border as is more characteristic of urban areas in such climates. Though urban forest cover can alter microclimate, these results did not validate the hypothesis that urban forest cover and latent heat fluxes are the governing cause of microclimate in the Phoenix area. Instead, this study suggests that urban microclimates are more a product of vegetation concentrations intermingling with other factors of the urban basics such as parking lots and buildings. More thorough assessments of differences in land surface cover category and their outcome on urban heating is required, and approaches of urban greening to lessen UHI consequences in desert cities also need to be compensated against the necessity to conserve water resources.

While Suscaa, Gaffin and Dell’Ossoa (2011) used filed investigation to explain the details firstly, to illustrate the positive end products of vegetation through observing both the air temperature in New York City and the surface temperature of three roofing systems. Secondly, in order to supply information about environmentally suitable options, three types of roofs were assessed: a black, a high-reflective and a comprehensive green roof. In this study the effect of surface albedo on radioactive forcing (RF) is introduced, examining the surface temperatures of the three roofs, calculating the difference of heat fluxes through them and the effects on life span of the roofs' building materials. The results reveal that the surface albedo positively impacts the environmental estimation of the white roof. The high surface albedo decreases both the energy use and the effect on climate change. The surface albedo also constantly shapes the environmental load concerning the green roof, even though most of the evaded bearings are due to the decrease in energy use. In this case, not only is the surface albedo important, the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere and the raise in the thermal opposition of the roof also play vital parts. This study provides constructive information for decision and policy producers for environmentally desirable preferences in urban planning, improvement policies for building energy demand. In addition, this research sights the positive effects that vegetation has on the urban heat island effects. Definitely, green roofs are competent at diminishing the use of energy for cooling and heating and as an upshot, the pinnacle of energy use. Moreover, the assessment of the product of the surface albedo on RF is not only an augmentation and an improvement for the environmental evaluation tools, but it presents helpful environmental facts. Undeniably, as shown in this research, the difference in surface albedo greatly shapes the bearing of the roofing systems. The urban-extensive adaptation of the black roofs into white or green roofs can have encouraging effects not only on micro-scale, but also on urban scale. In fact, the decline of the energy use for cooling minimizes the prospect of summer blackouts. The urban-extensive adaptation of black roofs into green roofs can present improved storm-water management, enhancement of air quality and boost in urban biodiversity.

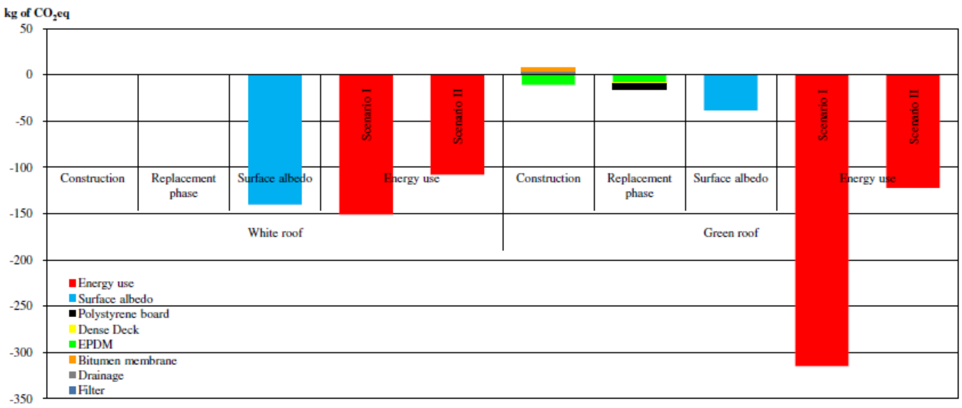

Fig. 3.1 Avoided impact on climate change; white and the green roofs compared to the black roof. (Suscaa, Gaffin and Dell'Ossoa, 2011)

Amiria et al. (2009) used Field investigation in their study. Hasty alterations of land use and land cover (LULC) in urban areas have become a main environmental anxiety due to environmental consequences, such as the cutback of green spaces and growth of urban heat islands (UHI). Observational and organizational strategies are essential to resolve this crisis successfully. One fast growing example of a city is The Tabriz metropolitan area in Iran, as a case study selected for this research. Multi-temporal images acquired by Landsat sensors on 3 specific chosen dates and years, were used to extract LULC classes and land surface temperature (LST) and then examined. The temperature vegetation index (TVX) space was constructed in order to study the temporal variability of thermal data and vegetation cover. The product showed that most changes due to urbanization were observable as the pixels migrated from the low temperature-dense vegetation condition to the high temperature-sparse vegetation condition. The results showed that, if applied over relatively long periods, the adopted methodology might be applied to detect and monitor urban expansion and to trace the changes in biophysical parameters such as NDVI and LST due to LULC changes.

Nowaka et al. (1996) used both field and data collection for detecting urban covers from aerial photographs. By over laying the photo samples from the US and Europe vegetation cover can be seen and discussed. The extent of line crossing tree heads divided by the total extent of the line generates percent tree cover. Standard errors can be predictable from the difference of the total length of cut off on dissimilar lines. Better precision is attained from more short lines than fewer long lines. Attention must be employed when using parallel lines in areas with sporadic features (e.g. central parallel roads or street trees) because the lines may match to the sporadic feature and lead to imprecise assessment of means and underestimates of variance. The results showed higher percentage of tree coverage in cities within forested areas and shaded green space than those located in grasslands, which still have more cover and canopy green space than cities situated in deserts. The only distinction in city land-use allocation amid likely natural vegetation varieties was that grassland cities had more ‘other land’ (cultivation, orchards, and miscellaneous) than forest cities. Percent sunshade green space was negatively associated with total green space in grassland and desert areas. Percent total green space was negatively associated with population mass for all cities combined, despite of probable natural vegetation variety. The prime urban land use is residential and the maximum percent total green space is on vacant lands. Average tree cover and shade green space for residential, institutional, park, and vacant land uses was peak in the forest type, while park and vacant land had the highest percent tree cover in forest cities. On the other hand, percent tree cover was maximum on park and residential lands in grassland and desert cities. Residential land for all probable natural vegetation types had maximum percent canopy green space.

3.2.2 Case studies, Surveys and Historical Data

Case Studies are good examples of existing samples for researchers benefit. They can observe the reality of a projects outcomes and results affecting the existing conditions. The advantages of such an approach is that it provides a breadth of knowledge for researchers to refer to as a source of collected, correlated, and compared data from the scientific community. They synthesize the findings of a certain topic and present them in a less detailed account than the original research, but still pertain to the important findings respectively. The cons of this method are that human beings might tend to be subjective or perhaps even biased sometimes with their evaluation. This can be ruled out by having enough numbers of subjects to develop a trend to give accurate results. It is also possible that some occupants' preferences are neglected or failed to be looked at fully if the sample chosen was not representative of the real life occupants. Again those can be eliminated by using standardized areas and carefully selecting the sample study.

Picot (2004) reports on a study on the evolutionary impact of vegetation in a newly built square in Milan designed by Gregotti. The aim of the work is to evaluate the impact of vegetation growth on users' comfort. The methodology adopted involves: sets of field measures (air and radiant temperature, wind velocity and relative humidity); a simplified thermal comfort evaluation with the energy budget method COMFA; and a scenario for the vegetation growth. When trees become adult we can observe different phenomena. The shading effect under an aged tree canopy clearly shows a reduction of the absorbed radiation by users, generating an energy budget very close to comfort (under 50 W/m2) even with a high air temperature. In the case of points exposed to direct sunlight all day long, tree growth reveals two phenomena of the global radiation absorbed by a user: (1) reduction, by the tree screening effect, of absorption of the diffuse solar global radiation, and (2) increase, by the elevation of the objects viewed in the sky hemisphere, in absorption of the terrestrial radiation.

Acara, Acarb and Eroglub (2005) used caste studies to look at the residential vegetation features in urban landscapes play an important role as indicators regarding urban biodiversity potential and cultural changing. They also include ornamental resources in the context to landscape appreciation for human environment. Therefore, this paper provides quantitative information on the distribution of plant species in urban residential landscape areas of Trabzon city (Turkey). In a total of 218 sampled areas, 274 plants species belonging to 70 families were surveyed with respect to residential use types of the city. The study results showed that among the species recorded in five residential type (traditional housing, detached housing, villa, apartment blocks and sites, mass housing for employees), non-native frequency of a total species are much and dominantly represent residential landscape structure. Additionally, the species richness and diversity is positively related to new urban development areas. But, it was clearly determined that the vegetation structure has tended to ornamental purposes different from traditional residential gardens including fruit and other benefiting species. Consequently, it can be evidence that the residential vegetation is ornamental plant resources to urban biodiversity and that the distribution of the species in urban landscapes follows necessities of city and human quality.

3.2.3 Computer Simulation

Simulation and computer modeling methods are very useful and provide a great deal of indication to what objects and forms could function before the real system is built and operational. It is a clever system where specific environmental and weather data are inputted into the system and thus creating the realistic environment to model and simulate your required calculations for the structures and designs. It is an economical way of research as it does not necessitate actual completed and constructed forms to perform simulations. It is flexible as the researcher has the capability of altering any surroundings, setting, environment and design characteristics of the system whenever essential, and data can be examined easily if needed. Moreover, simulation methods present a general depiction of actual situations where different circumstances (environmental, technical, energy-saving related) can be examined all together. For natural systems it was shown that simulation is used mostly to test shading effects and solar exposure of the areas. The disadvantages of this method is that usually the simulation takes a lot of time especially if they're large project models in 3D with various conditions being tested, which is usually the case. Even importing models from different software's is possible still it complicates the surface normal's in some software’s and causes the results to take triple the time to simulate which is time consuming to re-check or model from scratch. Sometimes 3D simulations are compromised for 2D ones which might be inaccurate. Also, there are chances of human error if information is inputted incorrectly or missed out. The chief constraint with computer simulations is their verification of accuracy; this verification procedure differs based on the focus of the study as well as variable of interest. Moreover, simulation models entail definite level of simplifications in contrast to their real life state in an urban area. For example, in the case of ENVI-met the model is shaped on a stringent rectangular grid; while in reality most city grids are free of containments. The other limitation is that it is unworkable to incorporate all the variables in one model; again in case of ENVI-met it is impossible to apply materials to the buildings or consider sources of anthropogenic heat in the urban areas.

In Dimoudi and Nikolopoulou (2002) the main aim of the project was a replication of the characteristics of microclimate and different urban feels with regards to the environment, in order to change its physical appearance in the urban sense, in order to establish the possible impact on the use of energy, environmental characteristics, and the prospect of renewable energy. Firstly, parametric studies of the thermal force of the urban environment’s vegetation were done in areas of air temperature decrease. This was carried out by simulations of the composition of the vegetation and its result on a park, using CFD analysis. From this, the interactions between “vegetation, climate and urban environment” were known. Secondly, a CFD analysis of thermal impression and reduction of air temperature within a wide urban environment was carried out. The next step was two different parametric analysis; firstly using the "mathematical plant: transpiration model", at the direct level of the plant;” and then using CFD analysis, plus PHOENICS program, at urban mass level. The first case provided an idea of the behavior of plants within varied restrictions, and an understanding of the manner of interactions between climate, vegetation and the urban environment. The second study, using the climatic features of Athens, explored the reduction of air temperature in the urban environment. The last case study, using the sky view factor of Athens, was an exploration of non-vegetation and variations in sizes of vegetation (height-width ratio) and their impacts based on two sites. Clearly, the simulations herein prove the easier access to results of real life situations that can be tested. In any other cases gathering and testing all these results by field observations would definitely have taken longer periods of times, not days but months to gather differing time periods shading effects or CFD movements and so on. The same goes for case studies that would need to be examined after implementing the project rather than before it is.

Spangenberg et al. (2008) talks about how vegetation is a key design constituent in improving urban microclimate and outside thermal comfort in urban spaces in hot climates. Firstly it reviewed the use of vegetation in hot climates: its main benefits in hot climates, which are reducing solar radiation and drop in air temperature due to shading and evapo-transpiration. While a single tree or small number of trees provides limited cooling, a large area of trees, such as parks, can provide significant cooling. This paper applied ENVI-met software to the climatic situation of Thessaloniki, Greece for tree-aligned streets and found that the result was lower mean radiant temperatures were lowered by over 40°C and surface temperatures by up to 20°C. With another simulation ("tree cover of 30% of the ground and 100% green roofs") using ENVI-met, this time in Rio de Janeiro, Brazil, it was found that a situation akin to the climate of a natural forest was produced. The same was the report from ongoing studies of the vegetation of another Brazilian city, São Paulo. The results in addition, gave an insight in to the different microclimatic conditions of the three sites, at daylight saving times, as follows: shading and evapo-transpiration mean lower temperature and increase in humidity. Trees in isolation and even rows of trees have little significance on reduction of air temperatures, and hardly any significance in improving air temperatures in urban heat islands. On the other hand, vegetating façades and roofs provide lower cooling loads. Thus, city-wide upgrade to large-scale greenery is necessary for greener environment and alleviation of São Paulo's urban heat island, backed up by modification of building codes and residents' initiatives. Future research includes studies of locally-grown urban trees, height of trees, kinds of tree canopies, "leaf area index (LAI) and leaf area density (LAD)". This research paper exemplifies excellent research using simulation due to the amount of simulations that were capable of being preformed for just one case study investigating different methods. This makes vast amounts of results available for the researcher to analyze helping the results to be more reliable and accurate.

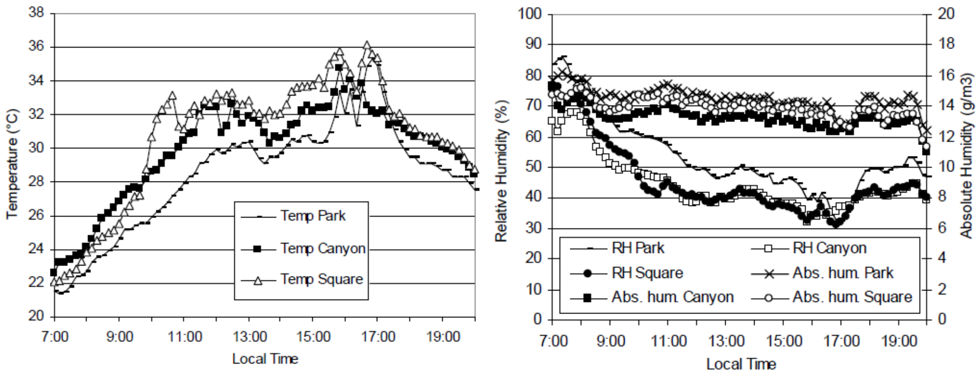

Fig. 3.2 A) Results of air temperature distribution for the park, the open square and the canyon. B) Results of relative and absolute humidity distribution for the park, the open square and the canyon. (Spangenberg et al.,2008)

Sailor (1996) investigated the potential regional climate impact of urban vegetation augmentation through simulations. Hypothetical cities were simulated at various latitudes and varying climatic conditions. For each of these, a base case scenario and an amplification of vegetation were done. For each case, 12 simulations were conducted to show the annual effect of urban vegetation, that is one per month. Three-dimensional simulations were used as models to show the relationship between rural and urban areas, including the daily effect of the emerging heat island. First the base cases were simulated, and then tested with the application of improved vegetation cover, under varying climates and latitudes. It was shown that the higher the latitude, the lower the CDD, while the lower the latitude the higher the HDD, owing to augmented vegetation. The model cities did not represent the topography, land-water boundaries and land-use share. Thus, increased humidity means potential decrease in evapo-transpiration, which then means the tendency of augmented vegetation to affect CDD or HDD is limited. In this regard, it was shown that atmospheric humidity only played a small part in influencing vegetation on “the degree day calculations”. The base case of Memphis, U.S.A., an increase in vegetation caused the HDD to increase by 0. 5%. Increasing surface moisture intensely changed the CDD and HDD values, while the changes in vegetation augmentation only led to a constant change in degree days. Summertime benefits from urban vegetation augmentation by reduced cooling loads, however in the winter, demand in heat energy is increased. One such example is in climates where gas-powered furnaces and air conditioners are used to meet heating and cooling loads, respectively. Here, urban vegetation could save electricity costs. For any given value of atmospheric humidity, urban vegetation only provides mild improvement in the cooling of the region. The simulation results showed that HDD increased by 0.5% while CDD reduced by 2.0%. Simulations investigating the role of soil moisture in the regional air-temperature effects of urban vegetation indicated that both CDD and HDD were sensitive to soil moisture availability and overall helping prove the researchers points.

