The thermal performance of green roofs in the hot, humid microclimate

الاداء الحراري لاسطح المباني الخضراء في المناخ الرطب والحار

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خلاصه

تعمل الأسطح الخضراء على التخفيف من تأثير الجزر الحرارية في المدن وتنظيم درجات حرارة المباني وتوفير تأثير إيجابي على البيئة التي تتواجد فيها المباني والمساكن.

وتستعرض هذا الموضوع دليل التأثير البيئي مع اوبدون الأسطح الخضراء في المناخ المحلي الحار والرطب في الإمارات العربية المتحدة وتقيس الأداء الحراري باستخدام الأسطح الخضراء عبر موديل انفي-ميت بمقياس الميكرومتر في مرسى دبي. وتشتمل المؤشرات التي تم قياسها في هذه التجربة البياض السطحي ودرجات الحرارة الإشعاعية والتدفق الحراري الكامن وعامل منظر السماء ومعدل التصويت المتوقع والرطوبة النسبية.ونسبة عدم رضى الناس وسرعة الرياح وجرى دراسة التحسينات في المباني بالنسبة لتفاعلها مع الهواء عبر استخدام برنامج انفي-ميت لقياس التفاوتات في درجات حرارة الأسطح الخضراء. وتنبأت نتائج تقييم درجات الحرارة الإشعاعية ومعدل التصويت المتوقع في 21/ يونيو عند الساعة 13:00 مساءاً وبتاريخ 21/ديسمبر في تمام الساعه 13:00 مساءاً بوجود تغييرات في درجات الحرارة نتيجة إلى تأثير الأسطح الخضراء. في زمنين مختلفين في السنه والبياض السطحي خلال شهر الحر والرطوبه ومستوى التصويت المتوقع ونسبة عدم الرضى كانت هي المتغير السائد في التوثيق بسبب تأثير الاسطح الخضراء وعلى أي حال خلال اشهر الشتاء والتغير في معدلات درجات الحراره كان واضحا الاشعاع الحراري والرطوبه في ظروف مقياس مرسى دبي واشتملت القيود في موديل انفي-ميت على طوبولوجيا النباتات المستخدمة وغطاء التربة ويمكن للبحوث الإضافية بناء على تقنية الأسطح الخضراء المشتملة على مستويات المناظر الطبيعية وغطاء النباتات في دولة الإمارات العربية المتحدة أن تساعد صناع القرار في تقييم فعالية تطبيق الأسطح الخضراء.واثارها الايجابيه في البيئة المحيطه .

Abstract

Green roofs can alleviate the heat island effect in cities, regulate building temperatures and provide a positive impact on the built environment. This thesis reviews the evidence of the environmental impact with and without green roofs in the hot, humid microclimate of the UAE and measures the thermal performance of using green roofs on a micro-scale urban ENVI-met model of the Dubai Marina. The parameters measured in this experiment include Surface Albedo, Exchange Coefficient of Heat, Mean Radiant Temperature (MRT), Relative Humidity (RH), Predicted Mean Vote (PMV) , Percentage of People Dissatisfied (PPD) and Wind Speed. Improvements in plant to air interaction were studied using ENVI-met to gauge the temperature variations of green roofs. A study conducted on June 21st at 1:00 pm and December 21st at 1:00 pm depicted changes in temperature due to the impact of green roofs between the two different times of the year. During the hot, humid month surface albedo, PMV and PPD were the predominant changes documented due to the impact of green roofs, however during the winter months changes in temperature such as, MRT and RH were clearly visible in the ENVI-met simulations. From the documented findings, green roofs have shown a marked improvement in the thermal comfort levels of the surrounding built environment.

Acknowledgement

Firstly, I humbly and graciously thank the Lord God Almighty for blessing me with the opportunity to study at The British University in Dubai (BUiD) and succeed in writing this dissertation.

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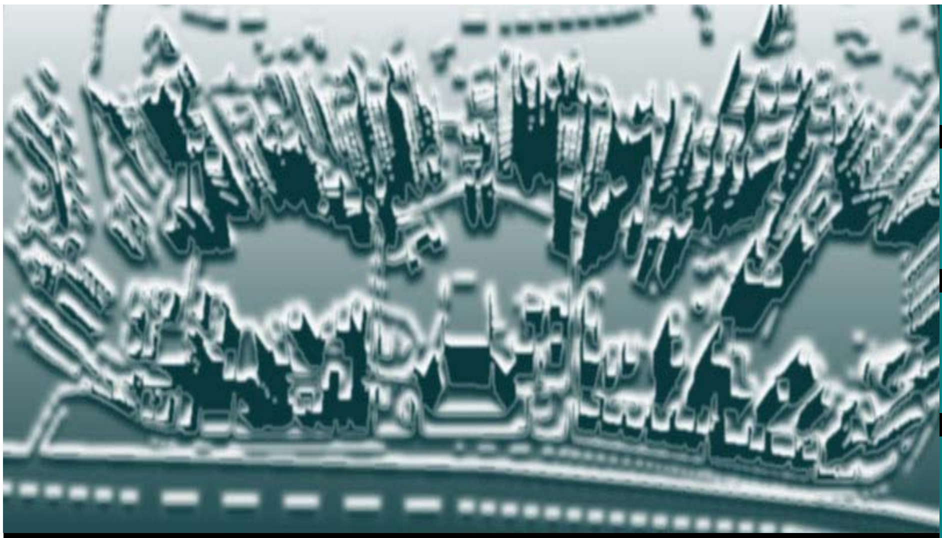

The Thermal Performance of Green Roofs in the Hot, Humid Micro-Climate

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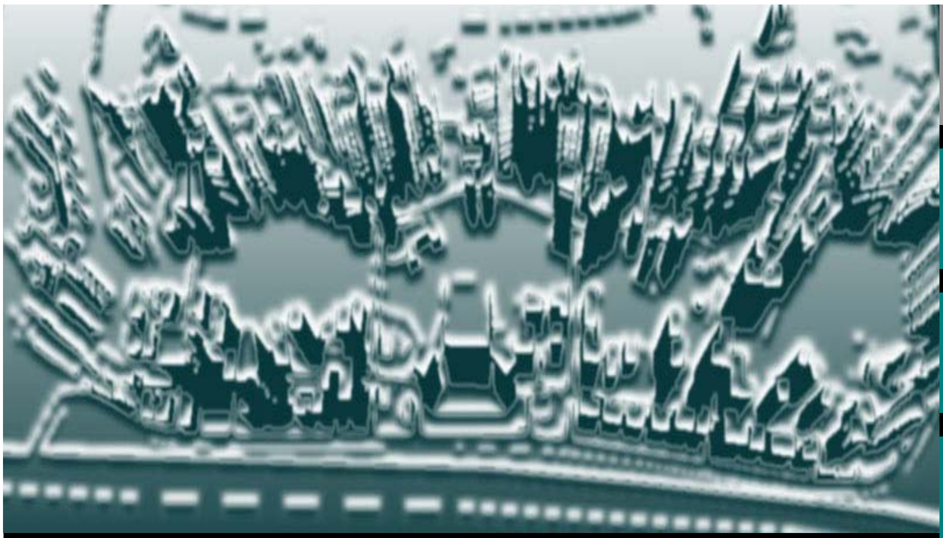


Chapter 1

Green Roofs: An Introduction

1.1 Introduction

Mahatma Gandhi believed that sustainability entailed an understanding of how our actions affect our environment, economy and community. He pronounced, “We must become the change we wish to see in the world.” Green roofs are a small step in this process (Cantor, 2008).

In hot humid regions using cooling strategies to aid energy savings and reduce pollution levels are of great necessity. The Dubai micro-climate in highly populated urban areas is characterized by a numerous buildings, infrastructure and hard scapes that absorb heat rapidly leaving massive hot spots, more commonly known as heat islands. In efforts to alleviate heat levels in the region, the Dubai municipal government adopted the green building initiative in 2008. This initiative encourages the use of green roofs on buildings because of the positive impacts on cooling hot areas, reducing carbon emissions and controlling energy consumption levels with in buildings leading to energy savings. Due to the high value of land in urban areas, there is an immediate need for green space alternatives.

Historically, green roof concept has been around for centuries, since 580 BC when King Nebuchadnezzar’s created the Hanging gardens of Babylon *(*Okeil, 2010). Today the global interest in the “green roof” or “roof top garden” has generated several benefits such as, substitution of productive land and possible usage for food production, controlling the urban heat island effect, integration of vegetation and soil as usable building materials; insulating and shielding the building form external climatic factors and noise, assisting in energy conservation, smart building operations, water management, urban infrastructure savings and economic benefits (Wong et al., 2003b).