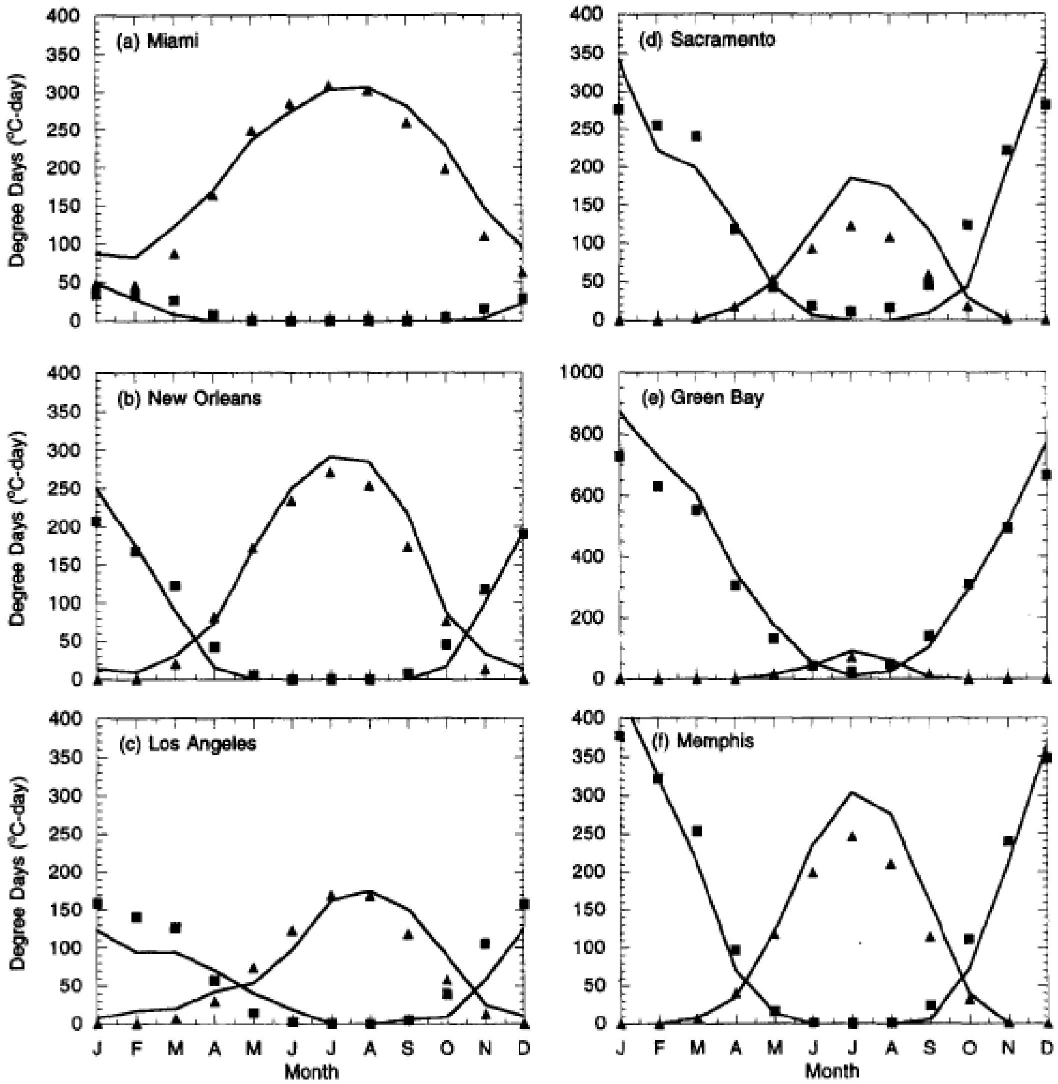

Fig. 3.3 Modeled (symbols) and actual (lines) monthly degree day totals for each city used in the simulations (triangles are CDD and squares are HDD). (Sailor, 1996)

3.3 Best Research Method

After the careful investigation of all the papers dealing with the different types of research methodologies and taking a look at their advantages and disadvantages, the 'best practice' research method for this topic was establish to be simulation. It is important to note here that the methods examined in this paper target different aspects of natural systems impacts. Field observations methods target the natural systems efficiency, simulation methods target shading effects as well as solar exposure around the sites and case studies target perceptions of different environmental conditions having existed and implemented. The 'good' research was preferred based on whether the aims of the researchers objectives were met through the research method, the significance of the data collected at the end of the research and the pros and cons of each method. All the research methods were helpful in their own ways however; the overall advantages and disadvantages weighed the decision to which method was the best. The simulation method was chosen because all its disadvantages can be eliminated by proper model design and careful data selection, as well as the greater advantages and reliability to required end results. The probable errors and reliability that could occur in both field observations and case study methods make them less dependable. Also, the information simulations add on to the overall data and results is the most important of all.

In conclusion, when analyzing the simulation research papers it is hard to pin-point which of the chosen papers best uses simulation as a research method since they all perform calculations on the basis of the specific boundaries that they want to test. Some have more factors to consider, others do more simulations for many scenarios, therefore they all perform to a certain degree in reliable results. Also, each paper uses a different simulation tool, from ENVI-met to Phoenix to Brevent and so forth which all perform in slightly similar manners but can either be stronger for certain areas like CFD results, urban contexts or radiance etc. In general, using more than one simulation tool can be beneficial in having more accurate results but sometimes staying with a fixed simulation tool can be easier to analyze and compare. All in all, simulation in general for this topic matter seems to be the better choice in gather data and evaluating it to prove the researchers hypothesis and objective theory or goals. Thus this proving that no matter which paper used simulation the results were at most successful and a clear choice for research method. Therefore the selected methodology for this paper is computer simulation. It covers the limitations of the research conditions and gives a good alternative to such limitations of obtaining lab equipment or undergoing surveys and so forth. The size of the research to be conducted to cover the topic being investigated is one of the most important limitations that possibly would make it difficult to undergo using other methodologies in such a short amount of time. Simulation allows for flexibility to model out several scenarios that do not exist in reality so far on the chosen site. The simulation method gives a higher level of control over both environmental and building related factors that may affect the results. Other limitations needed to be considered and swaying the decision for this methodology is the time frame of the research as the research will be investigating several vegetation sand dune mounds in all seasons throughout the year. Any other method would be costly and require longer amounts of time to cover all data collection.

3.4 Software selection

The research is proposed to measure micro-climatic differences in temperature. A good number of the software available is capable of simulating individual buildings and indoor spaces such as Integrated Environmental Solutions IES or Autodesk Ecotect Analysis, etc. The requirement of this research topic is for simulating outdoor urban spaces. Some of the software that can do that includes ENVI-met, CityCAD, CITY SHADOWS. CityCAD does not have the capability to model temperature and wind variations. City shadows is used to simulate solar exposure. ENVI-met was developed by Michael Bruse and has the ability to calculate wind flows, temperature variations, humidity, radiation fluxes, and much more. It is based on the fundamentals of fluid dynamics and thus has the ability to calculate flow around and between buildings and heat exchange between various surfaces (Bruse, 2003).

Computational Fluid Dynamics (CFD) software's are the most common software used for testing urban heat island effect. These software's resolve all the equations connected to the fluid within the urban areas and therefore they are able of approximating the allocation of urban heat island and its association to the geometry and configuration of urban environments. Conversely, CFD simulation is not very practical in examining the microclimatic effects of vegetation in the urban areas. This type of study necessitates software's that center on surface-plant-air relations within the urban areas. Due to the difficulty of these exchanges, there are few kinds of software that are competent of evaluating microclimatic effects of vegetation in the urban environments.

ENVI-met is one of these software's which is a three dimensional microclimatic model designed to analyze the interactions among surfaces, plants and air in the urban environments. This software is developed based on the fundamental laws of fluid dynamics and thermodynamics; it is proficient at simulating the flow around and between buildings, exchange processes of 65 heat and vapor at the ground surface and at walls, turbulence, exchange at vegetation and vegetation parameters, bioclimatology and particle dispersion (Envi-met,2004). In their assessment of the consequence of greenery on the microclimate of a campus, Wong and Jusuf (2008) used computer simulation with ENVI-met software. At first they performed GIS based surveys to measure the existing greenery as well as potential rooftop greenery on the campus. Then they used ENVI-met software in order to calculate the temperatures on the campus. Also Yu and Wong (2006) used ENVI-met simulations in order to study the cooling effects of urban greenery on reduction of UHI. Clearly the software allows the addition of vegetation and soil profiles and change of geographic locations. Since the study of research topic is more urban based and deals mainly with vegetation than clearly ENVI-met is the best software to use as it is free to acquire and deals with urban contexts. The secondary software used is Autodesk Ecotect Analysis for the weather tool plug-ins to obtain climatic data related to the country and site.

3.5 Location of Study and General Information

Dubai is one of the seven emirates of the United Arab Emirates (UAE). It is located south of the Persian Gulf on the Arabian Peninsula and has the largest population with the second-largest land territory by area of all the emirates, after Abu Dhabi. Today, Dubai has emerged as a global city and a business hub. Although Dubai's economy was built on the oil industry, currently the emirate's model of business, similar to that of Western countries, drives its economy, with the effect that its main revenues are now from tourism, real estate, and financial services. Dubai has recently attracted world attention through many innovative large construction projects and sports events. (Wikipedia, 2010)

Dubai lies directly within the Arabian Desert. However, the topography of Dubai is significantly different from that of the southern portion of the UAE in that much of Dubai's landscape is highlighted by sandy desert patterns, while gravel deserts dominate much of the southern region of the country. The sand consists mostly of crushed shell and coral and is fine, clean and white. East of the city, the salt-crusted coastal plains, known as sabkha, give way to a north-south running line of dunes. Farther east, the dunes grow larger and are tinged red with iron oxide. (Wikipedia, 2010)

3.6 Site selection

The area selected for this investigation is located in Dubai, Mirdif Al Shorooq community, a new district of Dubai. Figure 3.1 show the location of the site in Mirdif, Dubai.

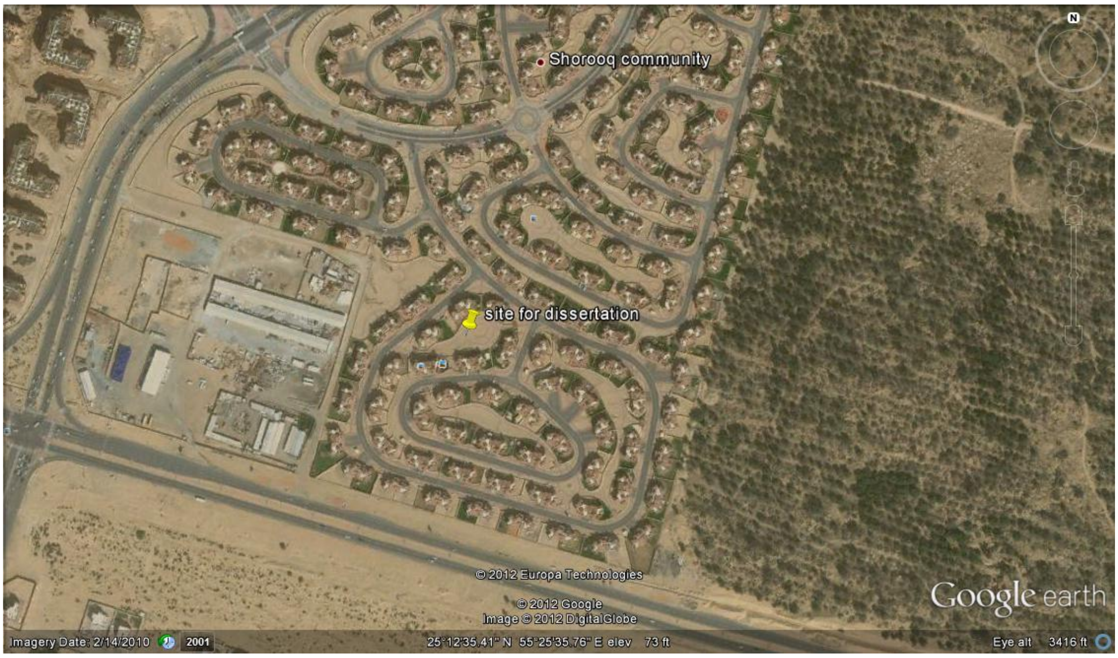

Figure 3.4 Pined point showing site location taken from Google earth.

The buildings in the area are all residential low rise ranging between 2 to 3 storey structures. There are pavements, sandy and asphalted roads. There are open spaces throughout, that have still not been fully vegetated, which would be perfect to use as a base example for the topic investigation. Since this area is a newly developed residential area and has potential for future landscape improvement this research topic will be beneficial to find out what would be the best configurations that can be implemented. Children can play in public vegetated spaces and the houses can benefit from the greenery and reduction in temperatures. Since most of the area is surrounding desert landscapes temperature plays a major role in effecting the human comfort in especially a residential housing district such as the chosen site.

3.7 Climate of Dubai

Dubai has a hot arid climate. Summers in Dubai are extremely hot, windy and dry, with an average high around 40 °C (104 °F) and overnight lows around 30 °C (86 °F). Most days are sunny throughout the year. Winters are cool and short with an average high of 23 °C (73 °F) and overnight lows of 14 °C (57 °F). Precipitation, however, has been increasing in the last few decades with accumulated rain reaching 150 mm (5.91 in) per year. Due to these harsh climatic issues to gain least heat gains into a building would need to follow certain design considerations, Dubai has a rich collection of buildings and structures of various architectural styles.

3.8 Aims and Objectives

The aim of this research is to find out the thermal effects by the application of vegetation in the shape of sand dune mounds in Dubai, UAE. This will be done using the software ENVI-met. Realistic urban structures will be modeled along with landscaped vegetation in form of sand dune like mounds then various simulations will be performed. The results of this study will include figures which show the temperature effects resulting from the integration of these features in the urban landscape and its effects on the shading of the surrounding buildings. Based on the output of these tests, certain optimal strategies would be selected for application in real conditions.

As observed in the scientific papers above demonstrate how vegetation can significantly encroach on the thermal microclimate in the urban areas and reveal valuable effects to the microclimate. Therefore, due to increase in energy consumption in the construction industry by 40%, it is essential to look for ways to save energy (Abu Dhabi Urban Planning Council, 2010). It is safe to assume that adding vegetation around the urban environment will contribute to energy savings, based on previous studies conducted. In this paper a focus on implementing vegetation in the urban environment, as well as, integrating an environmental concept derived from nature will be the basis of discussion. This research will however go a step farther and quantify the energy savings of a Vegetation integrating them into sand dune mound forms to alleviate the desired results of shading effects for the urban environments in Dubai.

Based on the aim and objectives of this research, expected outcomes are as follow:

1. Recognition of the most effective type and configuration of sand dune formation green fabric in urban areas of Dubai

2. Recognition of the best density of vegetation that produces reduction of heat in urban areas of Dubai

3. Recognition of best strategies of applying sand dune shaped vegetation for existing areas

Chapter 4: Computer Model Set-up and Validation

4.1 Software Validation

In order to validate the ENVI-met software with the chosen site, thermal images of Dubai were acquired from the Dubai municipality GIS department to test the accuracy of the results. Figure 4.1 shows an aerial image of Mirdif area taken from Google earth and Figure 4.3 is the actual site at Al Shorooq community in Mirdif, UAE that was chosen for study. Figure 4.2 and 4.4 show the same site in infrared images which was taken during mid February 2011.

Figure 4.1 Aerial image of Mirdif area, UAE.

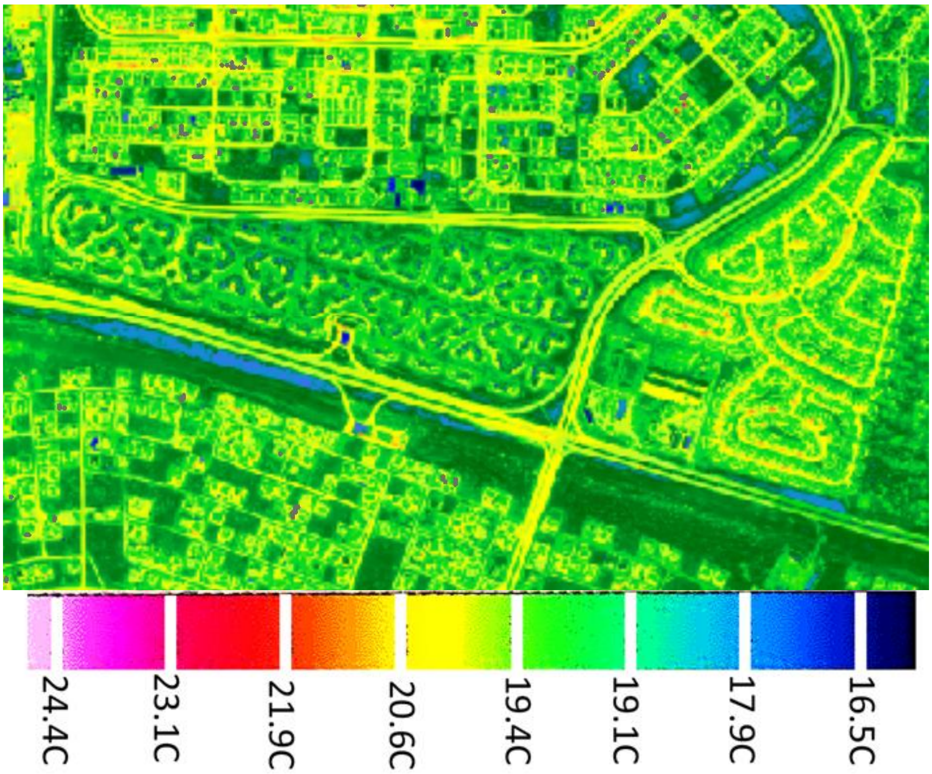

Figure 4.2 Thermal Image of Mirdif, UAE.

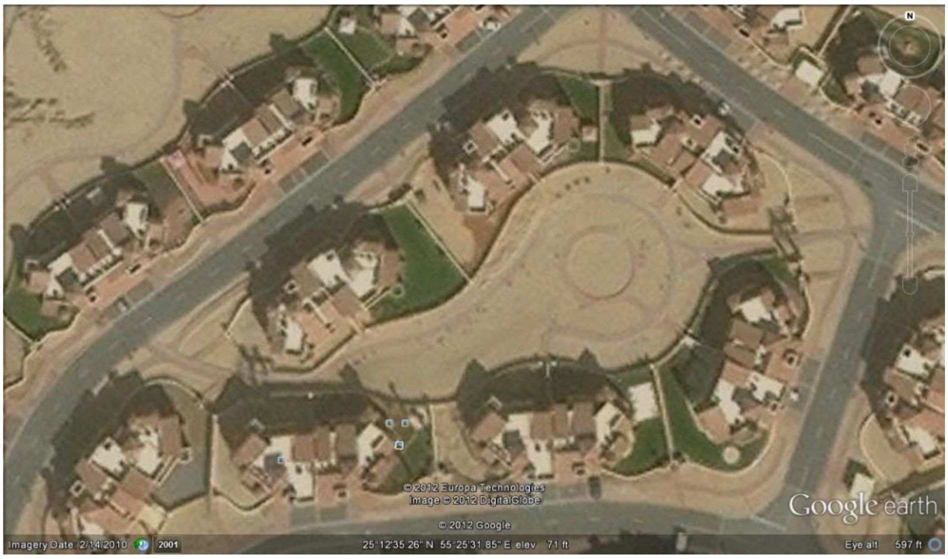

Figure 4.3 Aerial image of chosen site in AlShorooq community Mirdif, UAE.