Moreover, the environmental benefits include promoting biodiversity, reducing air pollution and dust, absorbing solar radiation by provision of reflective materials, creating attractive open spaces, providing wildlife habitat, opening more doors for re-using and recycling building materials, adopting stewardship and especially through the formation of areas that contribute to the health and well being of people.

Consequently, this research will explore the performance of green roofs in hot humid micro- climate, look at the current climatic situation, and study from literature review the past research taken on by academics. Assess the use of simulation software ENVI-met. Create a simulated comparison of a conventional roof versus green roofs under UAE microclimatic conditions. Formulate results and discussion based on the modelled scenario.

1.2 Global Concern and Motivation

Climate change and fears of global warming has emerged as an immediate concern. The UN Climate Change Conference held in Cancun, Mexico December 11, 2010 addressed these concerns. During this conference, governments of the world came together and agreed to work towards a low-emissions future (UNEP, 2010). It has now become clear that resistance is futile and action to address global warming should be executed immediately by all governments.

The initiatives clearly laid out at the conference aimed at offering environmental strategies, technologies and financial support approximately US$30 billion up to 2012 and US$100 billion in long-term funds by 2020 (to be raised) to assist developing countries meet the necessary global environmental targets. An agreement reached by all countries to meet global environmental targets involved the development of an agenda in which a below two degree 2°(Celsius) temperature rise is maintained (UNEP, 2010). Under this program countries are required to prepare a progress report every two years, advance low carbon development and implement strategies, technologies and market mechanisms to achieve low carbon results.

UN Climate Change Conference 2009 in Copenhagen addressed emission reduction suggesting that changes in infrastructure and policy would enable nations to meet 2020 temperature targets (UNEP, 2009). Urban planning and policy has to incorporate smart city planning solutions to mitigate Green House Gas (GHG) emission. The World Energy Council’s “Energy and Urban Innovation” report declared that by 2025 the number of mega-cities in the world are expected to rise from 2 (New York & Tokyo) in 1950 to 27. Cities that experienced a high population growth rate between 1975 and 2005 are Shenzhen (China), Dubai (Arab Emirates), Lagos (Nigeria) and Dhaka (Bangladesh), rising annually by approximately 5-10% (World Energy Council, 2010). The world’s energy demands are rapidly rising to meet the needs of the growing population. These demands are repetitively straining the earth’s natural resources leading to the question; “Do we have enough?”

Lester Brown founder of the World Watch organization, head of the UK Sustainable Development Commission and author of the book “World on the Edge: How to Prevent Environmental and Economic Collapse,” has forewarned of a development crisis in 2020, calling it the “ultimate recession,” resulting in a collapse of financial and economic systems due to food shortages, water scarcity, accelerating climate change, mass migration and high oil prices. He divulged that no generation has faced a challenge with the complexity, scale, and urgency of the one that we face (Brown, 2011). Over the decade’s reports of forests and habitat losses, endangered species, limited water supply, declining food supply and increased global warming temperatures have cautioned people and governments. Brown’s book is a catalyst for conveying the severity of climate change outlining the definitive role owned by our generation: “Change”.

1.3 The UAE Situation: Population

The UAE population expected to grow at an alarming rate by the year 2050. The country has experienced rapid development and multiple strains on the available resources. The UAE is the second largest economy in the GCC region. The UN Conference on Trade and Development (UNCTAD) projected a UAE population increase from 4.7 million in 2009 to 6.1 million in 2020, nearly doubling its current size to 8.25 million in 2050 (UAEInteract, 2010). The continual population growth has resulted in an increase in demands for energy, food, water, shelter and development. Habitat restoration, water management, food production and green spaces are vital in sustaining the environment and mitigating temperature rises.

1.4 Green Roof Fundamentals

Modern day climatic conditions require innovate solutions, such as green roofs to mitigate urban heat islands in dense cities. Green roofs are vegetated roofs that can be accomplished through construction of extensive, semi-intensive and intensive green roof systems. The difference between the three systems is explained on Table 1 (below) of section 1.4.1.

1.4.1 Types of Green Roof Systems

Table 1 below represents the details of three different types of green roof systems comparing the unique abilities of each. The *Extensive* green roof requires limited load bearing capacity and less initial investment costs compared to *Semi-Intensive* and *Intensive* green roofs. The mineral substrate layer is not deep and only substantial for low growing plant communities. Drought tolerant plants are the preferred species for this roof as they prone to sun exposure, wind and drought. Where as *Semi-Intensive* green roofs can range between *Extensive* and *Intensive* systems. It holds a higher load bearing capity and requires more initial investiment capital. It has a deeper substrate level allowing for a variety of plants with less resistance. *Intensive* green roofs on the other hand have no design or load limitations, are costly, require more maintainence and a harmonious plant community, that can accomodate several design and water features (IGRA, 2010). The knowledge of the three green roof systems are significant to specialists in the field when deciding which type of system can accommodate the roof type depending on load bearing conditions and costs. *Extensive* roofs are most common in urban areas when considering retrofitting because of load-bearing concerns, maintenance and irrigation requirements. Further study in the following chapters will determine the performance of using either systems depending on types of plants use and coverage.

Table 1. A comparison of the three different forms of Green Roofs (IGRA, 2010).

	Extensive Green Roof	**Semi-Intensive Green Roof**	**Intensive Green Roof**
Maintenance	Low	Periodically	High
Irrigation	No	Periodically	Regularly
Plant communities	Moss-Sedum-Herbs and Grasses	Grass-Herbs and Shrubs	Lawn or Perennials, Shrubs and Trees
System build-up height	60 - 200 mm	120 - 250 mm	150 - 400 mm on underground garages > 1000 mm
Weight	60 - 150 kg/m^2 13 -30 lb/sqft	120 - 200 kg/m^2 25 - 40 lb/sqft	180 - 500 kg/m^2 35 - 100 lb/sqft
Costs	Low	Middle	High
Use	Ecological protection layer	Designed Green Roof	Park like garden

1.4.2 Green Roof Layers

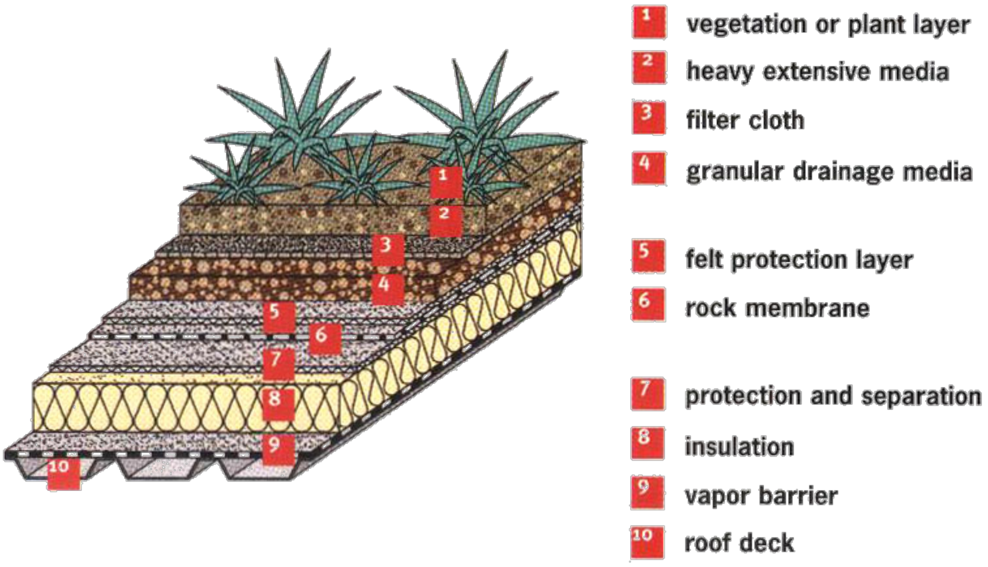


Figure 1: Green Roof Layers (Cantor, 2008).

Green roof construction is composed of several layers from the base roof deck to the plant layer (See figure 1). The vegetation layer being the top layer needs to be carefully selected as the type of vegetation used can affect green roof performance levels. Plant diversity is recommended for green roofs that help in withstanding infestations, low nutrition and reduced maintenance. Plant selection is based on the different climatic zones and dependant on resistance to extreme conditions (Cantor, 2008). The Crassulaceae plant family can survive the harsh green roof environments, easily absorb carbon dioxide and is cost effective (Luckett, 2009). It is essential to select plants that can survive its regional microclimate.