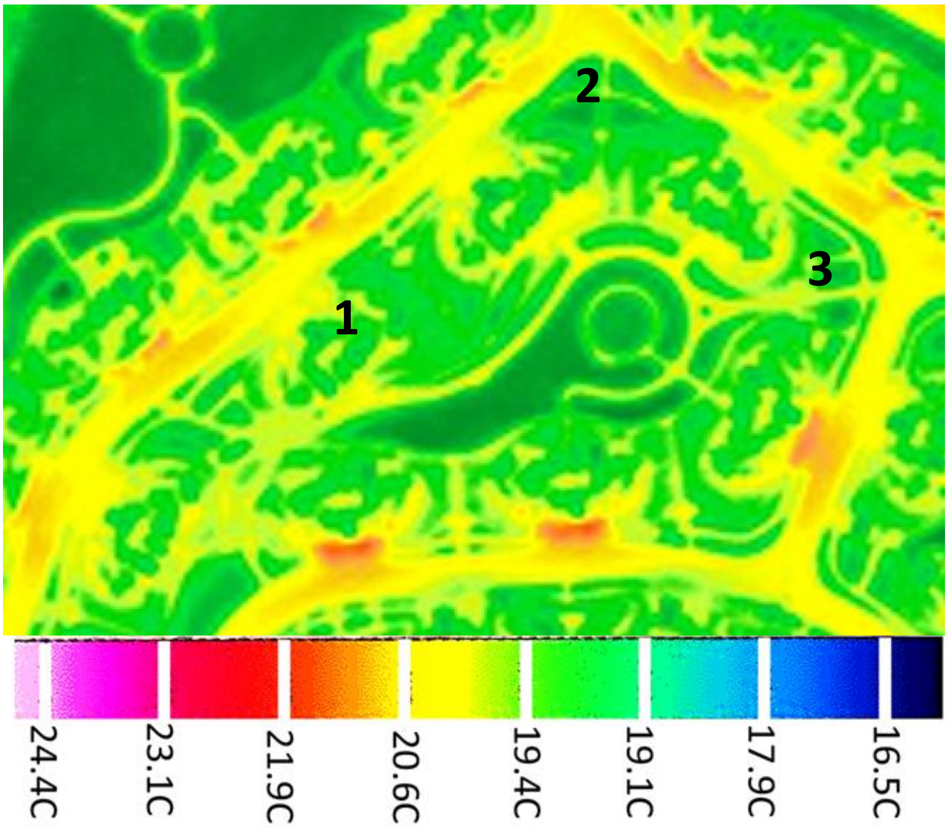

Figure 4.4 Thermal image of Site chosen for study in Al Shorooq community, Mirdif, UAE

It is important to note that the aerial thermal surveying of Dubai was done during winter due to the existence of excessive humidity and dust in the ambient air during the summer times. On the other hand, since the software is incapable of simulating very large areas at proper resolution, only a portion of the urban block (shown in Figure 4.1 and 4.2) was selected and modeled in ENVI-met; Figure 4.3 and 4.4 shows the site and its actual thermal image. After the site was modeled in ENVI-met, simulations were run during 15th of February 2011 (48 hours); to compare and test against the actual GIS thermal image in Figure 4.4. The initial inputs of climatic information used for this simulation are as follow:

1. Initial Temperature Atmosphere: 17.483 Degree Celsius (average temperature during mid February in Dubai)
2. Wind Speed in 10 m ab. Ground [m/s]: 4.16 m/s (average wind speed throughout the year)
3. Wind Direction (0:N..90:E..180:S..270:W..) : 315 or North West
4. Relative Humidity in 2m [%]: 61.917 % (average humidity during mid February in Dubai)

Feb. 15 2011 at 11:00

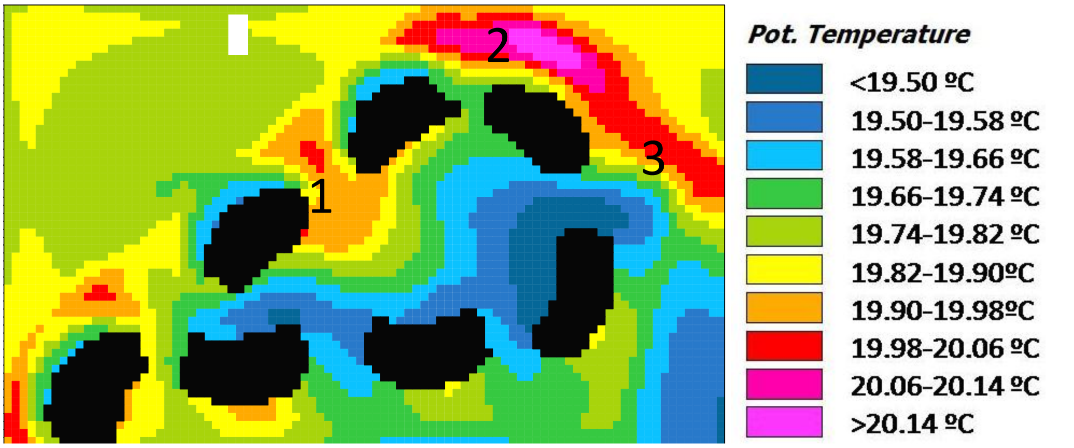

Figure 4.5a Simulated maps of surface temperature for the selected urban block from 11:00 -15:00 with three key points indicated.

Feb. 15 2011 at 12:00

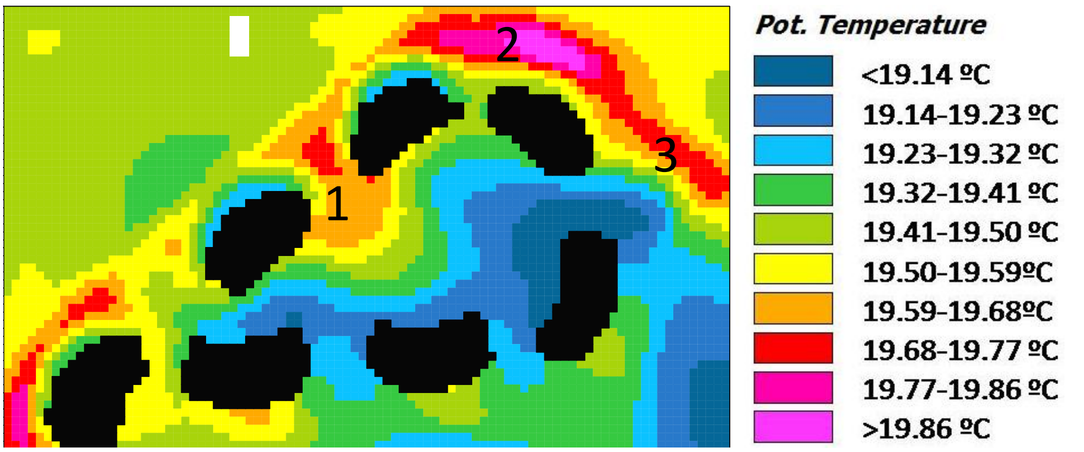

Figure 4.5b Simulated maps of surface temperature for the selected urban block from 11:00 -15:00 with three key points indicated.

Feb. 15 2011 at 13:00

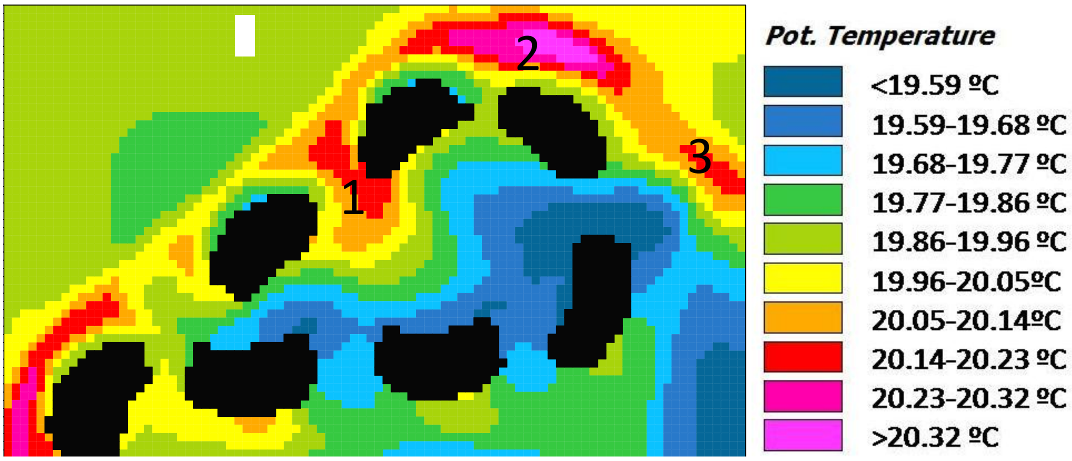

Figure 4.5c Simulated maps of surface temperature for the selected urban block from 11:00 -15:00 with three key points indicated.

When taking a quick comparison of these images with the actual GIS thermal image shown in Figure 4.4, it indicates that the pattern of temperature distribution of simulated images matches the actual image. For example the asphalted road shows high temperatures while sandy areas show cooler temperatures. Since the exact time of the actual thermal image is unknown (it is only known that the image was taken around noon) 3 spots have been selected and the exact temperatures of these spots have been compared against the temperatures of the actual image for each hour in Table 4.1. In order to measure the closeness of the simulated data to the actual data, the "difference in value" which is the difference between the real and simulated data has been calculated for each spot; a comparison of the difference in value for all hours indicates that during the hour 12:00, the difference is the lowest which means that this hour has the closest results to the real image. Also during hours 11:00 and 13:00 the results tend to be very close to the actual image and as the temperatures move away from these 3 hours the difference in value increases. Therefore it is very likely that the real image was taken around these three hours.

Table 4.1 Comparison of the simulated temperatures of 3 selected key points against the actual image temperatures from 11:00 to 13:00.

Time	Key point	Actual image temperature (^{0}C)	Simulated image temperature(^{0}C)	Difference in value
11:00	1	19.5	18.95	0.55
11:00	2	19.9	19.2	0.7
11:00	3	19.8	19.03	0.77
12:00	1	19.5	19.67	0.17
12:00	2	19.9	19.93	0.03
12:00	3	19.8	19.71	0.09
13:00	1	19.5	20.14	0.64
13:00	2	19.9	20.39	0.49
13:00	3	19.8	20.14	0.34

4.2 Model Validation

Before starting the actual simulations a verification run was performed to ensure the most appropriate scale required to acquire accurate results in a timely manner. All the simulations were run for a 48 hour period to insure that the simulation has reached steady state. The simulations were started at 1AM. The challenge of figuring out the appropriate grid size was overcome by setting up a group of simulations with varying grid sizes. The simulations were run to insure grid independence, i.e. that the results are not tainted by the size of the grid. Four grids with varying degrees of refinement were studied all shown in Figure 4.6. The model is drawn with each grid point representing 1m in reality making it a 1:1 scale. The second model is a 1:2 scale model; each grid point representing 2m in reality. The third model is a 1:3 scale model with every grid point representing 3 m in reality. Finally the last model was a 1:4 scale model with every grid point representing 4m in reality. All the simulated houses are 12m high. From the findings the finer grid in the 1:1 scale model gave higher resolution in the numerical temperature readings however the time it took for one simulation to be completed was approximately 2 weeks. The 1:2 scale model took half the time and the results were the closest in accuracy to the 1:1 scale model as seen in the comparison graph in figure 4.7 and table 4.2. Therefore, the simulation models were conducted in scale 1:2 for each season. Conversely, the scale model's boundary height (z-grid) was set at 20m when doing the grid scale tests.

August 15 2011 at 12:00 scale 1:1

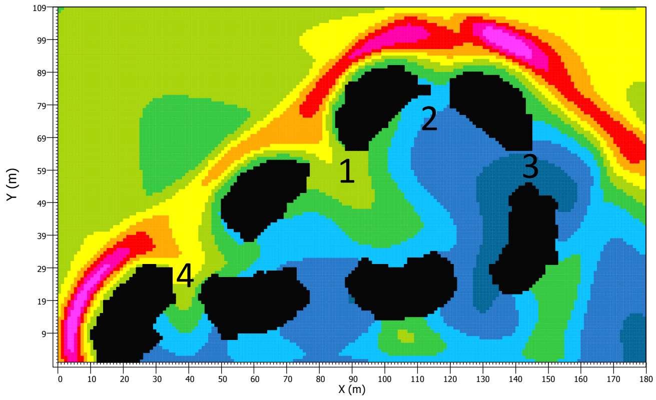

Figure 4.6a Grid Scale comparisons of Pot Temperature images for simulations taken in August at noon with four key points indicated.

August 15 2011 at 12:00 scale 1:2

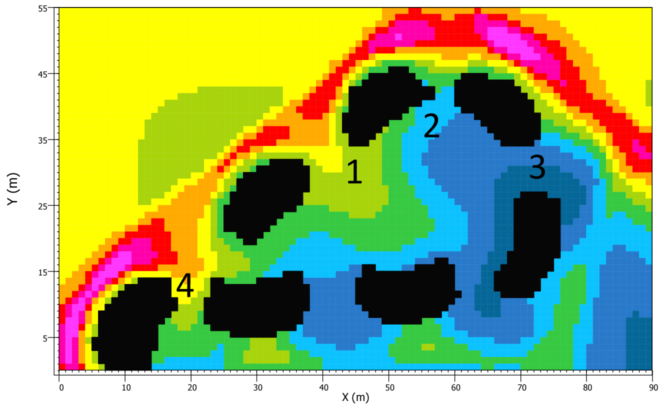

Figure 4.6b Grid Scale comparisons of Pot Temperature images for simulations taken in August at noon with four key points indicated.

August 15 2011 at 12:00 scale 1:3

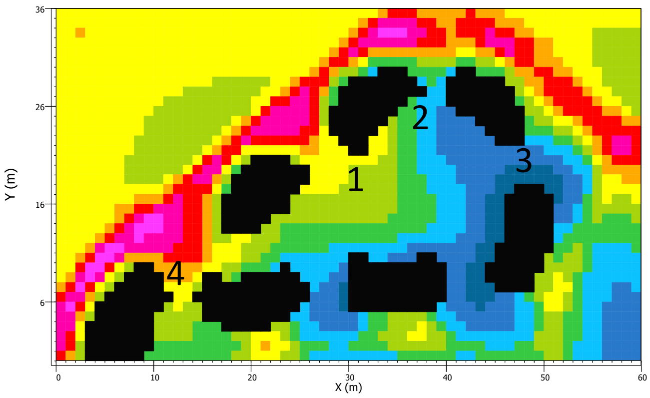

Figure 4.6c Grid Scale comparisons of Pot Temperature images for simulations taken in August at noon with four key points indicated.

August 15 2011 at 12:00 scale 1:4

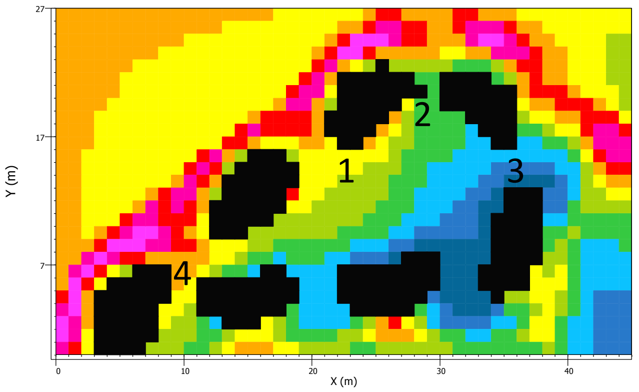

Figure 4.6d Grid Scale comparisons of Pot Temperature images for simulations taken in August at noon with four key points indicated.

Table 4.2 Grid scale comparison in Degree Celsius.

Grid scale	Key pt1	Key pt2	Key pt3	Key pt4
sc. 1:1	21.92	21.59	21.71	21.86
sc. 1:2	21.96	21.63	21.72	21.88
sc. 1:3	21.89	21.58	21.65	21.81
sc. 1:4	21.88	21.63	21.72	21.80

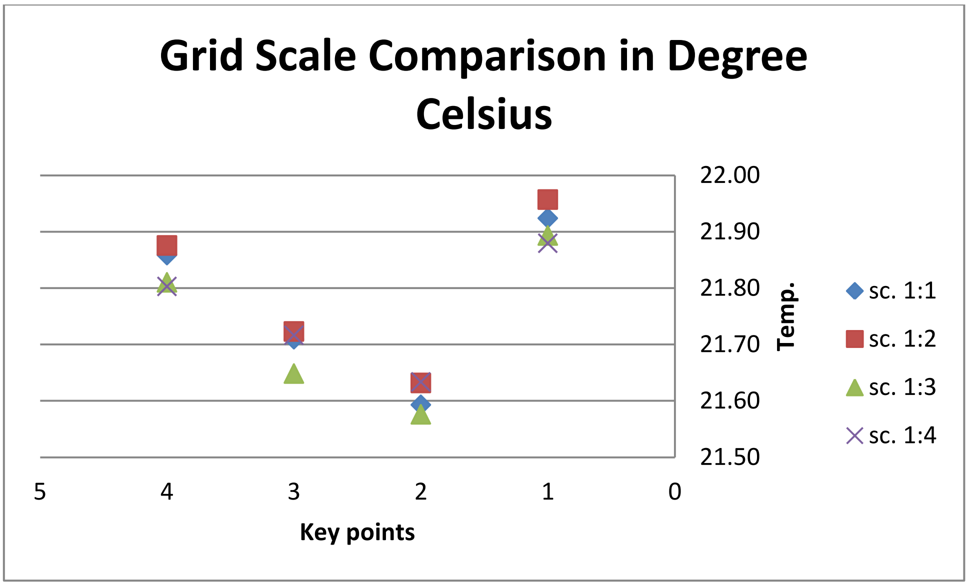

Figure 4.7 Graph of key points for each scale taken from figures 4.6 for Grid scale comparison in Degree Celsius.

Taking a step further, the main model area z-grid height was tested to see the effects on the model domain. The average temperature was taken for each at 12pm and compared. Having the z-grid height closer or further from the top of the buildings affects the results in ENVI-met as can be seen in the Table 4.3 and Figure 4.8. However, the results begin to level out and become the same once the height passes 20 meters. For purposes of accuracy z grid was taken at 25 meters.

Table 4.3 Z axis grid height comparisons in summer at 12pm for base case pavement.

Pavement Summer	12pm
z- grid Height	Avg. Temp. (°C)
15	26.6221
20	33.5381
25	33.5915

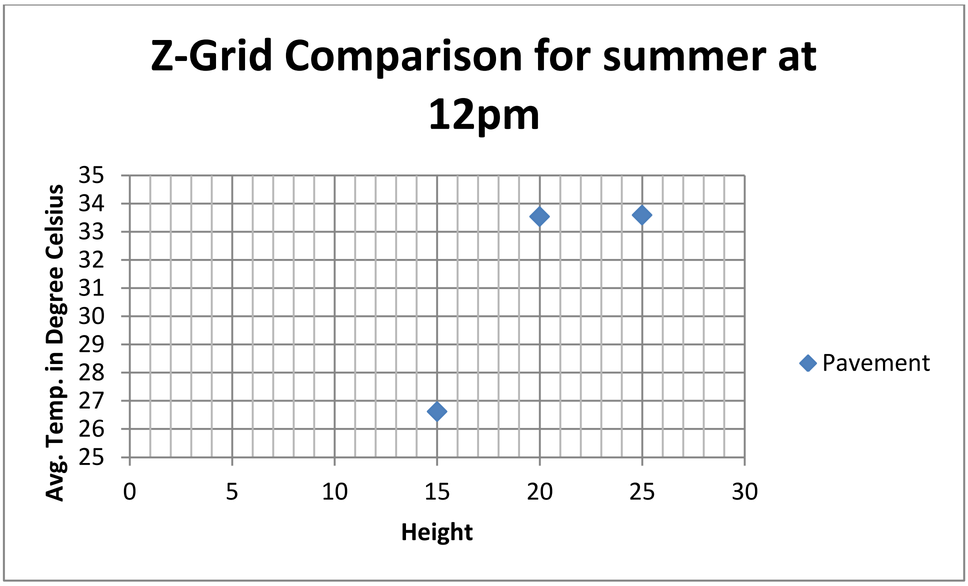

Figure 4.8 Graph showing points of average temperature difference in Degree Celsius at 12 pm in summer when changing z-axis grid heights

4.3 Simulation Methodology

Six different vegetation mound configurations will be simulated around the chosen site derived from the sand dune formation types discussed earlier in Chapter one. First the site will be modeled with just pavement, then a mixture or pavement with sand, and lastly just plain grass as base cases. After comes the sand dune shaped vegetation mounds as Barchan shaped, transverse shaped, parabolic shaped, longitudinal or Seif shaped, finally the Star shaped mounds. Each model will be simulated for each season of the year for 48hour duration: Summer, winter, autumn, spring, derived from ECOTEC weather tool. The number of variables that influence the occurrence and intensity of urban heat island effects are many and interconnected. Each on its own has an effect just as much as when interactive. In this research some of the variables are set as constants and acknowledged as effective factors supported by the literature reviews and previous research results presented earlier.

4.4 Variables

At the onset of the simulation process, it is important to define the fixed variables in the research and the independent variables which will be tested as well as dependant variables which change by changing the independent ones. Fixed variable are those that do not change throughout the simulations, which are the building material, height and time of day. The wind speed, site location and orientation, simulation duration, model scale, climate type, wind direction, are all constant variables throughout each simulation. The interdependent variables and the changeable ones are the temperature changes, relative humidity and dates for each different season and the vegetation shape and size. However the type of vegetation used are constant in its species but changed in shape to accommodate the different sand dune shapes. The types of profiles used are shown in Table 4.4.

Table 4.4 the vegetation and soil profile types used:

Symbol	Type	height	description
s	Road	-	Asphalt
p	pavement	-	concrete
sd	Soil	-	Sandy
g	grass	50cm	Average dense
m	maize	1.5 m	
h	hedge	2m	dense
ds	Tree	10m	Dense; distinct crown layer
sk	Tree	15m	Dense; distinct crown layer
dm	Tree	20m	Dense; distinct crown layer

The model parameters were set up according to the site specific data such as climatic information and building materials. Table 4.5 is a list of the different parameters required as software input for each simulation:

Table 4.5 Constant variables:

City Location:	Dubai, UAE. Lat: 25.25 Long 55.33 (as identified by the software)
Start Simulation at Time (HH:MM:SS):	=01:00:00
Total Simulation Time in Hours:	=48.00
Save Model State each min.	=60
Wind Speed in 10 m ab. Ground [m/s]	=4.16
Wind Direction(0:N,90:E,180:S,270:W)	=315 NW
Roughness Length z0 at Reference Point	=0.1
Specific Humidity in 2500 m [g Water/kg air]	=7

The Variables in Table 4.6 were taken from Ecotec Weather Tool as shown in Figures 4.9 and 4.10.

Table 4.6 The non- constant (changing) variables are:

Season	Start Simulation at Day (DD.MM.YYYY)	Initial Temperature Atmosphere [K]	Relative Humidity in 2m [%]
Summer Hottest Day	21.07.2011	310.933	62.500
Winter Coolest Day	15.01.2011	289.904	62.500
Autumn	03.11.2011	296.275	60.958
Spring	20.05.2011	305.188	49.208

One example for summer is shown below the rest can be found in Appendix B:

Daily Conditions:

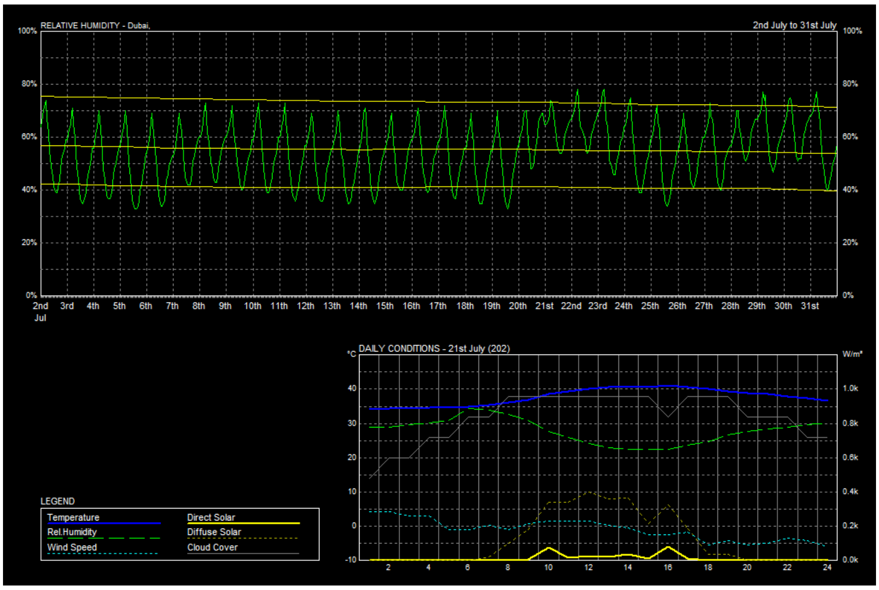

Figure 4.9 - Summer Hottest day 21st July temp. min: 34.2 max: 41 avg: 37.783 humidity min: 53 max: 74 avg 62.5

Wind Yearly Conditions:

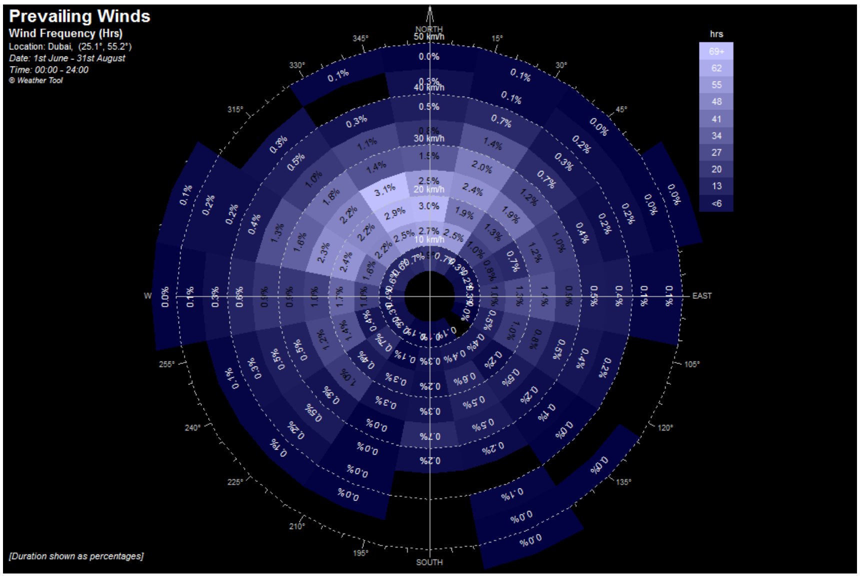

Figure 4.10 Wind speed and direction for Summer is mostly from the North west direction at and after taken the average wind speed it is at 15 km/h which converts to 4.16 m/s

4.5 Model Set-up

After verifying simulation runs explained in the first section of this chapter, the grid scale was selected to be 1:2. This scale was found to be the most suitable in order to approach as close as possible accurate readings of temperature calculations at the best time duration to complete simulations. The model is the representation of the original configuration on site that covers an area of 180m x 109m. The heights of the buildings were estimated at a 12 meter height considering the 3 storey residential structures. Figure 4.11 shows the Al Shorooq site chosen to perform the investigation on from which the model was traced into ENVI-met.

Figure 4.11 Site: Al Shorooq community Mirdif, Dubai

As to not complicate the input further, the site was taken at its orientation to north at 315 degrees, to limit the need to stagger grid points as best as possible, for both the buildings and streets. Figure 4.12 shows the Main ENVI-met function tab to start construction of models and simulations, etc.

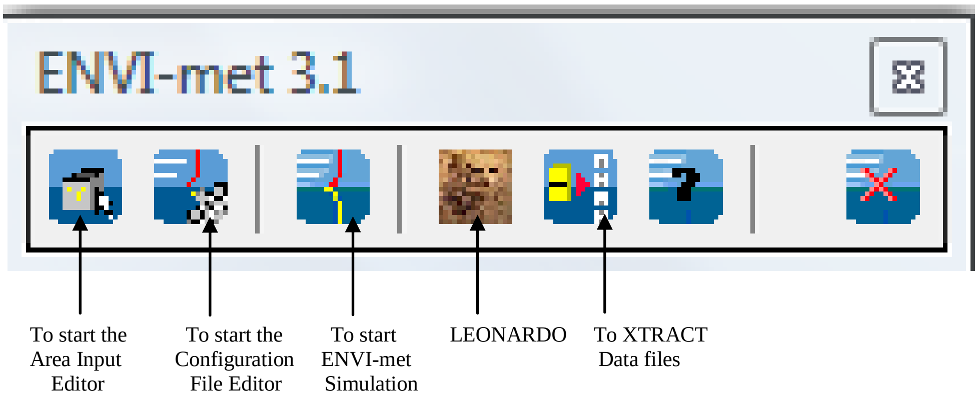

Figure 4.12 Main ENVI-met function tab

The Model domain was set up in the Area input file editor at 90x55x25 since the 1:2 scale was decided from the tests as the most appropriate scale. The size of the grid cells Dx and Dy were set at 2 representing every grid point as 2 meter for 1 meter distance, while Dz was kept at 1, meaning each grid point represents one meter vertically as shown in Figure 4.13.

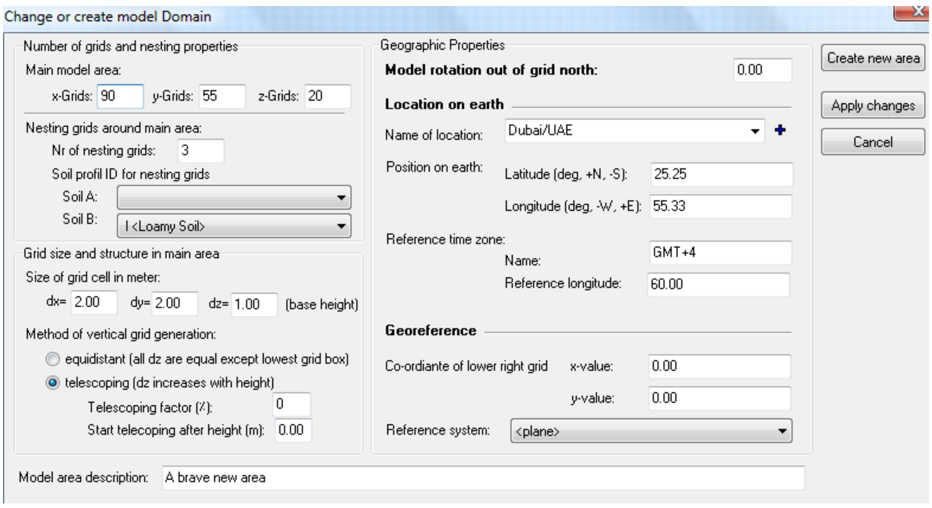

Figure 4.13 Example ENVI-met Area input file editor

The main model area had a total of 4950 grid points and 749 (15%) points are building units, which leaves 4201 (85%) points of open area. The model domain was configured for only the 7 houses in the center around the asphalted road, while the rest of the area was taken as sand. It should be noted that the number of building points refer to the fixed variable of building density which is constant in all tests. Besides the Input model, ENVI-met requires a configurations file for simulations runs. The variable values as discussed above in 4.3 are inputted here.

```
%------------------------------------------ENVI-met Configuration File V1.1
%------------------------------------------------------------------------
%MAIN-DATA --------------------------------
Name for Simulation (Text):                  =Example Simulation
Input file Model Area                        =[INPUT]\mirdifsite2parabolic.in
Filebase name for Output (Text):             =MySim
Output Directory:                            =[OUTPUT]\example
Start Simulation at Day (DD.MM.YYYY):        =21.07.2011
Start Simulation at Time (HH:MM:SS):         =01:00:00
Total Simulation Time in Hours:              =48.00
Save Model State each ? min                  =60
Wind Speed in 10 m ab. Ground [m/s]          =4.16
Wind Direction (0:N..90:E..180:S..270:W..)   =315
Roughness Length z0 at Reference Point       =0.1
Initial Temperature Atmosphere [K]           =310.933
Specific Humidity in 2500 m [g Water/kg air] =7
Relative Humidity in 2m [%]                  =62.500
Database Plants                              =Plants.dat

         ( End of Basic Data )
         ( Following: Optional data. The order of sections is free. )
         ( Missing Sections will keep default data. )

[NESTINGAREA]______________________________Settings for nesting
Use aver. solar input in nesting area (0:n,1:y) =1
Include Nesting Grids in Output (0:n,1:y)       =0
[TIMESTEPS] ___________________________________Dynamical Timesteps
Sun height for switching dt(0) -> dt(1)       =40
Sun height for switching dt(1) -> dt(2)       =50
Time step (s) for interval 1 dt(0)            =3.0
Time step (s) for interval 2 dt(1)            =2.0
Time step (s) for interval 3 dt(2)            =1.0
```

Figure 4.14 Example ENVI-met configuration file for summer

Finally to start the model simulation, the start ENVI-met tab is chosen as shown in Figure 4.12. There are three versions to choose from depending on the size of your model area starting from 100x100. Since the model area here being tested is below 100, than that was the version used for the simulation. The Area definition box is then opened from the 100x100 version chosen and the model configuration (Figure 4.14) including the area input file are loaded to run the simulation for each parameters being tested.

4.5.1 Base model Parameters

In order to standardize the condition of the built up area and direct all the focus on the vegetation, 3 simplified urban block models were designed Models were constructed with the North direction facing upwards as shown in the Top Left corner of the Figures. The first of the Base models produced and shown in Figure 4.15, represent the pavement configuration, where only pavement soil profile was placed around the central open space in between the 7 residential houses.

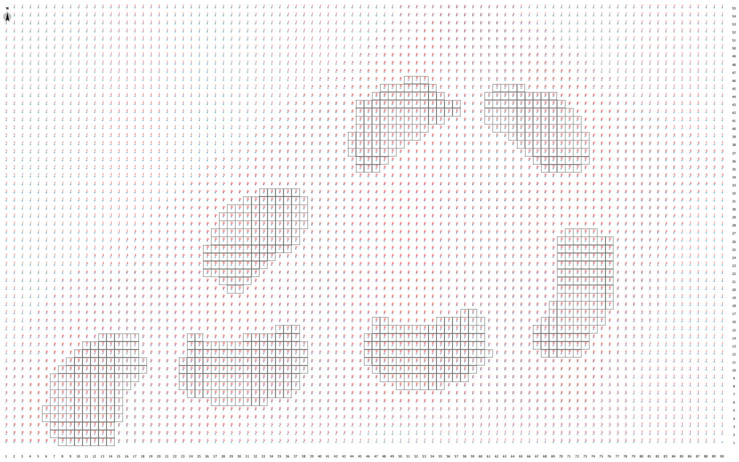

Figure 4.15 - Just Pavement Parameter

The next is a mixture of both sandy soil and concrete pavement as in reality seen in the image in figure 4.11. This configuration will be referred to as the mix configuration from here on as seen in Figure 4.16.

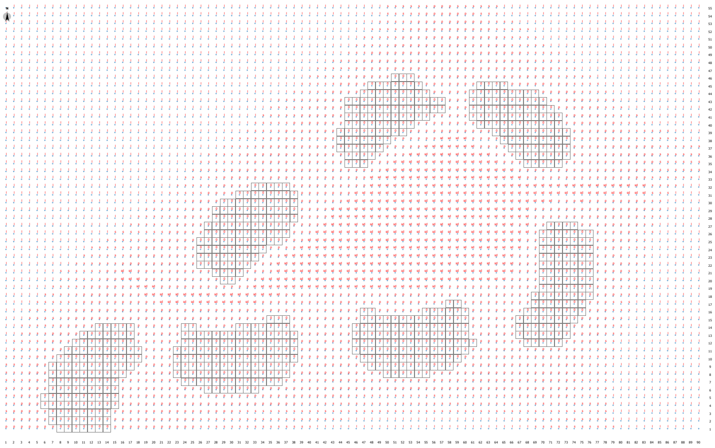

Figure 4.16 - Mix Parameter (pavement and sandy soil)

Thirdly the just grass (g:grass 50 cm average dense) configuration around the central open space and residential buildings is shown in figure 4.23. This configuration will be referred to as the just grass configuration from here on. Figure 4.15 and 4.16 will be the two configurations trying to mimic the real site and will be set as Base configurations to compare the other models with to see the results after implementing the vegetation mounds within the same site. Figure 4.17 will be the third Base model to compare the changes in heights of the other vegetation mounds as compared to a lower level of vegetation.