Heavy Extensive Media or growing substrate is more commonly referred to as soil. Light-weight soil mixes is primarily top soil and media weight is a primary concern. Reducing the growing media minimizes costs (Cantor, 2008). The chosen top soil must consist of a mix organic and inorganic soil to ensure effective growth and plant survival, (Luckett, 2009). The filter fabric is used to prevent particles from reaching the drainage layer. The granular drainage media consisting of synthetic or composite layer collects excess water and directs it to the water management system through external or internal drains in the design (Cantor, 2008).

The felt protection layer is used to prevent the roots from penetrating the waterproofing. The membrane sheets are sealed to ensure no gaps are available for the root to penetrate (Dunnett and Kingsbury, 2008). Insulation can limit heat gain or loss depending of design system (Cantor, 2008). Waterproofing consists of a lot of different materials and is a necessary component in greet roof design (Dunnett and Kingsbury, 2008). It ensures durability of the roof system. The roof deck can be reinforced concrete, precast concrete planks, steel and steel concrete composites. The type of deck chosen is dependant on the green roof system type (Cantor, 2008).

1.5 Urbanization in Cities and Green Roofs

In this present generation, more people are moving to cities in search of economic opportunity to improve their living standards. Cities are currently degrading the environment by consuming large amounts of energy and producing excessive amounts of waste. The only beacon of hope to the current generation is to make these cities more sustainable. Kisner (2008) citing the US National Research Council states that by 2030, 4.1 billion people will be living urban areas in the middle and low income countries where 3.1 billion live in rural areas. To combat threats of food security and poverty many cities have turned to urban agriculture. Green roofs are a promising potential for urban agriculture due to high land values and minimal green space.

Urban development seeks to provide infrastructure, greening, transport, food, social and health networks. Rapid urbanization has led to many environmental consequences in cities all contributing to global warming. UHI is a result of high temperatures in city, due to loss of greenery, building development and paving. The albedo in these hard surfaces has significantly increased. Albedo is known as the amount of energy a surface reflects and radiates. Albedo is measured on a scale of 0-1(hottest to coolest).

High temperatures in urban areas range from 2-8 °F than the surrounding areas. The intensity UHI depends on climate, topography and urban design. Continuing trends are leading to global warming on a large scale. As global warming continues, heat islands will grow. Hard and dark surfaces contribute greatly to this phenomenon absorbing heat energy and radiating it back into the air. Gravel roofs contain 0.08 albedo compared to grass which is 0.25 and 0.6 for reflective roofing. Aphsalt and concrete roofs play a major role in the heat island effect (Earth Pledge, 2005). See figure 2 for an example of UHI effect in Dubai, UAE where peak effect is shown in the dense urban downtown area of Dubai.

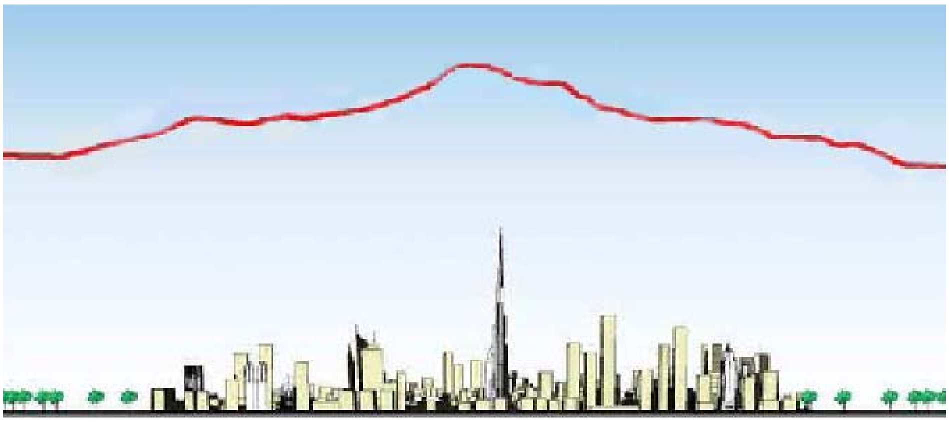


Figure 2: UHI effect in Dubai (DM, 2009).

1.6 Dissertation Aim and Objectives

This research will explore the thermal performance of green roofs in hot humid micro-climate. Green roofs are an effective way of incorporating aesthetically pleasing green areas with in a city while capitalizing on land values and integrating green spaces in building. This will be done by assessing the outdoor thermal comfort parameters such as, surface albedo, exchange coefficient of heat, mean radiant temperature (MRT), relative humidity (RH), predicted mean vote (PMV), percentage of people dissatisfied (PPD) and wind speed. A look into the green roof contribution to the built environment can validate the expected results that will ensure green roofs as a recommended necessity for a sustainable future.

Objectives of this research involve:

1. To research the thermal performance of green roofs as a means to mitigate urban heat islands by literature review and ENVI-met simulation.
2. To test the strategy for introducing vegetation on the roof system in the hot humid UAE climate.
3. To research the potential environmental ratings achieved in the utilization of green roofs by the LEED and Estidama rating systems used in the UAE.
4. To study heat levels in a dense urban area in the UAE by analysing the Dubai Marina as a case study.
5. To incorporate green roofs in dense urban areas and test the potential environmental benefits if any.
6. To draw conclusions from the results of the green roof experiment and discuss the potential implications of using green roofs.

1.7 Dissertation Organization

The dissertation organization following the introduction investigates through literature review in chapter 2, the performance measures of green roofs, the benefits and challenges of using such system and parameters and variables effecting green roof thermal performance. Chapter 3 details the research methodology and the steps taken to formulate the research with insight into the back ground work done. Chapter 4 tests green roof performance levels through simulation a discussion and results of which follows in chapter 5. Chapter 6 concludes the investigation with potential outlook further research and development. The details of the chapters are listed as follows:

- **Chapter 2: Measuring Green Roof Performance**
  Chapter 2 will include a literature discussing green roof systems. This will include the benefits and challenges of using such system, the parameters used to measure performance, life cycle analysis and case studies.

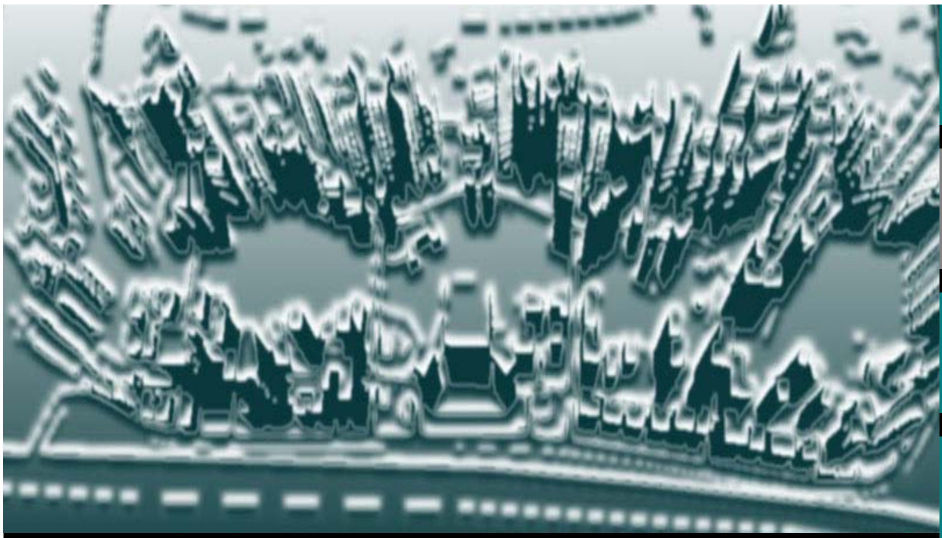
- **Chapter 3: Investigating Green Roof Research Methods**
  Chapter 3 will study previous experiments and simulations conducted to investigate the scope of research. A recommended research tool and chosen research method will be discussed and validated.

- **Chapter 4: Defining the Green Roof Experiment**
  Chapter 4 will highlight the context of the green roof experiment and model configuration. The ENVI-met inputs and simulation procedure of the base model with a conventional roof and green roof model will be defined.

- **Chapter 5: Results on Green Roof Thermal Studies**
  Chapter 5 will engage discussion on the results drawn from the simulation study evaluating the performance levels based on the parameters measured in the modelled environment.

- **Chapter 6: Conclusions and Recommendations**
  Chapter 6 will conclude addressing the research question, the benefits of some scenarios as opposed to others, the challenges faced during the experiment and recommendations for future research.

Green roofs have been utilized for many innovative creations since the hanging gardens of Babylon. Global concerns have changed our perception of the world. Rapid urbanization has led to demand for improvement in the way we perceive cities and green roof are an imperative factor in that process. Chapter 1 introduces the green roof fundamentals, dissertation aim, objectives and organization. In chapter 2 we will take a look into the potential benefits and disadvantages of green roofs in the UAE and evaluate green roof performance through literature review.



Chapter 2

A Closer Look At Green Roofs In The UAE

2.1 Introduction

Why green roofs? Chapter 2 measures green roof performance by studying the benefits and challenges in utilizing green roofs. The thermal performance of green roofs is then assessed looking at the variables that are measured to achieve reasonable comfort levels. These variables can be studied by any designer, architect, engineer or green roof professional involved in the design process. An in depth analysis on the variables considered in vegetation selection, water management, life cycle cost analysis and local rating systems practised also detail the thermal performance of green roof in the hot humid micro-climate.

2.2 Climate

The UAE climate is generally hot and dry. According to the climate data from National Center of Meteorology and Seismology in the UAE (2010), temperature ranges from hot humid summer months reaching a high of 48 °C (118.4 °F) to warm winter months reaching a minimum of 14 °C (50 and 57.2 °F). Humid south-eastern winds (sharqi) dominate the coastal region during the summer, where as cool north-westerly winds (shamal) develop during the winter months. Humidity is high during the summer reaching over 90% but declining to 50-60% in the coastal regions during the winter. Rainfall is limited arriving in short sharp bursts during the winter months. Thunder and dust storms occur during the summer accompanied with severe flash floods over the south east mountains. The region is characterised by regular formation of dew that assists in the survival of plants and wildlife.

2.3 Assessing Green Roof Performance

In assessing green roof performance, it is important to look at the benefits and challenges faced in the design of green roofs, especially when accommodating for the UAE micro-climate. The benefits of green roofs involve investigating its performance and contribution to urbanism in the UAE and its micro-climate. It is important to also consider the challenges that can affect performance such as, location, internal and external factors than can be adapted for optimised performance.

2.3.1 Benefits of Green Roofs in the UAE

Mass Urbanization, global warming, limited availability of land space and food security are issues confronted by the UAE. The UAE government has adopted the green roofs policy to combat these concerns. Dubai Municipality (DM) launched the green roof initiative with hopes of raising the city's green area per capita to 23.4 square meters by the end of 2011 (Green Roofs, 2010). The focal idea behind using green roofs is to positively contribute the building of Green roofs to the Built Environment. The several benefits include:

Benefit 1: Mitigating Urban Heat Islands

With concerns of the UHI phenomanon heightening global warming and its threat to human health, many steps are being taken to alleviate the situation. Green spaces naturally cool urban areas reducing heat levels. This cooling is reached through evapotranspiration, a heat induced process of water evaporating from plant transpiration or plant s weating. According to Green Roofs for Healthy Cities in short, GRHC (2010) a vegetated area of $1m^2$ through process of evapotranspiration can vaporise 0.5 liters of water in one day evaporating a yearly rate of 700 liters/ m^2 .

Alexandri and Jones (2008) found through their study of an urban canyon that green roofs and walls can decrease temperatures and solar radiation impact depending on the amount of vegetation placed on a surface. If placed in a microclimate model of an urban block, then the temperatures with in that block will reduce, if placed on a city scale level then temperatures city wide will reduce (Alexandri and Jones, 2008). As governments strive to maintain a below 2° temperature rise, the implementation of green roofs in a city or cities can mitigate UHI and combat carbon emissions.

Vegetating roofs predominantely consistant of hard reflective surfaces can also mitigate heat islands by filtering dust and smog that contribute to global warming. Although it is still uncertain how much foliage is required to significantly reduce temperatures, a modelling study was conducted at the University of British Columbia by Dr. Brad Bass and others, supervised by Dr. Roland Skull to test the potential temperature reduction. The mesoscale atmospheric simulation measured the city's current UHI reduction by vegetation to be 1°C over a 1/4 city area which extended to 1/3 when applied a 50% green roof scenerio. The maximun cooling achieved with green roof coverage was 2°C.

Further study showed that only 6% green roofs were actually irrigated as the model decreased irrigation in non-urbanized areas concluding that less than 50% of green roofs were required to realize the temperature reduction (GRHC, 2010). The exact percentage of green roofs could not be determined as a number of uncertainties were prevelant in the model. However, a detailed simulation studying the necessary paraments and levels of temperature reduction achieved using a range of 5% to 50% could give a more accurate approximation. Climate factors effect the data output and a modelling study for regional testing is recommended and will be investigated in this hypotesis.

Benefit 2: Air Quality

Urban areas of the city are highly polluted with dust, smog, nitrogen oxides, carbon monoxides, diesel exhaust gases, etc. Vegetation can filter the air by trapping harmful particles (Cantor, 2008). The International Green Roof Association (2010) reported a 0.2kg/ annum filteration capacity for pollutants. Green roofs can greatly benefit the hot humid UAE climate by filtering the high dust levels and polluntants accumulated in the city. Depending on the size and capacity of green roofs the potential to reduce air pollution can contribute immensely to the health and livehood of the inhabitants.

Benefit 3: Acoustical Insulation

The International Green Roof Association (2010) reports that use of green roofs can result in a sound reflection reduction by 3 dB and improve sound insulation by 8 dB. Acoustical insulation is particularly important when considering when to live. Vegetation and soil provides an effective barrier for shielding electromagnetic waves caused by airplanes, trucks, cars and machinery. Green Roofs for Healthy Cities (2010) recorded that a substrate layer of 12 cm can reduce sound by 40 decibels and 20 cm thick layer can result in a noise reduction of 46-50 decibels. With the ongoing construction in residential areas of the UAE, acoustical insulation can shield residents from construction works and machinery. In commercial environments this can prevent possible disruption to the work environment, enhancing productivity.

Benefit 4: Water Management

Water conservation using Green Roofs could be a very instrumental in water management. In 2006, the Environment Agency of Abu Dhabi (EAD) expressed the need for efficient water management techniques based on concerns of depleting water resources over the next 50 years (EAD, 2006). Green roof systems can effectively reuse grey water to reduce wastage. In hot humid climates storm water management through green roofs can be highly beneficial in accommodating for periods of heavy rain. Heavy rains in Dubai during January, 2011 caused flooding in residential areas due to over taxed drainage systems (See figure 3).

Figure 3: Drainage in Dubai (Gulfnews, January 17, 2011).

Green roofs can temporary delay water run-off by 50-90% depending on the type of growing medium or strata used (See figure 4). GRHC (2010) stated that the graph represented in figure 4 compared the cumulative rainfall and runoff from the green roof and the reference roof during a 34mm rain event over a 15hour period in October 2001. Results suggested that the green roof delayed runoff and reduced the runoff rate and volume. Delaying runoff to the local water system can relieve overloaded drainage systems during peak over flows. Green vegetated roofs with strata of 4 – 20 cm can hold up to 10-15 cm of water (GRHC, 2010). This retention is also dependant on field capacity, porosity, geo-textile layer, water retention, flow and relief drain spacing (DM, 2009).

A study by Environment Canada on the city of Toronto found cost savings of $14.5 million (CND) by using green roofs as a storage tank for the city costs $60 million (CND), greening six percent of the city’s roof would cost $45 million (CND) and retain 3.6 million cubic meters of water per year (Earth Pledge, 2005). This water eventually gets picked up by the natural water cycle through transpiration/ evaporation. Besides temporal delay, green roofs can moderate water temperature and filter water through its substrate before reaching the drains (GRHC, 2010). Berndtsson (2010) found that higher values of acidity, ph 5 or 6 can be reduced to ph 7 or 8 controlling ph levels and mitigating mild acid rain. According to Velazquez (2005), self-sustainable passive water retention systems can be developed by welding the protection membrane with ponding elements on a roof with a 4 % slope. During summer periods, green roofs can retain 70 – 90% of precipitation, where as in winter this percentage is reduced to 25-40%.