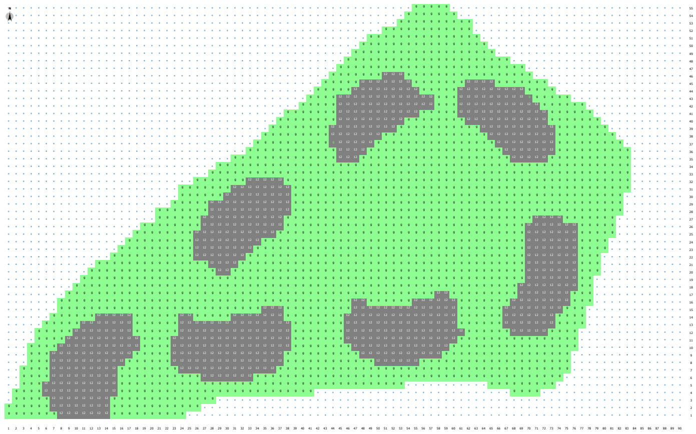

Figure 4.17 - Just Grass Parameter

4.5.2 Sand Dune Vegetation model Parameters

The Fourth model produced on ENVI-met was modeled to represent the barchans sand dunes layout with all the vegetation types mentioned in the above section depicting the shape of the sand dune with the vegetation heights as seen in Figure 4.18. The highest mound point was the dm:20 meter trees then as it staggered downwards in height from the sk:15 meter tree, ds:10 meter tree, h: 2 meter hedge, then m:1.5 meter maze, until finally back to the g:50 cm grass, as shown in the below figure. The shapes of the sand dunes were modeled from the definitions mentioned in the first chapter where we have the formations of the Barchans is a U-shaped dune with its tips pointing downwind or away from the wind. As the wind usually blows North, North-West in Dubai the sand dunes were placed in the downwind direction around the site in the North-West direction, having the highest trees at its crescent point.

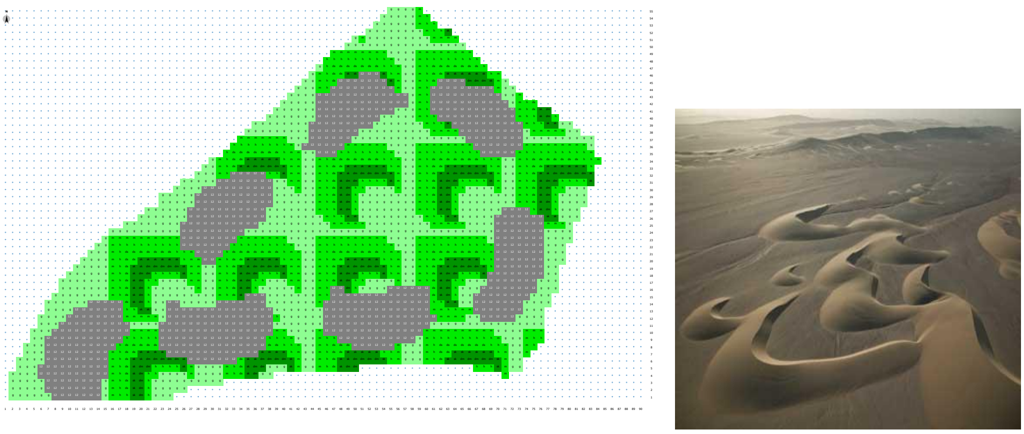

Figure 4.18 Left image is of modeled Barchan Parameter in ENVI-met. On the right is a Perspective image taken of Barchan Sand Dunes.

The Fifth configuration in Figure 4.19 is the parabolic mounds which are the mirrored image of the Barchans as they have the tips upwind or into the wind. The same vegetation was used as to configure the mound shape and formation with their appropriate vegetation heights, as shown in Figure 4.19.

Figure 4.19 Left image is of modeled Parabolic Parameter in ENVI-met. On the right is a Perspective image of parabolic Sand Dunes.

Sixth configuration is the Seif mound seen in Figure 4.20 and yet again the same vegetation types were used keeping in mind the heights and shapes of the formations as with all the configurations here on. Just as the figure below of a longitudinal sand dune, they are high at the ridge and snake like. They are parallel to each other and with the wind, thus the taller trees are set to represent the ridges as seen in the model below.

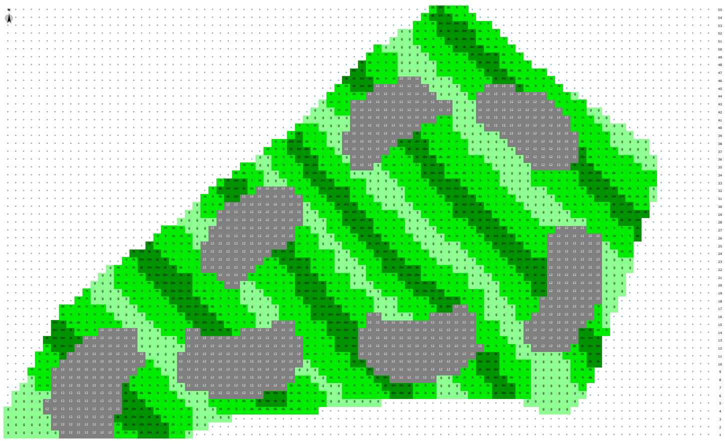

Figure 4.20 Left image is modeled Seif Parameter in ENVI-met. On the right is a Perspective image of Seif Sand Dunes

Seventh configuration is the transverse mound as seen in Figure 4.21 that resembles a water or sand ripple effect and is perpendicular to the wind direction. North faces upwards so the wind direction is North-West and perpendicular to the mound formation, as seen below.

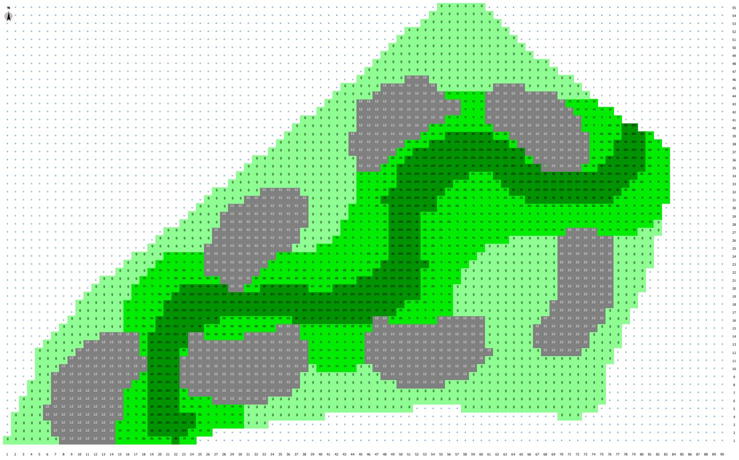


Figure 4.21 Left image of modeled Transverse Parameter in ENVI-met. On the right is a Perspective image of Transverse Sand Dunes.

Eighth configuration is the Star mound as seen in Figure 4.22 which is as described by its name has arms spreading out like a star shape. It grows upwards and is shaped by multiply wind directions, as shown in the figures below. The Taller tree's were used for the crescent and then leveled out with the lower trees to shape it like a star.

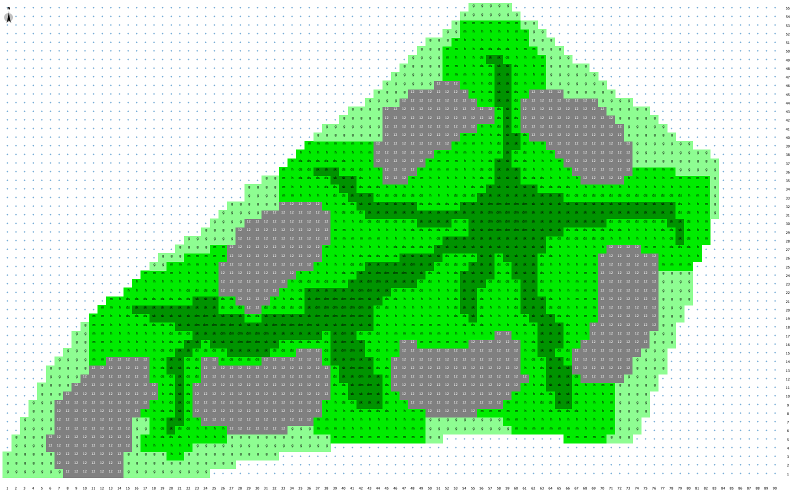


Figure 4.22 Left image of modeled Star Parameter in ENVI-met. On the right is a Perspective image of Star Sand Dunes.

For each of the eight models, the chosen dates for each simulations depended on the season being tested as mentioned above in section 4.2. Furthermore, results starting from 1 am for 48 hours were tabulated and saved at 60 minute intervals allowing for buffer timings and overcoming any challenges faced in errors from the simulations. This was to ensure the results not to be compromised by the initialization spin-up at the beginning of each simulation, when all the buildup of energy is being calculated. The configuration files used to run the simulation included climatic details as mentioned at the end of section 4.2. Finally, when coming to analyzing the results the data needed to be extracted and processed to be analyzed. The results can be opened in LEONARDO tab or from The Xtract tab (Figure 4.12) to input the information for the simulation output data. LEONARDO opens the data in map format while the Xtract the results can be opened into excel sheets. The results tabulated 4950 grid points in total. When analyzing the data the open spaces were the main focus, therefore the building surface temperatures needed to be illuminated to get accurate results.

4.6 Problems faced

Some of the challenges faced during the simulations were errors that needed rectifying, i.e. the time-set which was an error related to the model numerical set-up in relation to the solar height due to the simulation being run in a city with higher solar angles, the time steps needed to be reduced from the default values.

Others were simple human errors when inputting the data for change of season or typo’s with data inputs and so forth. At times the computers would get turned off from outside factors even when all measures were taken to insure the computers were labeled not to be touched or turned off. Also the model itself got corrupted at one point and all the models needed to be reconstructed and all the simulations needed to be tested again before repeating them all over again. The biggest challenge of all was finding enough amounts of computers to run all these simulations and the duration it took for each simulation to run accurately with no errors. The total simulation time started out at 7 days but after rectifying the model the time ranged from 3 to 5 days per simulation.

Finally, when the data was extracted and the building surface temperatures needed to be removed (example shown in Appendix A) and thus the remaining data averaged to compare the temperature differences, it was very time consuming. Each simulation ran for 48 hours saving data at each hour separately for each season and each parameter being tested. Due to lack of time the results for a 24 hour day was only taken for one season to analyze the effect of each parameter configured. Then 3 individual times during the day for each of the seasons were used to continue the remaining analysis, which will be discussed further in the following chapter.

Chapter 5: Results and Discussion

5.1 Introduction

After running the simulations, the result files were visualized in map format through LEONARDO, which show the gradient temperature distribution within the space. Visual maps indicate temperature through color gradients represented in Kelvin. For the purpose of consistency and ease of making sense of the results, as the norm mostly used, the results

horizontal cutting plane at 1-meter height from ground level. Numerical data was then extracted using the Xtract tab and opened through Excel. Each file contained 4950 coordinate entries, representing values at each simulated grid point, as mentioned in the previous chapter. After deleting all building surface temperature points, the Numerical data extracted into excel are then represented graphically by mapping the average temperatures for each configuration and season. As mentioned in the previous chapter, only one graph was tabulated for a 24 hour day of all the model parameters in summer due to lack of time. The results are shown in the following - Table 5.2 and Figure 5.2. As shown, there is a clear reduction in temperature when the vegetation mounds are added to the site

5.2 Results Discussion

Table 5.2 Average Temperature results for all model parameter configurations of a 24 hour day in summer.

Time in hr.	P(°C)	(sd+p)(°C)	g(°C)	Barch.(°C)	Trans.(°C)	Parab.(°C)	Seif(°C)	Star(°C)
1	26.21	26.05	26.05	26.11	26.13	26.09	26.06	26.07
2	27.11	27.09	27.11	26.99	26.97	26.94	26.90	26.89
3	27.16	27.12	27.12	27.02	27.00	26.97	26.93	26.92
4	27.15	27.09	27.00	27.00	26.98	26.95	26.91	26.90
5	27.11	27.04	27.03	26.96	26.94	26.91	26.87	26.85
6	27.07	26.98	26.97	26.91	26.89	26.86	26.82	26.81
7	27.31	27.18	27.16	27.13	27.13	27.08	27.04	27.05
8	28.36	27.99	27.99	27.97	28.01	27.94	27.84	27.92
9	29.76	29.25	29.11	29.10	29.14	29.10	28.92	29.01
10	31.26	30.54	30.33	30.35	30.36	30.35	30.13	30.17
11	32.58	31.73	31.47	31.50	31.45	31.51	31.26	31.20
12	33.59	32.82	32.49	32.42	32.35	32.45	32.15	32.05
13	34.36	33.74	33.35	33.03	32.98	33.09	32.77	32.64
14	34.85	34.46	34.00	33.40	33.35	33.50	33.14	32.99
15	35.03	34.94	34.38	33.41	33.42	33.55	33.14	32.99
16	34.84	35.02	34.33	32.99	33.05	33.15	32.70	32.61
17	34.04	34.39	33.63	32.17	32.26	32.30	31.88	32.04
18	32.58	32.98	32.33	31.05	31.11	31.13	30.78	30.77
19	31.14	31.50	30.99	29.96	29.99	30.00	29.70	29.67
20	30.54	30.86	30.42	29.50	29.52	29.53	29.26	29.22
21	30.14	30.41	30.02	29.18	29.20	29.20	28.95	28.91
22	29.82	30.07	29.70	28.93	28.94	28.94	28.71	28.67
23	29.56	29.78	29.43	28.71	28.72	28.72	28.50	28.47
24	29.33	29.53	29.20	28.52	28.53	28.53	28.32	28.29

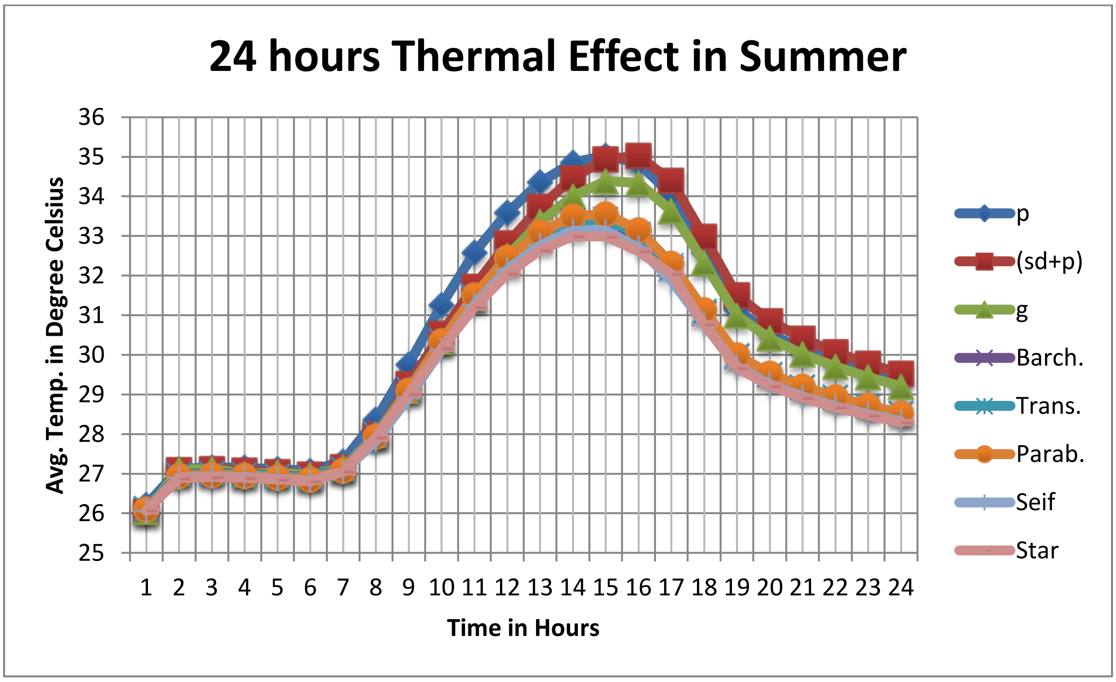

Figure 5.2 Graph showing the hourly average temperature in degree Celsius for all model parameter configurations in the season of summer

By taking the difference in all the model parameter configurations, shown in Tables 5.3 and 5.4, it clearly shows that there is approximately 1 degree Celsius change from the pavement base case to the addition of vegetations, even if it was just grass. When comparing the base cases with each other it is seen that even with adding sand with the pavement there is a 0.78 degree Celsius difference compared with the just pavement model. Grass on the other hand is evidently improving the temperature when added to the site by 1.10 degree Celsius when compared to the pavement and 0.33 degree Celsius change when compared to the mixture of sand and pavement model. However, the main focus of the study is to compare the sand dune formation vegetation mounds in comparison to the base case scenarios. This behavior is also proved in the work of Susca, Gaffin, and Dell'Osso (2011) where a 2 degree Celsius was reported when vegetation was added.

Table 5.3 Average temperature differences at 12pm taken from table 5.2 between all three base case scenarios.

Model Parameters	Base case Subtraction (ºC)			Difference (ºC)
p-(sd+p)	33.59	-	32.82	0.78
p-g	33.59	-	32.49	1.10
(sd+p)-g	32.82	-	32.49	0.33

When looking at the differences concurred between the three base cases and the five sand dune vegetation shaped mounds we see even further improvement in temperature around the site. Sequentially the best configuration from the five is the Star mound, then Seif, Transverse, Barchan and finally Parabolic. When calculating the differences between the pavement base case and the vegetation parameters it is seen that there is a maximum of 1.54 degree Celsius improvement until a 1.14 degree Celsius change (Table 5.4).

Table 5.4 Average temperature differences at 12pm taken from table 5.2 between the three base case scenarios and the Model Parameter configurations

Model Parameters	Base cases – Vegetation mounds (^{0}C)			Difference (^{0}C)
p-Barch.	33.59	-	32.42	1.17
p-Trans.	33.59	-	32.35	1.25
p-Parab.	33.59	-	32.45	1.14
p-Seif	33.59	-	32.15	1.44
p-star	33.59	-	32.05	1.54
(sd+p)-Barch	32.82	-	32.42	0.39
(sd+p)-Trans.	32.82	-	32.35	0.47
(sd+p)-Parab.	32.82	-	32.45	0.36
(sd+p)-Seif	32.82	-	32.15	0.67
(sd+p)-star	32.82	-	32.05	0.77
g-Barch	32.49	-	32.42	0.07
g-Trans.	32.49	-	32.35	0.14
g-Parab.	32.49	-	32.45	0.03
g-Seif	32.49	-	32.15	0.34
g-star	32.49	-	32.05	0.44

When comparing all the vegetation mound cases, the one that employs only grass, has the highest surface temperature in all four seasons. This performance is also apparent in the work of Cao et al. (2010) who deduced that grass has the least effect in dropping surface temperatures compared to trees and shrubs in urban parks. The weak behavior of grass is linked to its lack of complexity in terms of density and irregularity of undergrowth. As a result, the configurations with more trees' than grass result in lower surface temperatures in all seasons compared to other configurations. Accordingly, presence of trees has the most enormous effects in decreasing the surface temperatures particularly during hot seasons; this conclusion relate to results of Cao et al. (2010) who suggest that trees have the best cooling effects related to other forms of greenery.