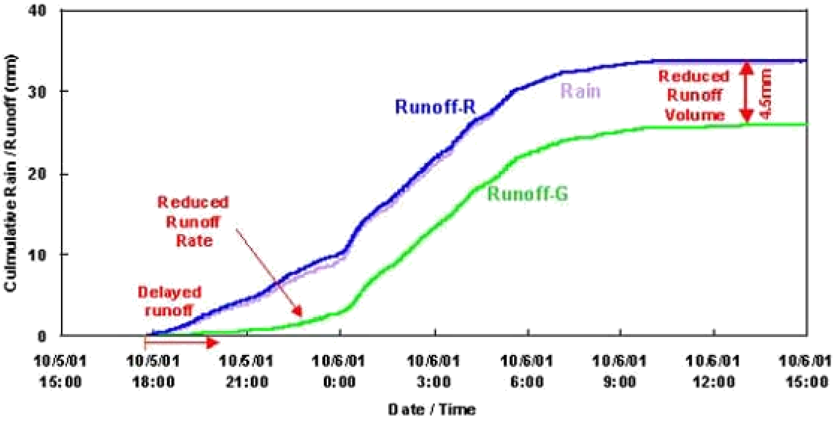


Figure 4: Water run off rates (NRCIR, 2002 in GRHC, 2010).

Benefit 5: Heat Insulation

Vegetation and soil can absorb surface heat Green roofs have been used to insulate buildings. Velazquez (2005) citing Chris Wark engineer and energy modeler of green roof innovations explained that solar heat is managed through foliage and thermal mass of soil substrate where as leaf transpiration results in solar hear being transferred to the air. Insulation properties can be maximized through use of external shading devices, type of growing medium, soil density, moisture content and choice of plant leaf area index (LAI). Higher moisture content in plants and a higher LAI (size of leaves) can result in better insulation rate and carbon emissions reduction (Velazquez, 2005). Velazquez (2005) also reported that green roofs reduced internal cooling by 30% when compared to conventional roofs with an R-18 value. This study reported the reduction of thermal resistance values (R-Values) using DOE 212 modeling tool. Cooler ambient air temperatures can significantly reduce taxation on air conditioning systems.

Benefit 6: Materials with a Suitable Solar Reflective Index

The type of materials used on the roof has an impact on the temperature profile. A conventional asphalt roof could reach 160°F on a hot summer day where as a vegetated roof can reach up to 80°F. The type of soil substrate, depth and foliage also affects the temperature efficiency of green roofs. The thicker the soil substrate the higher the U-values suggesting better insulation. Soil density can affect moisture content and less dense soil having more air pockets has higher U-values. High moisture content in soil can increase heat conductivity so a dryer soil condition is recommended (Castleton et al. 2010). The energy saving potential of materials used can determine heat gain/ loss into buildings. In the UAE, it is suitable to select materials that can result in a reduction of heat gain into the building which will in turn, increase indoor thermal comfort levels and reduce taxation to the air conditioning systems.

Benefit 7: Economic Benefits

Several economic benefits exist with the development of the green roof industry, such as creation of employment opportunities, higher initial costs can be offset through the life cycle cost analysis (Discussed in 2.4). Possible municipal benefits can be incurred through water management resulting in economic incentives. Using green roofs protects the roof structure extending the life span of the roof by decreasing maintenance costs and energy costs. A study conducted by Environment Canada using a Micro Axess Simulation achieved a 25% cooling needs reduction (GRHC, 2010). Reducing cooling needs in the UAE climate can reduce energy requirements by the city. Concerns for future energy sources are highly evident with the UAE seeking nuclear power as an alternative energy source, any measures to alleviate energy requirements is welcomed.

Benefit 8: Increasing Photovoltaic Efficiency

In some developments green roofs are combined with photovoltaic's to enhance solar performance using the limited land space available. This is done by providing a steady base for the installation and through modulating surface temperature fluctuation (Cantor, 2008). Dunnett and Kingsbury (2008) citing research from Kohler et al. (2007) suggested that care will have to be given to ensure that plants do not over lap the photovoltaic panels. Combining green roofs and photovoltaic power can be a great resource in this region because of the abundant solar resource available in the UAE through out the year. Further studies to incorporate green roofs and solar power in this region are highly recommended.

Benefit 9: Habitat Restoration

As more land areas are paved and urban areas are populated with buildings, habitats and ecosystems are destroyed. Many countries are facing rapid extinction of several wildlife species due to mass urbanization. Green Roofs restore habitats and promotes biodiversity by compensating for the limited land space available in cities. The International Green Roof Association (2010) reports that rare wildlife species are harboured on green roofs and contributes to the unique character of the eco-system. The Chicago City Hall building accommodates a 22,000 sq.ft. green roof with a soil depth of 4in, 6in,18in housing 150 varieties of trees, vines, grasses, shrubs and plant species (Earth Pledge, 2005). Biodiversity ensures a healthy soil life and a well balanced eco-system.

Benefit 10: Enhance Food Production

Food production has become an immediate concern in cities. Alarmed governments facing issues such as limited land available for food supply and high transportation costs has led to governments considering ideas of self-sustaining cities. Green roofs designed for urban farming and food production can benefit from fresher produce, local food production and access, transport, distribution and controlled levels of fertilizers and pesticides (GRHC, 2010). Green Roofs for Health Cities (2010) reports that The Fairmount Waterfront Hotel in Vancouver incurs a savings of $30,000 a year by growing its own herbs, flowers and vegetables on its roof. Dunnett and Kingsbury (2008) stated that herbs grow best in sunny situations with free draining soils. The UAE can benefit from producing its own food variety on green roofs and reducing it reliance on imports from other countries. Hotels and residents stand to benefit more acquiring fresh produce. Caution should be practised when determining the type of produce available for the hot humid micro-climate, soil typology, green roof structural loads and maintenance.

Benefit 11: Environmental Monitoring

With the development of new technologies, green roofs installation can be measured to determine the impacts of usage on an urban scale. These technologies can measure variables such as, air temperature, green roof temperature at different times per day, the amount of water absorbed, storm water run off, increase in bio mass of plant materials, acoustical and solar insulation and leakage (Cantor, 2008). These technologies can assist in testing the performance of green roofs on a regional scale to determine the impact of vegetated roofs on certain climatic zones (this will be looked at in detail on chapter 4.)

Benefit 12: Aesthetics, Impact on Health & Worker Productivity

Green roofs or roof gardens can be used for recreation facilities, roof cafes and sporting areas. The multi-purpose use of roofs gardens extend from social environments to work and city environments. Green areas are known for soothing the human psyche. This concept is theorized to come from human evolutionary heritage Biophilia (a connection between humans and nature.) The notion of biophilia is popular, as roof gardens are known for its therapeutic effect in hospitals, hotels, offices and urban centres adding to the emotional and physical comfort of employees by alleviating stress levels and increasing productivity in urban districts (IGRA, 2010). Green roofs and gardens are also known to improve property values and building marketability (6 to 15% to home value according to British and American standards). The St. Luke’s Science Center Healing Garden in Tokyo, Japan facilitates for rehabilitation, exercise and socializing on the urban city vegetated roof open to hospital patients and public (Earth Pledge, 2005). Incorporating green roofs can add to environmental aesthetics, enhancing the space and inducing positive emotions/ impacts to all inhabitants of the city. In dense urban cities green areas can create a sense of serenity, providing for a quiet getaway form the every hustle and bustle of city and relieving stress levels that can affect health.

Benefit 13: Stewardship

Green roof development can educate people on the climatic concerns facing the environment and the preventative measure that can be taken (Cantor, 2008). Well designed green roof can serve as an example for other developments to progress in a sustainable manner. It can serve as a case study in the UAE for other developments to follow suit. A well designed innovative green roof can inspire other building designs.

Benefit 14: Indoor Air Temperature

During the summer periods Green Roofs can greatly reduce indoor air temperatures by reducing solar radiation impacts on roof tops, thus reducing cooling loads with in the building, decreasing air-conditioning usage and save on energy consumption (Earth Pledge, 2005). Alexandri and Jones (2008) estimated that energy consumptions of buildings using green roofs can result in a 32% to 100% savings. Meeting Indoor thermal comfort levels in the hot humid climate is a challenge. Using green roofs can meet with high savings contributing to immediate returns on investment from reduced energy consumption.

Benefit 15: Increased Roof Life

Conventional roofs are sujected to temperature differences of more than 100°C during the year with a change in 60°C over a span of 24 hours. In hot-humid climates, high levels of solar radiation accelerate this aging process, resulting in material fatigue, shrinking, cracking and leakage. Green roofs can sheild the roof from harsh UV rays and can keep the structure cool, thus increasing the life span. According to the International Green Roof Association (2010), this vegetation buffer can reduce temperature stresses by 35°C per annum and 15°C over a spam of 24 hours (IGRA, 2010). Increased roof life can result in a returns of investment over roof life span. Concerns faced by developers in the UAE involve short term returns on investment and other areas of costing will be further discussed in the Lifecycle Ananlysis section 2.5.

Table 2 (overleaf) represents a comparative study conducted in the USA of green roofs versus conventional eco-roofs suggesting that although conventional roofs excelled in being of lower initial investment costs the environmental benefits of green roofs out numbered the cost benefits of conventional roofs. Green roofs may have long term financial returns on investment however the environmental returns can be incurred immediately.

Table 2: A comparison between conventional and green roofs (Earth Pledge, 2006).

Table 1-2. COMPARISON OF ECO-ROOF AND CONVENTIONAL ROOFS

Subject	Ecoroof	Conventional Roof
Storm Water		
Volume Retention	10-35% during wet season, 65-100% during dry season	None
Peak Volume Flow	All storms reduced run off peaks	None
Temperature Mitigation	All storms	None
Improved Water Quality	Retains atmospheric deposition and retards roof material degradation. Reduced volumes reduce pollutant loadings	No
Urban Heat Island	Prevents temperature increases	None
Air Quality	Filters Air, Stores Carbon, Increases evapotranspiration	None
Energy Conservation	Insulates Buildings	None
Vegetation	Allows season evapotranspiration, provides photosynthesis, oxygen, carbon, water balance	None
Green Space	Replace green space lost to building footprint, although not equal to a forest	None
Zoning Flooring Area Bonus	3ft^2 to 10.28m^2 added floor area ratio for each eco-roof ft^2 when building cover over 60% (in Portland)	None
City Drainage Fee Reduction	To be determined, maybe up to 35% in Portland	None
Approved as storm water management	For all current city requirements (in Portland)	No
Habitat	For all current city requirements	None
Livability	Buffers noise, eliminates glare, alternative aesthetic, offers passive recreation	None
Costs	Highly variable from \$5-\$12 per square foot (\$53-8 - \$129.12m^2) new construction and \$7-\$20 ft^2 (\$75.32-\$215.20 m^2) retrofits	Highly variable from \$2 -\$10 per square foot (\$21.52 – \$107.6 per m^2) new construction and \$4-\$15 per square foot (\$43.04 m^2 -\$161.40 per m^2) retrofits
Cost Offers	Reduced storm water facilities, energy savings, higher rental value, increased property values, reduced need for insulation materials, reduced waste to landfill, add jobs and industry	None
Durability	Waterproof membrane protected from solar and temperature exposure lasts more that 36 years; membranes protected from operations and maintenance staff damage	Little protection, exposure to elements, lasts less than 20 years

Addressing the benefits of green roofs is necessary in observing the overall performance of green roofs however equally important are the challenges faced in the design process. These conditions are required to meet the builder’s needs, governmental and technical system codes and regulations. Further detail on the challenges involved in green roof design will be detailed in the next section.

2.3.2 Design Challenges facing Green Roof Implementation

Optimal performance of green roofs involve design challenges that should be confronted considering features such as, roofing loads, wind, location, installation costs, accessibility and types of plants selected. Investigating these conditions ensures a successful performance rate of green roofs and durability.

Challenge 1: Load Bearing Considerations

A number of developments considering green roofs but the main question arising is “Can buildings sustain the loads of green roofs?” There are different load bearing requirements for the each type of green roof system. These loads should be considered in the initial design of buildings. According to the IGRA (2010) the new structural design standards (Eurocodes) have introduced changes to the loading code suggesting that existing building have the reserve capacity to sustain green roof loads. A mandatory structural assessment by a professional body should be carried to establish load capacity especially when considering intensive roof design which not only requires load consideration but depth for plant roots. Climate conditions also determine the load bearing capacity of the roof, in Northern regions of the world, roofs are designed to accommodate for snow loads. These loads are not prevalent in UAE climate and therefore should be advised upon by the regulatory authority.

Challenge 2: Wind Factor Pressure

Green roofs are vulnerable to wind uplift (See figure 5). Dunnett and Kingsbury (2010) noted that green roofs are susceptible to varied surface pressure on flat roofs and mostly intense near the edges and corners. Preventative measures to reduce vulnerability can be done by ensuring that the waterproofing is bonded to the roof with a strip of gravel, stones, pavers, around the edges. This acts vegetated barrier for protection against wind damage to plants. FFL German Guidelines and Green Roofs for Healthy City Guidelines studied a variety of ballast to protect green roofs from wind uplift. Design conditions for wind uplift studied by Green roofs for Healthy Cities (2010) can be seen in Appendix B.

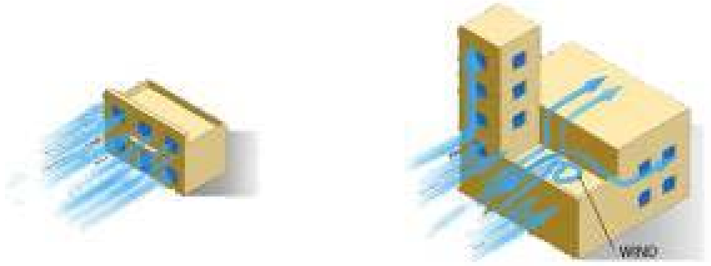


Figure 5: Wind Pressure on Buildings (DM, 2009).

Challenge 3: Location

Dubai Municipality (2009) stated that the location of the green roof is instrumental in the design. Height, orientation, sun, wind and shading can affect the performance of green roofs. Views to and from the roof can also play an importance role is measuring the success criteria for green roofs, it impact on people and surroundings. Transporting plant material to green roofs can be expensive. It is important to consider local plant selection that responds to the climate and types of material selection when considering logistics.

Challenge 4: Accessibility

Access is crucial in green roof design as it is relevant for installation, maintenance, and material transportation. Healthy and safety regulations should be met if designed for public use and this can be done through creation of elevator and stairwell access (DM, 2009). Dubai Municipality (2009) mandates the compliance of United Arab Emirates Federal Law no. 25, 1999 Article 22 delegating access for Special Need users.

Challenge 5: Costs

Installation of green roofs should be carried out by an experienced professional as it can determine the success factor and longevity of the roof (Luckett, 2009). Installation costs can be high but successful installation can reduce maintenance cost and ensure increased roof lifespan. Okiel (2010) found that in some scenarios green roofs are not accepted because building ownership is restricted and at present there is no incentive offered to consider a long term payback period.

Challenge 6: Plant Selection

The right plant selection is essential in determining green roof performance. Plant selection is dependant on many factors such as, climate, project, roof load bearing capacity, depth of roof (to accommodate for roots), plant growth rate, timings, irrigation and maintenance (Snodgrass, 2006). In the hot, humid climate drought tolerant plants are recommend as they require minimal maintenance.

The type of plant selected can enhance performance rate of green roofs and alleviate heat island levels. A closer look into the impact of plant selection recommended for the UAE will be briefly covered in section 2.3, influencing green roof performance through plants.

2.4 Influencing Green Roof Performance through Plants

As discussed in the previous section, vegetated canopies moderate solar heat gain. They provide shading for the substrate reducing green roof temperatures. Dimoudi and Nikolopoulou (2003) documented the positive impact of vegetation on the microclimate through reduced solar heat gain on vertical and horizontal surfaces through shading, evapotranspiration during summer periods and increase latent cooling by evapotranspiration. Vegetation variables discussed in this section for successful performance of green roofs are leaf area density/ leaf area index, plant height, soil substrate, planted roof types and plant selection for hot humid micro-climates.

Leaf Area Density (LAD) and Leaf Area Index (LAI) represent the vertical leaf distribution of plants. Fahmy et al. (2010) modelled the LAD to get an accurate measure of the thermal performances of trees in metropolitan Cairo. The LAD profile of a modelled tree was developed based on assumed LAI values and uploaded into the ENVI-met data base. Other means of generating LAD values can be through field measure or empirical models. Fahmy et al. (2010) found that increased leaf density and tree height could contribute to better shading and solar interception. Theodosiou (2003) expressed foliage density and as Leaf Area Index (LAI) in simulation. LAI is defined as the flat upper leaf area of a tree. Wong et al. (2003) found that higher temperatures were measured under sparse foliage where as, more dense, thick foliage reduced temperature levels. Kumar and Kaushik, (2005) created parametric variations in LAI and thickness to stabilize the fluctuating values of solar heat flux. This resulted in a heat flux reduction of 4W/m2. Spala et. Al. (2008) found that increased LAI significantly reduced energy consumption levels of a school building in Athens Greece during the summer period by 15-58% resulting in environmental and economical savings.