Furthermore, when the results for the pavement configuration were tabulated into a graph for all four seasons to see the effect in a single day seen in Table 5.5 and Figure 5.3, it is clear that there is a peak duration starting from 8:00 am until 16:00 pm due to the fact that solar radiation increases in these hours of the day. In Spangenberg et al. (2008) and Dimoudi and Nikolopoulou (2002) both confirm the observations above that the vegetation improves temperature during the peak times of the day. This is evident when referring to Figure 5.1 where the vegetation configurations show lower temperature surfaces during the peak timings.

Table 5.5 Hourly average temperatures in degree Celsius for Pavement Parameter Configuration for all four seasons

Pavement Configuration				
Time in Hr.	Summer (^oC)	Winter (^oC)	Spring (^oC)	Autumn (^oC)
1	26.2106	18.4114	24.1369	21.1043
2	27.1099	15.9773	23.7928	19.8061
3	27.1598	15.4906	23.6518	19.4544
4	27.1494	15.1787	23.5437	19.2213
5	27.114	14.9466	23.4482	19.0345
6	27.0699	14.7692	23.3635	18.8728
7	27.3121	14.6232	23.7871	18.7283
8	28.3623	14.5753	24.9954	19.1366
9	29.7582	15.2436	26.5327	20.2063
10	31.2601	16.2883	28.0852	21.4168
11	32.5765	17.2042	29.2715	22.4389
12	33.5915	17.834	30.1246	23.054
13	34.3553	18.1925	30.738	23.3291
14	34.8512	18.2666	31.1396	23.2926
15	35.0278	18.0698	31.1963	22.9364
16	34.8367	17.5472	30.8581	22.2132
17	34.0436	16.7023	29.9928	21.0775
18	32.5771	15.9127	28.4483	20.2749
19	31.138	15.5535	27.0663	19.8923
20	30.5374	15.3007	26.51	19.6266
21	30.1355	15.1043	26.1462	19.4219
22	29.8234	14.944	25.8654	19.251
23	29.5593	14.8063	25.6326	19.1032
24	29.3303	14.6891	25.4282	18.9655

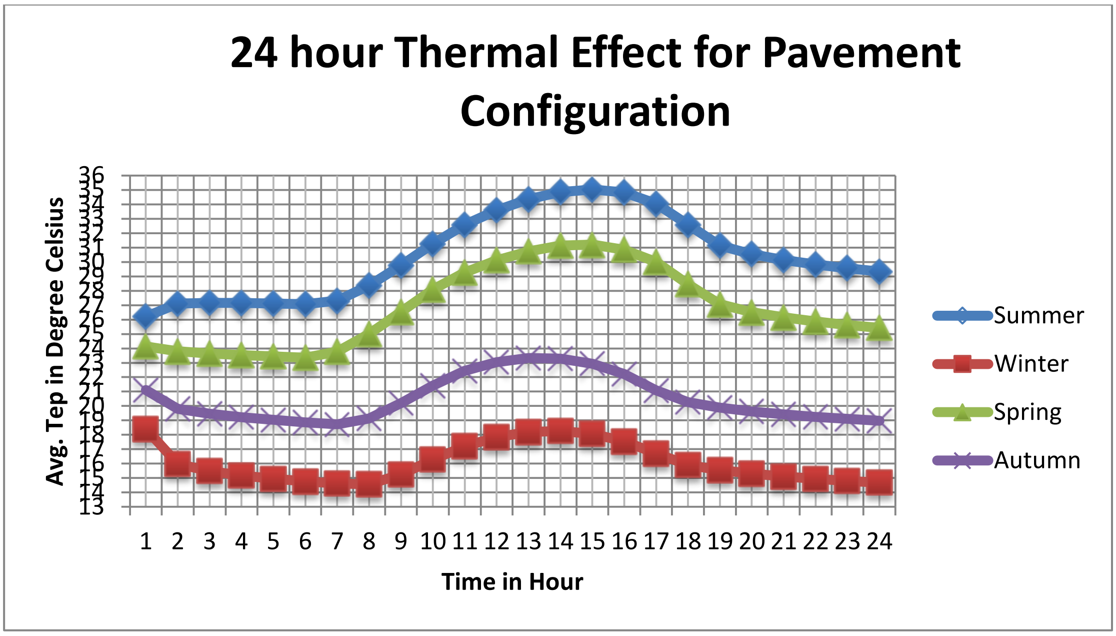

Figure 5.3 Graph showing the hourly average temperature in degree Celsius for the pavement model parameter configuration for all seasons

When analyzing the results for all the configurations for 3 different times during a day for each season, it clearly emphasizes the benefits of the vegetation mounds presence around the site. Even more, as can be seen in Table 5.6 and Figures 5.4-5.7, the Temperature differs at 4pm and 12pm with the changing of the seasons. In both summer and spring 4 pm is at higher temperatures than at 12pm, while the opposite goes for autumn and winter. This indicates that the peak duration changes in cooler seasons and is shortened, due to the fact that the sun angle is lower in winter than in summer.

Table 5.6 Shows three different chosen hours in a day of average temperature in degree Celsius for all Configuration and all four seasons.

Summer								
time	P (^{0}C)	(sd+p) (^{0}C)	g (^{0}C)	Barch. (^{0}C)	Trans. (^{0}C)	Parab. (^{0}C)	Seif (^{0}C)	Star (^{0}C)
9am	29.76	29.25	29.11	29.10	29.14	29.10	28.92	29.01
12pm	33.59	32.82	32.49	32.42	32.35	32.45	32.15	32.05
4pm	34.84	35.02	34.33	32.99	33.05	33.15	32.70	32.61
Spring								
time	P (^{0}C)	(sd+p) (^{0}C)	g (^{0}C)	Barch. (^{0}C)	Trans. (^{0}C)	Parab. (^{0}C)	Seif (^{0}C)	Star (^{0}C)
9am	26.53	26.39	26.20	25.64	25.85	25.81	25.61	25.72
12pm	30.12	29.92	29.63	29.05	28.98	29.09	28.82	28.74
4pm	30.86	30.66	30.24	29.30	29.36	29.59	29.08	29.01

Autumn								
time	P (°C)	(sd+p) (°C)	g (°C)	Barch. (°C)	Trans. (°C)	Parab. (°C)	Seif (°C)	Star (°C)
9am	20.21	20.12	20.01	19.81	19.83	19.79	19.78	19.77
12pm	23.05	22.94	22.46	22.36	22.34	22.35	22.24	21.90
4pm	22.21	22.10	21.90	21.55	21.60	21.54	21.35	21.44
Winter								
time	P (°C)	(sd+p) (°C)	g (°C)	Barch. (°C)	Trans. (°C)	Parab. (°C)	Seif (°C)	Star (°C)
9am	15.24	15.19	15.12	15.06	15.05	15.06	15.05	15.06
12pm	17.83	17.76	17.61	17.31	17.30	17.31	17.25	17.20
4pm	17.55	17.47	17.29	16.98	17.02	16.98	16.84	16.92

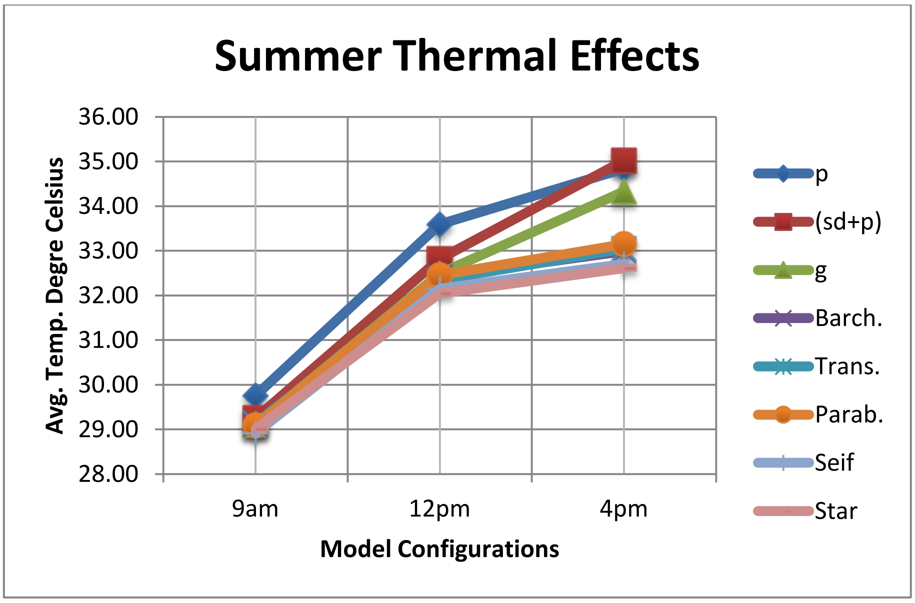

Figure 5.4 Average Temperature in Degree Celsius of Three different chosen hours in a day in summer for all Configurations.

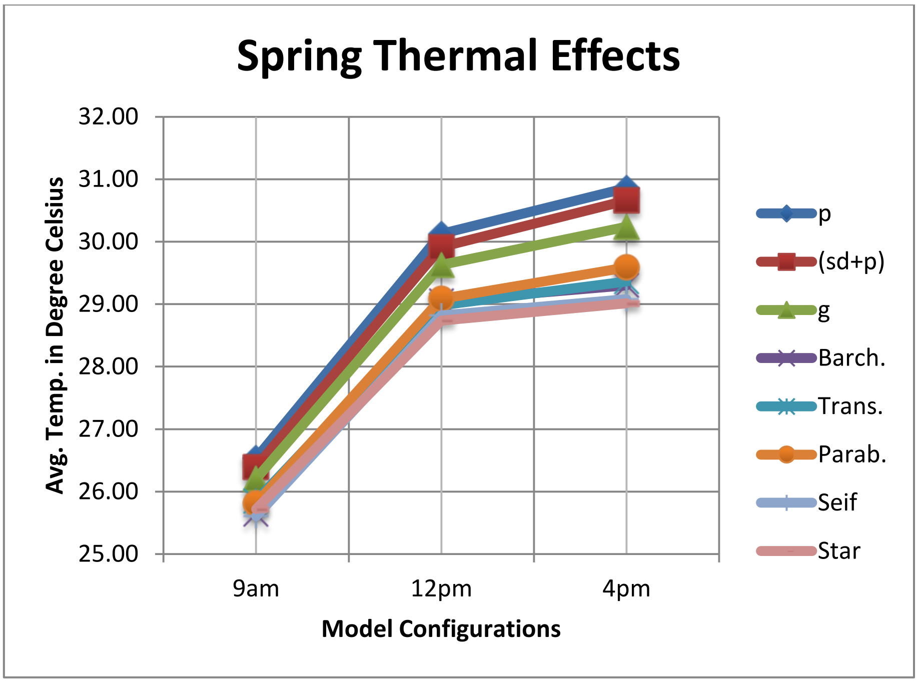

Figure 5.5 Average Temperature in Degree Celsius of Three different chosen hours in a day in spring for all Configurations.

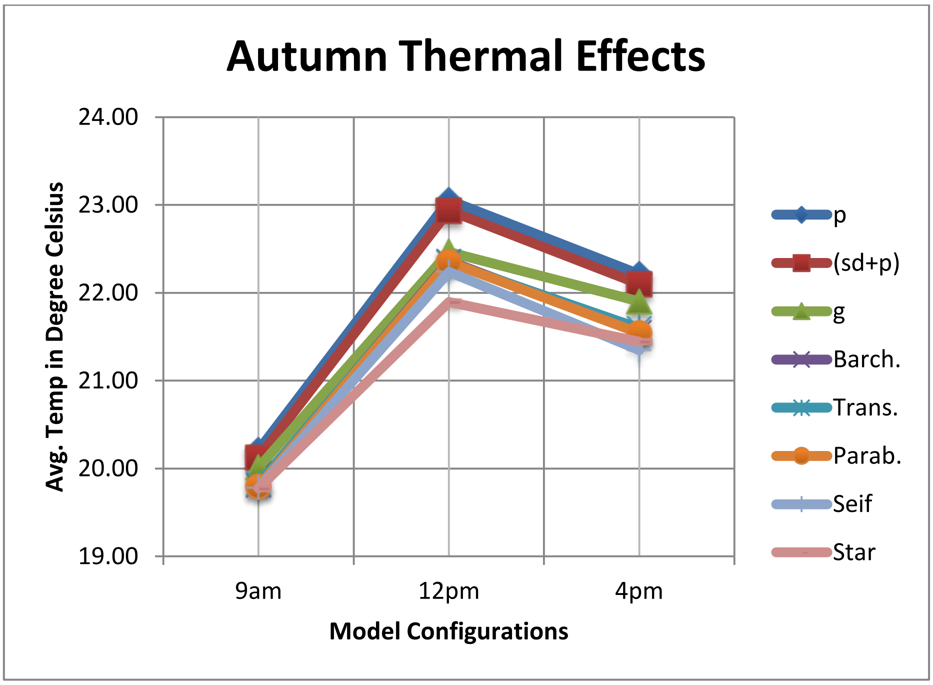

Figure 5.6 Average Temperature in Degree Celsius of Three different chosen hours in a day in autumn for all Configurations.

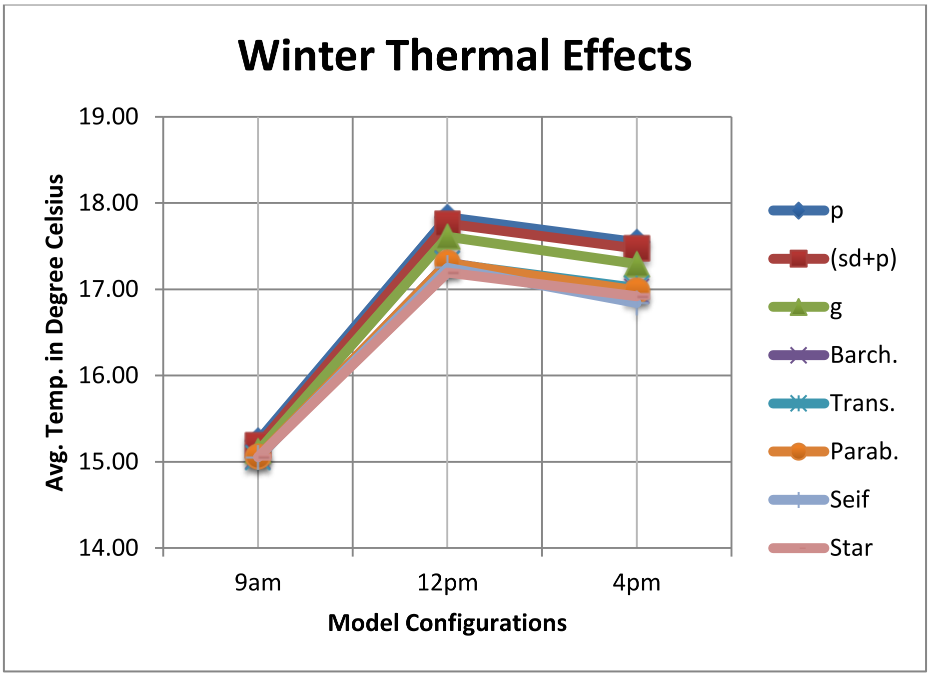

Figure 5.7 Average Temperature in Degree Celsius of Three different chosen hours in a day in winter for all Configurations.

The purpose of having the greenery shaped as sand dune formations was to link back to the nature of the countries surrounding desert and implement it in a manner that could promote heat reduction. The shapes of the formations effect the temperature reduction due to its compactness. The cooling effects of greenery in all these cases, is related to the compactness of the greenery and its natural formations. Cao et al. (2010) in their study of cooling effects for parks explain that the compactness of the parks result in better cooling effects. Crow, Brown, and De Young (2005) also compare the benefits of a more natural composition as compared to a rigid and edged arrangement of urban vegetation and concluded the diverse natural formations were better. Even further, Zhoua et al. (2011) examined the consequence of land cover arrangement and discovered Land Surface Temperatures (LST) can be significantly increased or decreased by different spatial arrangements of land cover features. Additionally, they claimed LST reduces with the increase of shape complexity and changeability of vegetation. Increase in edge compactness and shape complexity of vegetation can amplify shade, provided by vegetation, for surrounding areas and thus, decrease LST and progress the exchanges between vegetation and built-up areas and thus ease energy exchange.

The Star configuration (Figure 4.22) gave the best results as it has the most trees and mixed vegetation, emphasizing the previous discoveries mentioned above. It is the most diverse of the five vegetation dune formations and has the best shape complexity and changeability of vegetation types, thus the decrease in LST. The Barchan (Figure 4.18 and Parabolic (Figure 4.19) formations have the least decrease in LST, not inclusive of the grass configuration that was already discussed. The rigidity and edged arrangements seem to be the reason behind this. When looking at them separately, the Barchan has a more decrease in LST than does the parabolic. This can go further to the fact that the shapes are directed towards or against the wind. Since the Barchan formation has the tips facing away from the wind and the Parabolic facing into the wind, the Parabolic shaped tree's could be cupping and blocking the wind flow at the tree's height and the 1 meter range being examined. On the other hand, the Barchan formation is curving away from the wind and is less of a barrier. However, since the wind results are not being examined in this research paper, it could be something worth investigating further in the future. The Seif (Figure 4.20) and Transverse (Figure 4.21) formations come after the Star in its effects in decreasing LST. Again amount of vegetation changeability and shape complexity play a role; the less complex and diverse the arrangement the less decrease in LST.

Chapter 6: Conclusion and Recommendations

6.1 Conclusion

The main focus of this research was on the effect of greenery shaped as sand dune formations on reduction of excess heat in the urban areas of Dubai and linking back to the natural habitat skyline. In order to study this effect, five parameters of sand dune types including, composition of base cases of pavement, mixture of pavement with sand, and just grass were selected for further investigations. 32 tests were developed each featuring the different configuration for each season; the results were interpreted based on average hourly surface temperatures of areas around the buildings (data from the buildings were eliminated). All configurations were tested on the same site in AlShorooq community of Mirdif, Dubai.

The results from all parts of the research revealed that in terms of composition of greenery, the ones with the most trees and mix of vegetation 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 plant life. In terms of the composition of the trees, it is concluded that vegetation formations with most use of trees with natural and diverse arrangements are the best in terms of reducing surface temperatures. In contrast, vegetation formations with rigid and edged arrangements perform less in reducing surface temperatures. On the other hand, Increase in edge compactness and shape complexity of vegetation can decrease LST and progress the exchanges between vegetation and built-up areas.

All in all, vegetation has an adverse benefit not only on the reduction of temperatures around the urban area but from many of the studies discussed in chapter 2, additional benefits are received for users comforts when living around or nearby vegetation, as sited by Picot (2004). Bringing back to the natural surroundings of the area is just as important in benefiting the results received, as is the decrease in thermal effects. Thus when combining the two even further increased gains are procured. The conclusion of this research illustrates the significance of greenery in reducing surplus heat and creating balanced microclimatic conditions in urban areas, as well as, the advantage of utilizing natural formations from the surrounding landscape.

6.2 Recommendations

When designing urban spaces, it is recommended to implement as much greenery within the landscape as possible and reduce the building dominated master plans. Urban planners should always keep in mind the magnitude of green fabric in generating stable and healthy microclimates in urban areas. The more the trees implemented around the site the better. It is also recommended to mix different vegetation types around the urban areas and arrange them in as natural and diverse formations as can be done. Further, reduction of grassy areas in comparison to increase of trees should be considered. Trees being utilized should be high with wide canopies to provide maximum shade. Urban planners should always aim for edge compactness in pre-existing conditions. When designing, the landscape should try to mesh with the existing surroundings, linking back to the area's historic characteristics for additional visual benefits. There needs to be a deeper understanding to the mechanism of vegetation placement and organization before selection and application. Identification of best locations for vegetation, in comparison to the hotspots in an area, as to select most efficient compositions to solve excess heat before implementation occurs. Other suggestions can be guided towards including trees and shrubs along roads, pedestrian paths, and even within parking lots. As a general rule it is suggested to aspire to diminishing the hard surfaces such as concrete and asphalt.

6.3 Recommendations for Further Research

After completing this investigation, a few future possibilities can be researched in this field to fill the gap of knowledge not presented here; some of these possibilities are:

1. Investigating the effects of wind speed and direction, air temperature in decreasing LST.

2. Exploring other varieties of greenery that wasn't explored in this paper on reducing the surface temperatures in urban areas

3. Testing the most advantageous configurations on other pre-existing/newly designed urban areas with different characteristics, such as location, size, land use, and other microclimatic conditions.

4. Considering to indentify the most competent types of trees appropriate for urban areas in Dubai;

5. Exploring the cost of maintenance of vegetation in different forms and energy savings.

6. exploring the effect on users comfort levels

7. combining field investigations and surveys to compare with the results of simulations

8. Analyzing the effects of orientation of vegetation.

9. Testing the effects of vegetation against buildings with different materials and geometry.

10. Create a database for all findings as to help achieve optimal strategies for all to use.

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Appendix A - Samples of Extracted Data in Kelvin showing only page 1 out of 74 for Pavement at 9 am in summer (remaining files available in soft copy)

Table A. 1: Part of extracted data Temperature (K) for pavement simulation in summer at 9 am after eliminating building 0 values

x(m)	y(m)	Pot. Temperature (K)	Pot. Temperature (°C)
1	109	302.5208	29.3708
1	107	302.5191	
1	105	302.5175	
1	103	302.5158	
1	101	302.5143	
3	109	302.5191	
3	107	302.5177	
3	105	302.5164	
3	103	302.515	
3	101	302.5136	
5	109	302.5174	
5	107	302.5164	
5	105	302.5154	
5	103	302.5144	
5	101	302.5133	
7	109	302.5158	
7	107	302.515	
7	105	302.5145	
7	103	302.5139	
7	101	302.5132	
9	109	302.5144	
9	107	302.5138	
9	105	302.5135	
9	103	302.5134	
9	101	302.5132	
11	109	302.5132	
11	107	302.5126	
11	105	302.5126	
11	103	302.5128	
11	101	302.5131	
11	99	302.5131	
11	97	302.513	
11	95	302.5127	
11	93	302.5122	
11	91	302.5115	
11	89	302.5107	
11	87	302.5098	
11	85	302.5089	

Table A. 2: Part of extracted data Temperature (K) for pavement simulation in summer at 9 am without eliminating building values highlighted in red.

x(m)	y(m)	Pot. Temperature (K)	Formula for eliminating 0 values representing the (building)
123	0 109.0	0 302.4786	#VALUE!
123	0 107.0	0 302.5721	#VALUE!
123	0 105.0	0 302.6573	#VALUE!
123	0 103.0	0 302.7279	#VALUE!
123	0 101.0	0 302.7936	#VALUE!
123	0 99.00	302.8539	302.8539
123	0 97.00	302.9067	302.9067
123	0 95.00	302.9493	302.9493
123	0 93.00	302.9774	302.9774
123	0 91.00	302.9855	302.9855

Table A. 3: A single point on the model grid was chosen and tabulated for each configuration of the temperature in degree Celsius for a 48 hour period.

Summer							
Time	p	g	barch.	trans.	para.	seif	star
1:00	26.4	26.2	26.3	26.3	26.3	26.2	26.1
2:00	27.4	27.3	27.1	27.2	27.1	27.1	27.0
3:00	27.4	27.3	27.2	27.3	27.1	27.1	27.0
4:00	27.4	27.3	27.2	27.3	27.1	27.1	27.0
5:00	27.4	27.2	27.1	27.2	27.1	27.0	27.0
6:00	27.4	27.2	27.1	27.2	27.0	27.0	26.9
7:00	27.6	27.4	27.3	27.4	27.3	27.7	27.2
8:00	28.6	28.2	28.1	28.3	28.1	27.9	28.0
9:00	29.9	29.2	29.2	29.3	29.2	29.0	29.0
10:00	31.4	30.4	30.4	30.5	30.4	30.2	30.2
11:00	32.8	31.6	31.6	31.6	31.5	31.3	31.2
12:00	33.9	32.6	32.5	32.4	32.4	32.2	32.0
13:00	34.6	33.4	33.0	33.0	33.0	32.8	32.6
14:00	35.0	34.0	33.4	33.3	33.4	33.1	32.9
15:00	35.1	34.3	33.3	33.4	33.5	33.1	32.9
16:00	34.9	34.3	32.9	33.1	33.1	32.7	32.6
17:00	34.2	33.6	32.2	32.4	32.3	31.9	31.9
18:00	32.8	32.4	31.1	31.3	31.3	30.9	30.9
19:00	31.4	31.1	30.1	30.2	30.1	29.8	29.7
20:00	30.8	30.6	29.6	29.8	29.7	29.4	29.3
21:00	30.4	30.2	29.3	29.5	29.4	29.1	29.0
22:00	30.1	29.9	29.1	29.2	29.1	28.9	28.8
23:00	29.9	29.6	28.8	29.0	28.9	28.7	28.6
0:00	29.6	29.4	28.7	28.8	28.7	28.5	28.4

1:00	29.4	29.2	28.5	28.6	28.5	28.3	28.2
2:00	29.2	29.0	28.3	28.5	28.4	28.2	28.1
3:00	29.1	28.8	28.2	28.4	28.2	28.1	28.0
4:00	28.9	28.7	28.1	28.2	28.1	27.9	27.9
5:00	28.8	28.5	28.0	28.1	28.0	27.8	27.7
6:00	28.6	28.4	27.9	28.0	27.9	27.7	27.6
7:00	28.8	28.7	28.1	28.3	28.1	27.9	27.9
8:00	29.9	29.7	28.9	29.1	28.9	28.7	28.7
9:00	31.3	31.2	30.0	30.2	30.1	29.7	29.8
10:00	33.0	33.2	31.4	31.5	31.4	31.1	31.0
11:00	34.7	35.6	32.9	32.9	32.9	32.5	32.3
12:00	36.5	38.3	34.2	34.1	34.3	33.8	33.5
13:00	38.5	40.6	35.4	35.3	35.5	34.9	34.5
14:00	40.6	41.7	36.6	36.4	36.8	36.0	35.5
15:00	41.5	41.8	37.5	37.4	37.9	36.7	36.3
16:00	41.1	41.3	37.7	37.7	38.1	36.9	36.6
17:00	40.1	40.2	37.1	37.1	37.4	36.4	36.2
18:00	38.4	38.6	35.7	35.8	35.9	35.1	34.9
19:00	36.4	36.7	33.8	33.9	34.0	33.3	33.1
20:00	35.4	35.7	32.9	33.0	33.1	32.4	32.3
21:00	34.6	35.1	32.3	32.4	32.4	31.9	31.8
22:00	33.9	34.5	31.9	32.0	32.0	31.5	31.4
23:00	33.4	34.1	31.6	31.7	31.7	31.2	31.0
0:00	33.0	33.7	31.3	31.4	31.4	30.9	30.8

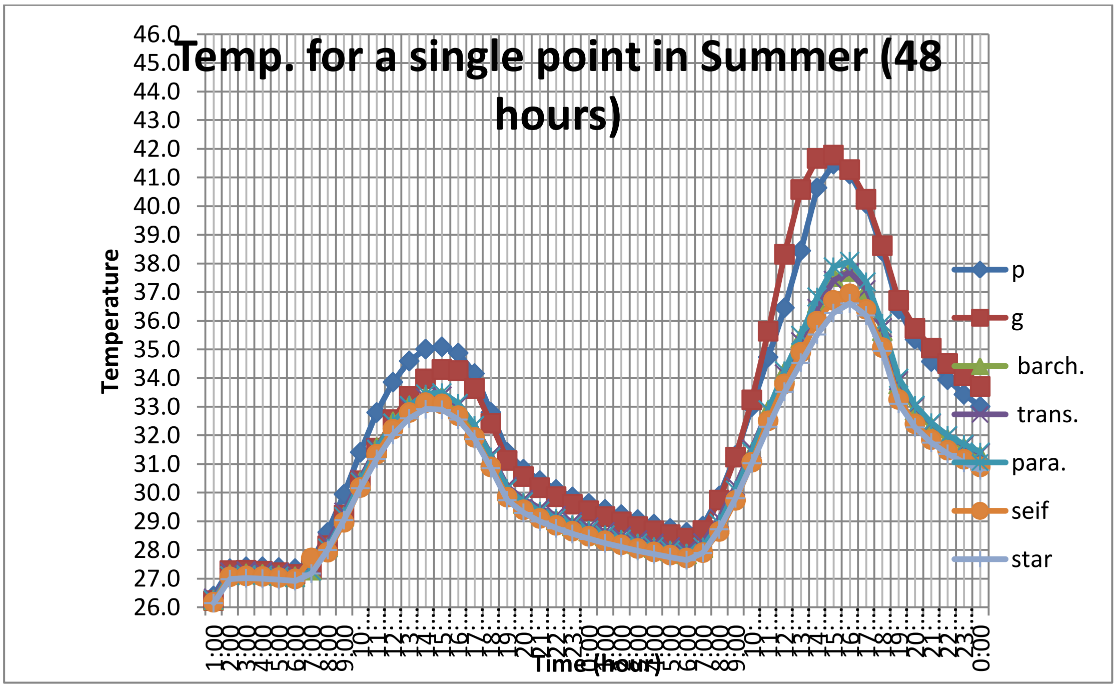


Figure A. 1: Graph showing the temperature change in degree Celsius at a single point on the model grid of each configuration for a 48 hour period.

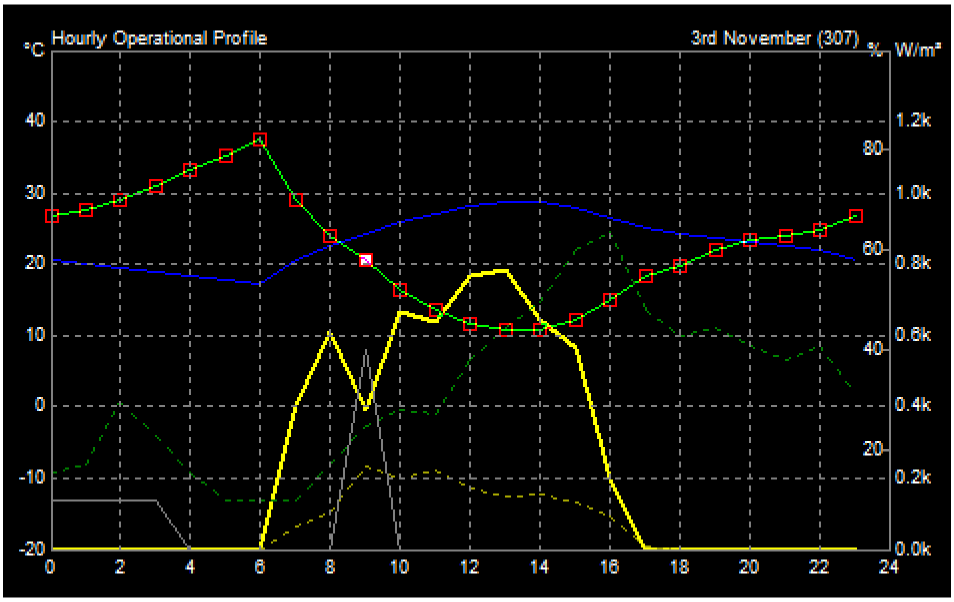
Table A. 4: A few points from the tabulated results for each configuration in winter at 9am the rest of the data and for the remaining seasons can be found in the soft copies.

Pavement			Mix			Grass			Barchan		
x(m)	y(m)	Pot. Temperature (K)	x(m)	y(m)	Pot. Temperature (K)	x(m)	y(m)	Pot. Temperature (K)	x(m)	y(m)	Pot. Temperature (K)
1	109	288.1965	1	109	288.1994	1	109	288.147	1	109	288.0911
3	109	288.1962	3	109	288.1992	3	109	288.1468	3	109	288.0906
5	109	288.1959	5	109	288.1989	5	109	288.1464	5	109	288.09
7	109	288.1956	7	109	288.1985	7	109	288.1461	7	109	288.0893
9	109	288.1953	9	109	288.1982	9	109	288.1457	9	109	288.0886

Transverse			Parabolic			Seif			Star		
x(m)	y(m)	Pot. Temperature (K)	x(m)	y(m)	Pot. Temperature (K)	x(m)	y(m)	Pot. Temperature (K)	x(m)	y(m)	Pot. Temperature (K)
1	109	288.0844	1	109	288.1075	1	109	288.0857	1	109	288.1006
3	109	288.084	3	109	288.107	3	109	288.0853	3	109	288.1001
5	109	288.0834	5	109	288.1064	5	109	288.0847	5	109	288.0995
7	109	288.0827	7	109	288.1057	7	109	288.0841	7	109	288.0988
9	109	288.082	9	109	288.105	9	109	288.0834	9	109	288.0981

Appendix B -Variables data taken from Ecotec Weather tool for each season

Figure B.1 Autumn 3rd Nov. actual temp min : 17.200 max : 28.700 avg 23.125 and humidity min: 44.000 max: 82.000 avg: 60.958



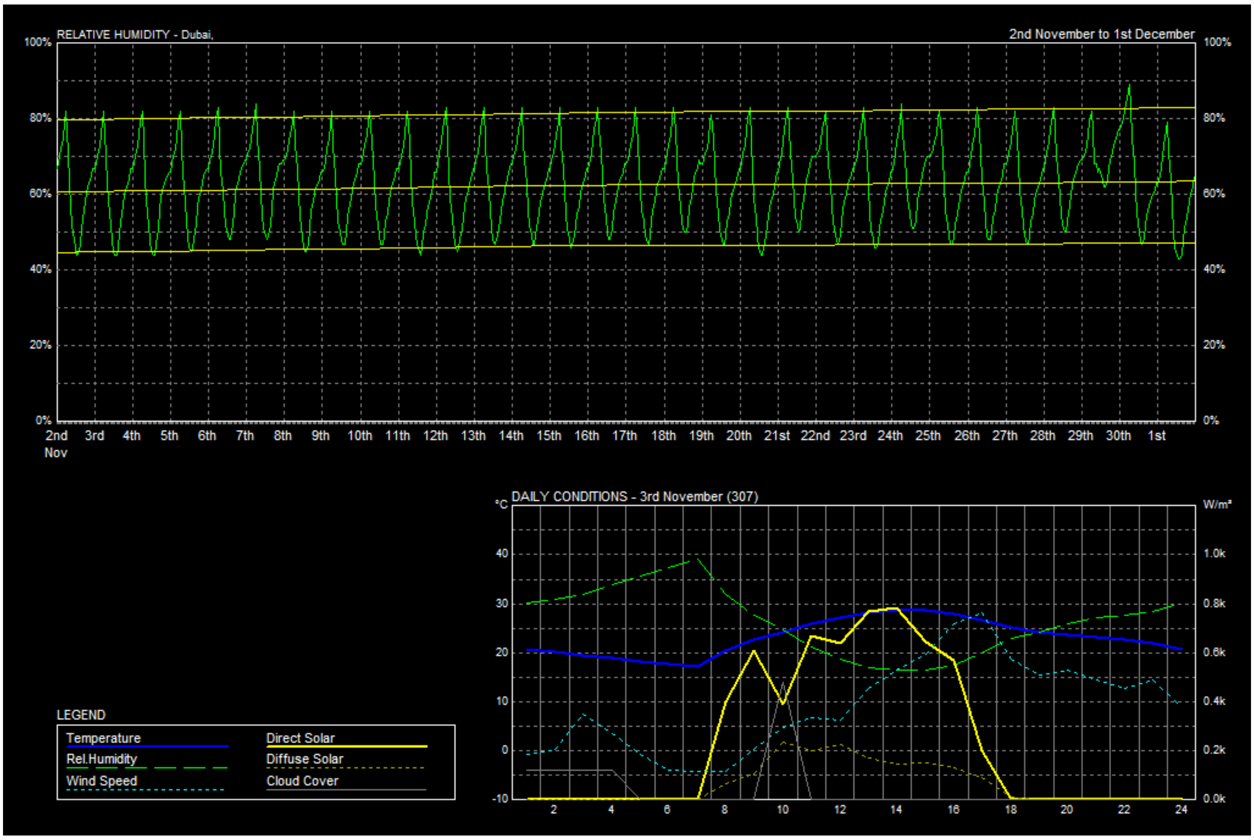
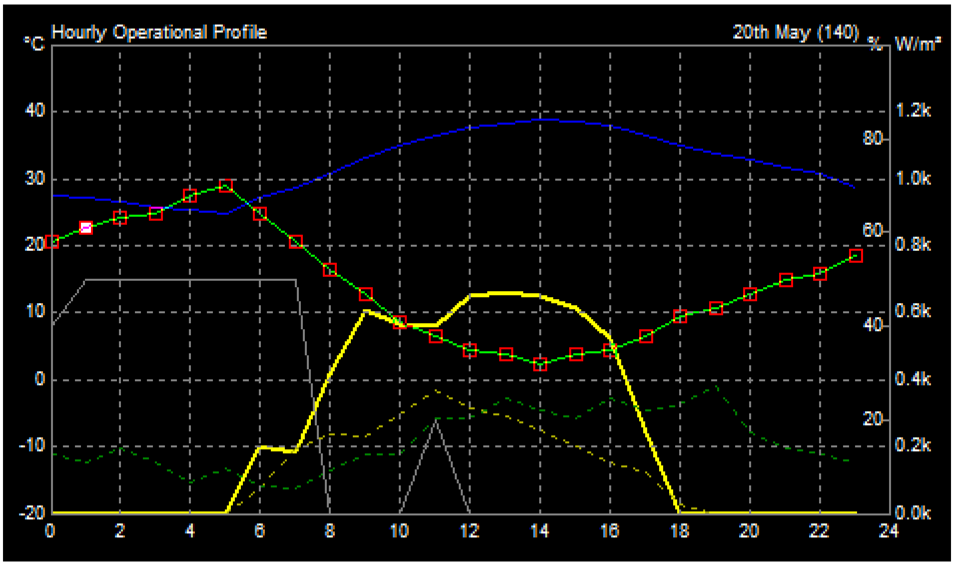