Plant height determines the level of solar radiation regulated on green roofs. Theodosiou (2003) studied the temperature levels under low foliage and high foliage height and found that incidental solar radiation created heat flow inversion under low foliage height. High foliage height did not constrict air flow and heat exchange resulting in cooler soil surfaces by shading and transpiration. Plant height is restricted to the type of greening being used for the roof such as extensive, intensive or semi-intensive typology. In such scenarios building load considerations and climatic factors should be addressed in assuring effective thermal performance of roof.

Soil substrate has an impact on the thermal stresses of the green roof. A simulated study model of a field study in Florida conducted by Sailer (2008) using EnergyPlus found that thicker soil layers increased insulation levels. According to Wong et al. (2003 a & b) bare soil and foliage provide combined insulation to the roof and while foliage offers sun protection, wet soil can add to roof insulation. The surface temperatures were measured under a conventional roof type setting, vegetated roof and soil layer. It was found that heat transfer took place faster on ground than when covered with soil or vegetation. Ambient air temperatures measured at different heights were confirmed. It was found that there was no difference in humidity levels with or without plants. Radiation levels measured were substantially lower with vegetation areas than without proving that gardens assist in mitigating Urban Heat Islands. Theodosiou (2003) found that low ambient air temperatures combined with high thermal inertia lowered soil temperatures but stated that lower thermal roofs stress offer maximum cooling potential only under thick soil layers. Williams et al. (2010) found that Australian cities require increased substrate depths with minimal irrigation for various plant life forms to survive. Substantial substrate depth should be studied further for effective performance of green roofs in the UAE.

Planted roof type is determined by the type of selected vegetation for either extensive, semi-intensive or intensive greening. Theodosiou (2003) found that the type of planted roof can have an effect on the lag time of the thermal flux. Planted roof with high vegetated volume can create increased thermal inertia, shading and transpiration to provide cooling for day with extreme summer temperatures. The conducted study also found that medium vegetated volume can provide adequate cooling under extreme summer temperatures, while low vegetated volume provided poor protection under extreme conditions. Rosheidat and Bryan (2010) studied moisture content on vegetation on an irrigated grass lawn and found that the moisture enhanced cooling and reduced temperatures day time temperatures by 23.91°C reaching lowest at 19.91°C.Therefore from this study the importance of plant selection criteria on green roofs can have a signification impact on the thermal performance of green roofs in the hot humid micro-climate.

Plant selection as mentioned above is an important criterion in thermal performance of green roofs. The type of plants selected and performance levels is largely dependant on the type of climate conditions of the proposed green roof site. In this case the type of climate in the UAE is hot and humid requiring plant species that can thrive in these conditions ideally involving drought resistant plants that require low maintenance and low initial costs. Shashua-Bar et al. (2009) suggested using trees than grass which consumed large amounts of water. Although Shashua-Bar and others suggested trees as a better alternative for green roofs, load considerations, climate type and roof type need to be considered in the plant selection process. Table 2 represents the approved plant list by the Dubai Municipality suitable for the UAE climate.

Table 3: Plant list suitable for the UAE Climate (DM, 2009).

No.	DM Plant List	Type	Plant Height	Community	Maintenance	Cost
1	Agave americana	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
2	Agave americana	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
3	Antigonon leptopus	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
4	Antirrhinum Hybrid Dwarf	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
5	Azadirachta indica	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
6	Bauhinia varigata	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
7	Beacarnea recurvata	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
8	Bismarckia nobilis	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
9	Caesalpinia pulcherrima	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
10	Callistemon lanceolatus	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
11	Carica papaya	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
12	Caryota mitis	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
13	Cassia fistula	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
14	Chamaerops humilis	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
15	Citrus aurantifolia	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
16	Cocos nucifera	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
17	Conocarpus erectus sericeus	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
18	Cryptostagia randiflora	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
19	Cycas media Citrus sinensis	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
20	Cycas revoluta	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
21	Cyperus papyrus	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
22	Delonix regia	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
23	Euphorbia canariensis	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
24	Ficus benjamina	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
25	Ficus carica	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High

26	ficus nitida	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
27	Ficus rubiginosa	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
28	Furcraea foetida	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
29	Gliricidia sepium	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
30	Hibiscus Spp.	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
31	Ipomoea palmata	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
32	Ixora spp.	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
33	Jacaranda imosifolia	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
34	Jacquemontia pentantha	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
35	Jasminum grandiflorum	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
36	Lantana Camara	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
37	Mangifera indica	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
38	Nymphaea spp.	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
39	Pachypodium lamerei	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
40	Pandanus utilis	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
41	Paspalium Vagiratum	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
42	Pedilanthus ithimaloides	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
43	Pelargonium Grandiflora	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
44	Peltophorum inerme	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
45	Petunia Spp.	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
46	Phoenix dactylifera	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
47	Phoenix roebelenii	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
48	Plumeria spp	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
49	Portulaca Grandiflora	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
50	Portulacaria afra	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
51	Pritchardia pacifica	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
52	Psidium guaiva	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
53	Ravenala adagascariensis	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
54	Rhoeo Spathacea	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low

55	Roystonea regia	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
56	Ruellia Macrantha	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
57	Sansavieria slendrica	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
58	Sesevium Portulacastrum	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
59	Setcreasea Purpurea	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
60	Spathodea campanulata	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
61	Tagets Erecta	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
62	Tecoma smithi	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
63	Tecoma stans	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
64	Tecomella undulata	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
65	Tristellateia australasiae	Semi-Intensive	250 - 500 mm	Groundcover/Grass/Shrubs	Periodic	Middle
66	Typha latifolia	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
67	Vinca Rosa	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low
68	Washingtonia filifera	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
69	Yucca aloifolia	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
70	Yucca filamentosa	Intensive	250 - 1000mm	Lawn/Perennials/Shrubs/Trees	High	High
71	Zoysia Sp.	Extensive	150 - 250 mm	Groundcovers/Grass	Low	Low

Table 3 displays the list of plants suitable for extensive, semi-intensive and intensive green roof showing plant height range, plant community, maintenance and cost factors that greatly influence plant selection criteria. Images of the listed plants can be acquired in Appendix C. Successful vegetated performance of green roofs is measured by leaf area density/ leaf area index, plant height, soil substrate, planted roof types and plant selection for hot humid micro-climates. Sun exposure, hardiness zones, environment and geography great influence plant selection. Elevating green roofs to roof level can strain foliage and soil and care should to be taken to ensure longevity (Snodgrass and Snodgrass, 2006). Vegetation performance is detrimental to green roofs and water management is next step to guarantee upkeep.

2.5 Managing Green Roof Water Strategy

Water management is an essential factor for green roof performance. In the UAE climate water maintenance and irrigation for green roof performance is a challenge. Although green roofs mitigate storm water runoff, the average rainfall in the UAE is sparse and means of integrating an intelligent storm water system in urban planning is highly sought out for as not all vegetation is drought resistance and any means to conserve water is valued.

Fioretti et al. (2010) and Hilten et al. (2008) evaluated water management and drainage strategies to maximize optimal use of green roofs. Hilten et al. (2008) calculated parameters such as soil moisture content, runoff, rainfall, and water retention levels. A model program called HYDRUS-1D was used to simulate the experiment and determine the results. Fioretti et al. (2010) discussed water retention rates effecting evapotranspiration due to moisture content in soil. This mitigates storm water drainage resulting in a cooling outcome. In cooling the surrounding and surface areas, urban heat island levels can be reduced.

Green roofs can filter water from pollutants through some forms of phosphorus and nitrogen, and heavy metals (Berndtsson, 2010). The use of grey water as a water management technique to recycle the building water supply can be further investigated to assess its value to green roof overall and thermal performance. Wong et al. (2003 a & b) suggested wet soils can increase insulation properties, keep surfaces cooler, contribute to evapotranspiration of plants, result in cooler ambient air temperatures and less building energy consumption. This in turn reduces anthropogenic heating, increases building durability and environmental pay back can be integrated into the life cycle analysis of green roof performance.

According to the Dubai Municipality Green Roof Code 3.3.5, irrigation systems are largely dependant on the type of green roof available, climate, site, water supply, pressure, maintenance, planter size and plant physiology. Green roofs can be irrigated either manually, fully automatic or semi-automatic. A green roof irrigation water tank is required which can be located at the lower level of the building. Supply from this tank can be provided by Dubai Electricity and Water Authority (DEWA), recycled building water, A/C condensed water, roof drainage water/storm water system and DEWA back up water supply (DM, 2009). Water management systems are essential in the UAE because of scarce water resources, a smart, sophisticated, green water management system in place can guarantee thermal performance of green roofs and possible payback options when measured by the Life Cycle Analysis (LCA) system which be studied in the next section.