Figure B.2 Spring 20th May temp. min.: 24.700 max.: 39.000 avg.: 32.038 humidity: min.: 32 max.: 70 avg.: 49.208



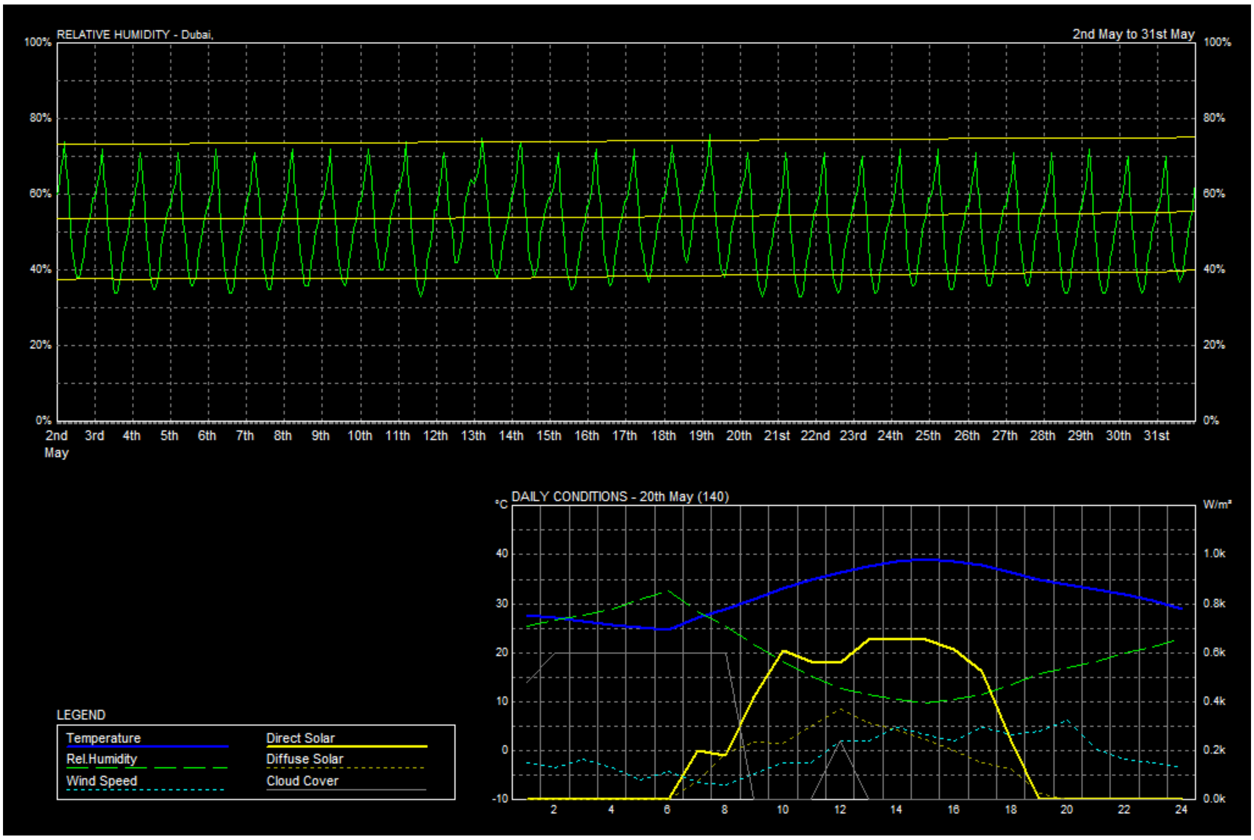


Figure B.3 Summer Hottest day 21st July temp. min.: 34.2 max.: 41 avg.: 37.783 humidity min.: 53 max.: 74 avg.: 62.5

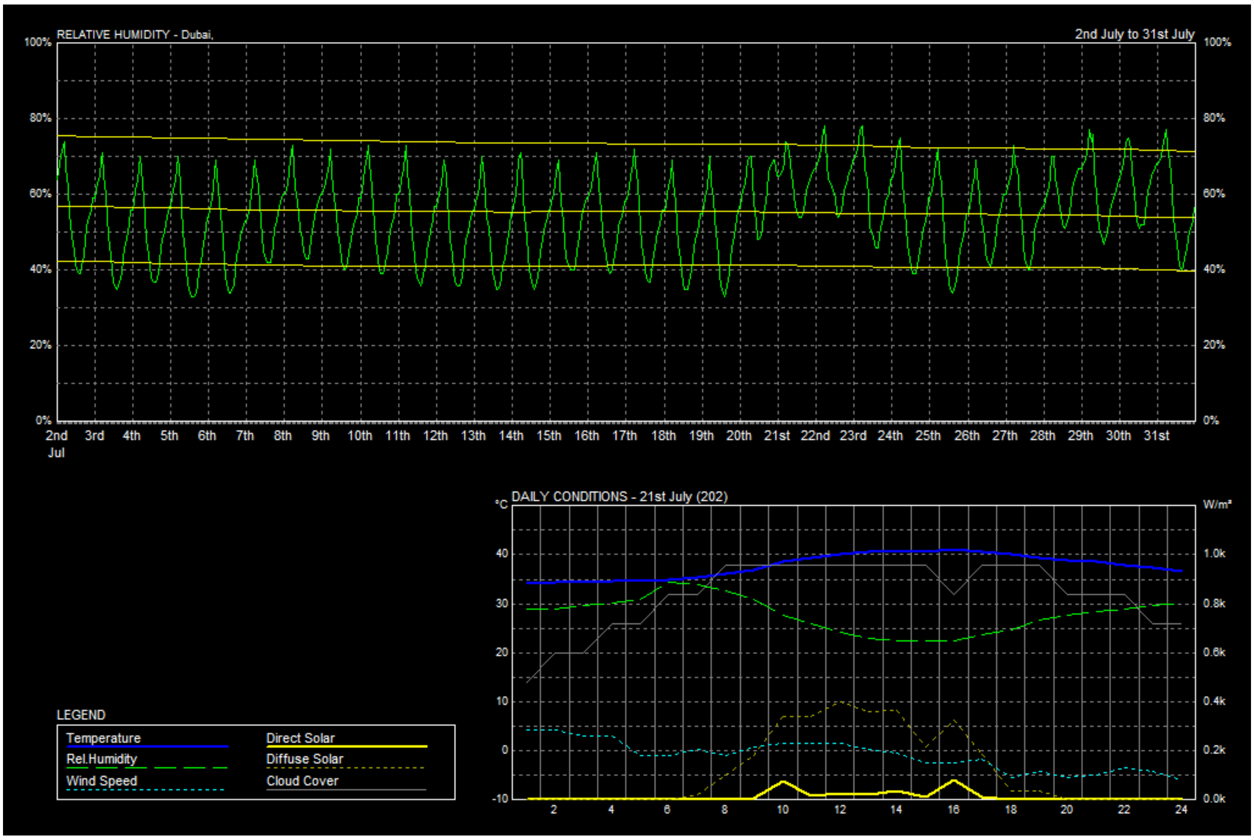


Figure B.4 Winter Coolest day 15th Jan. temp. min.: 6.5 max.: 27.7 avg.: 16.754 humidity min.: 46 max.: 80 avg.: 62.500

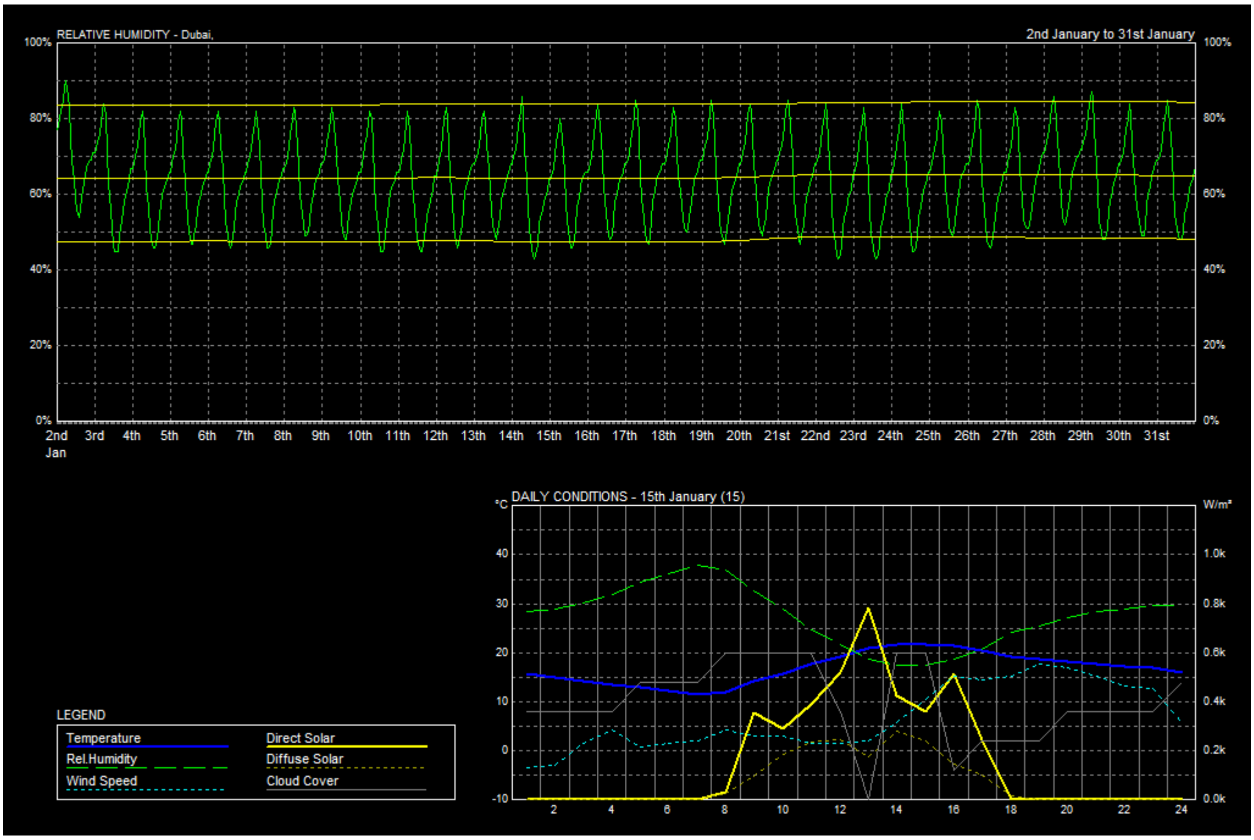


Figure B.5 Summer prevailing winds

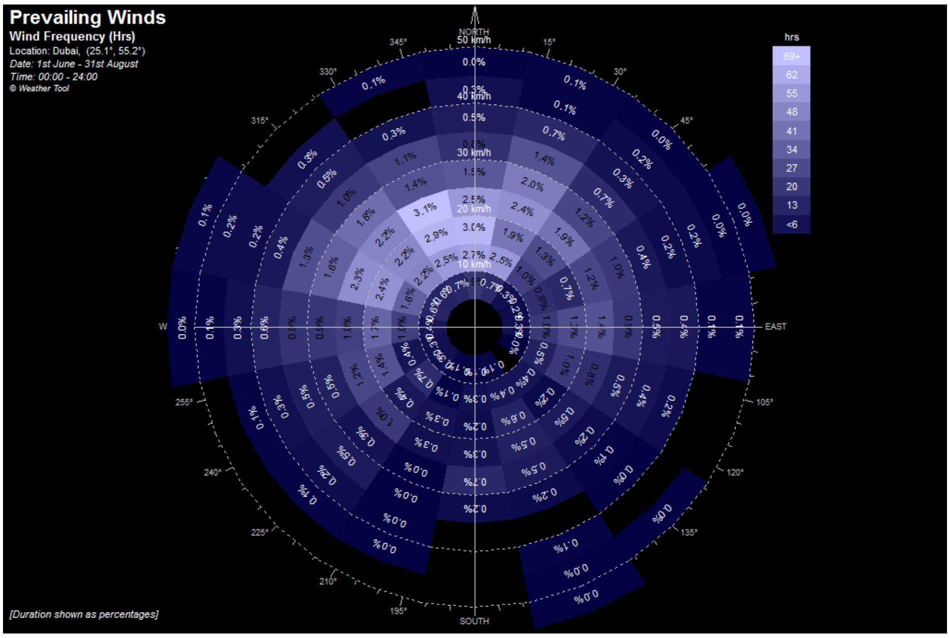


Figure B.6 Autumn prevailing winds

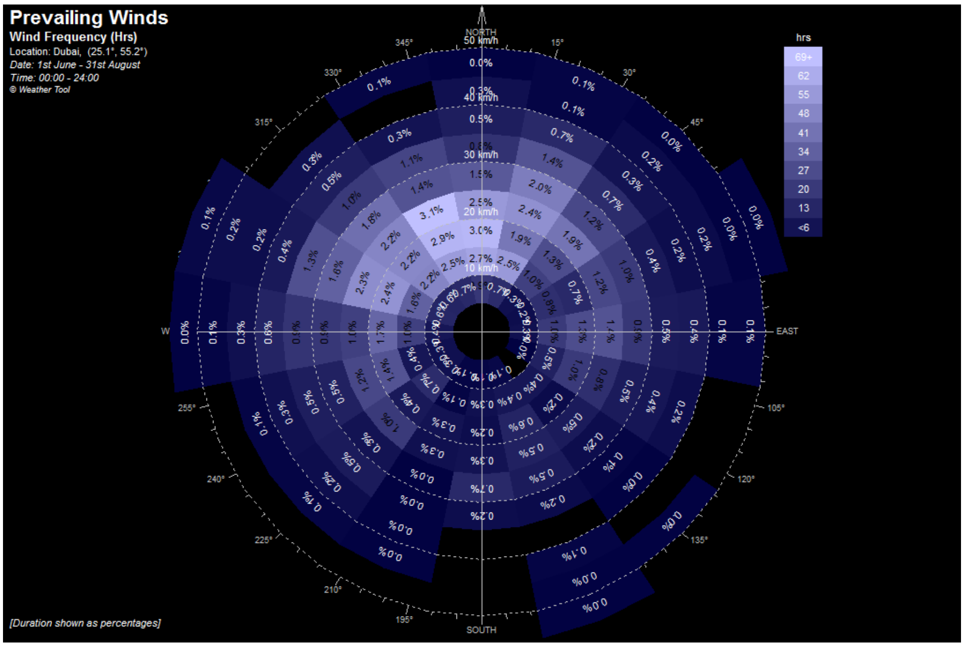


Figure B.7 Winter prevailing winds

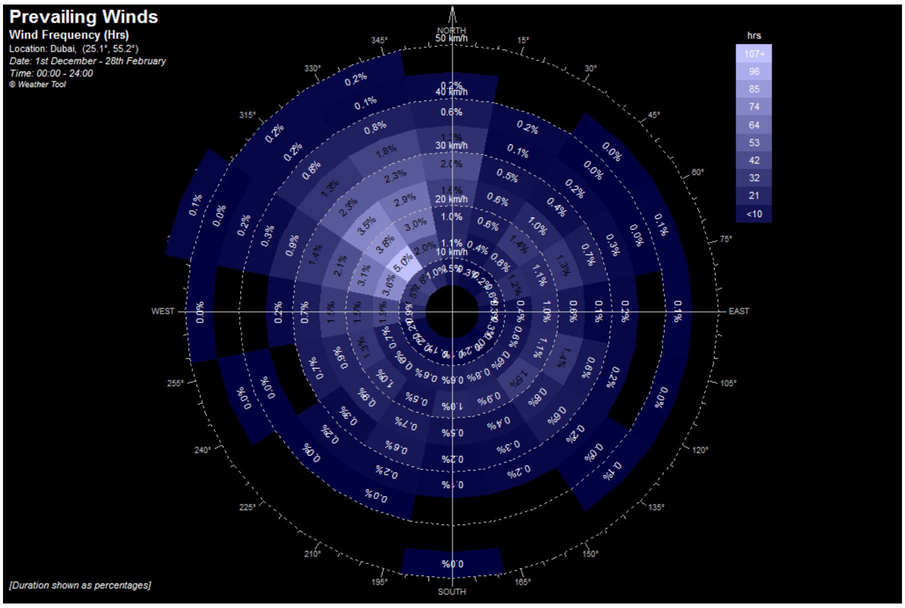


Figure B.8 Spring prevailing winds