2.6 Analysing Life Cycle Analysis (LCA) of Green Roofs

Developers, Designers, Engineers and Green Roof professionals are using Life Cycle Analysis (LCA) to determine the environmental impact of green roofs. In assessing the thermal performance of green roofs, the reduced energy consumption levels, longevity of roof life, environmental payback can be measured through LCA. The LCA conducted by Kosareo et al. (2007) and Cater and Keeler (2007) estimated that by thermal performance, inventory, materials, mass transportation variables in green roof design can contribute to a reduced environmental impact. However, Kosareo also points out that the measurements are location and climate specific where further investigation is required to monitor regional outcomes.

A comparative environmental life cycle assessment of green roof for a commercial building in Pittsburgh, US was performed by Castleton et al. (2010) between a green roof and a conventional roof. Although the initial costs of the green roof were high, the green roof lifetime was estimated to last 45 years compared to the conventional roof lifetime of 15 years. The thermal conductivity of the green roof was found to have a considerable impact on the LCA (Castleton et al. 2010). An LCA study conducted on Madrid, Spain by Saiz (2006) estimated that summer cooling loads were reduced by 6 %, during peak hour cooling loads reduced in the upper floors by 25% due to the green roof solar deflection properties lowering roof surface temperatures and heat flux. Superior thermal performance of green roof can ensure durability resulting in short and long term environmental returns.

Besides LCA, another incentive for developing green roofs is through green rating systems used in UAE. Credit gained for rating systems such as LEED and Estidama can value to the building and enhance longevity and cost savings through energy efficient design. This will be introduced in the next section.

2.7 Rating Green Roof Performance in the UAE

The two popular green ratings systems used in the UAE are LEED (Leadership in Energy, Efficient Design) and Estidama (Arabic for Sustainability). These ratings measure the performance overall performance levels of green roofs in response to criteria suggested in each guideline. The performance rating systems measured by LEED are governed under the titled category:

- Sustainable Sites
- Water efficiency
- Energy and atmosphere
- Materials and Resources
- Innovation in Design
- Regional Priority

The categories measured by Estidama V1.0 are governed under:

- Integrated Development Process
- Natural Systems
- Liveable Buildings: Outdoors
- Precious Water
- Resourceful Energy
- Stewarding Materials
- Innovating Practice

LEED is the American green building guideline and popular and international rating system. However regional and climate specific targets led to the development of green building assessment bodies in other countries. The local green building assessment body in the UAE for the emirate of Abu Dhabi is Estidama, a system especially created for this temperate zone. This rating system has been established in the Emirate of Abu Dhabi by the Urban Planning Council and has become a mandatory requirement for all developments. The important of using these systems is that each sustainable initiative used is carefully documented and transparent to all involved in the design and rating process.

According to the United States Green Building Council USGBC (2009), green roofs can earn credits by the **LEED** system under the following categories:

Sustainable Sites

▪ Credit 5.1 Site Development—Protect-Restore Habitat:	1 point
▪ Credit 6.1 Stormwater Design:	1 point
▪ Credit 6.2 Stormwater Design:	1 point
▪ Credit 7.2 Heat Island Effect—Roof:	1 point

Water efficiency

▪ Credit 1 Water Efficient Landscaping:	2-4 points
▪ Credit 2 Innovative Wastewater Technologies:	2 points

Energy and atmosphere

- Credit 1 Optimize Energy Performance: 1–19 points

Materials and Resources

- Credit 1.1 Building Reuse: 1-3 points
- Credit 3 Materials Reuse: 1-2 points
- Credit 5 Regional Materials: 1-2 points

Innovation in Design

- Credit 1 Innovation in Design: 1-5 points

Regional Priority

- Credit 1 Regional Priority: 1-4 points

Total Points Possible: 14- 45

LEED Certification Ratings:

Certified	26-32 points
Silver	33-38 points
Gold	39-51 points
Platinum	52 or more points

According to the Abu Dhabi Urban Planning Council, UPC (2010), green roofs can earn credits by the **Estidama V 1.0** system under the following categories:

IDP Integrated Development Process

- IDP-1 Life Cycle Costing: 4 points

NS Natural Systems

- NS-3 Ecological Enhancement: 2 points
- NS-4 Habitat Creation & Restoration: 6 points

LBo Liveable Buildings: Outdoors

- LBo-1 Improved Outdoor Thermal Comfort: 2 points
- LBo-4 Active Urban Environments: 1 points
- LBo-5 Private Outdoor Space: 1 points

PW Precious Water

- PW-2.1 Exterior Water Use Reduction: Landscaping: 8 points
- PW-4 Stormwater: 4 points

RE Resourceful Energy

- RE-2 Cool Building Strategies: 6 points

SM Stewarding Materials

- SM-6 Design for Durability: 1 points

- SM-8 Material Reuse: 1 points
- SM-9 Regional Materials: 2 points

IP Innovating Practice

- IP-1 Innovative Cultural & Regional Practices: 1 points
- IP-2 Innovating Practice: 2 points

Total Points Possible: 41 Points

Estidama V 1.0 Certification Ratings:

All mandatory credits 1 Pearl
All mandatory credits + 60 credit points 2 Pearl
All mandatory credits + 85 credit points 3 Pearl
All mandatory credits + 115 credit points 4 Pearl
All mandatory credits + 140 credit points 5 Pearl

On going examination process keep design professionals trained in the required categories ensuring carefully planned and executed developments. Certification of the regional and international systems adds to prestige of a development or buildings. Green roof performance measures by ratings systems such as, LEED and Estimada are incentives that can add to marketability, further research and development to enhance performance levels. Thermal comfort is an important criterion to be achieved. It is through enhanced green roof thermal performance spaces become more liveable, building reach optimal energy performance that habitats can be restored and urban heat islands can be mitigated.

An example of green roofs contribution to performance ratings is Canada's Vancouver Convention Centre (See figure 6) that is certified LEED® Platinum for new construction by the Canada Green Building Council (CGBC). Owned by the British Columbia Pavilion, its six acre intensive green roof contains more than 400,000 indigenous plants and grasses from the Gulf Islands. It is home to birds, insects and small mammals. 80% of the building's grey water is recycled and used for irrigation and toilet flushing. Planted over 12" growth media, the insulation capacity is projected to reduce summer heat gain by 95% (Greenroof, 2010). This is a highly innovative project that serves as precedence for others to harness sustainable techniques in green roof design.

Figure 6: Vancouver Convention Centre (Greenroof, 2010).

Rating systems that promote green roofs are important in assessing the thermal performance of green roofs in the hot humid microclimate, the parameters studied to measure heat levels are surface albedo, coefficient of heat, relative humidity, mean radiant temperature and airflow. Consequently this will be addressed in the next section 2.6 Measuring Green Roof Thermal Performance.

2.8 Measuring Green Roof Thermal Performance

Understanding the thermal performance of green roofs is a significant resource in defining the urban environment in the UAE. There are a range of levels to which heat islands can occur around a single building, a small scale vegetated area or large scale city area. Research from several experiments conducted under hot, humid conditions have been evaluated for the purpose of this study, these included cases in the United States such as, Phoenix, Arizona and Los Angeles, California and Florida and other countries such as, Singapore, Japan, Israel, Austraila, Estonia, Italy, Greece, Bangladesh, India etc. In assessing the thermal performance of green roofs in the hot humid microclimate, the parameters studied to measure heat levels are surface albedo, surface temperature, vegetated canopies, evapotranspiration from vegetation, air flow, street canyon conditions in dense urban areas, building heights, humidity, anthropogenic heating from mobile and stationary sources.

Albedo determines the solar reflectivity on a surface. According to Taha (1997) the albedo levels for most cities range from 0.10 to 0.20. North African towns are considered a good example of surface albedo ranging from 0.30-0.45. Extensive the vegetation in towns lead to a higher the surface albedo. Water has a lower albedo that light color buildings however this is dependant on the depth of water and angle of the sun rays. Taha (1997) found that temperatures on a summer day can be reduced by 4°C by changing surface albedo from 0.25 to 0.40 in a typical mid-latitude warm climate. A mesoscale simulation model developed by Taha (1997) found that surface albedo in Los Angeles can result in a 2°C temperature decrease. This decrease suggested lower electricity consumption by 10% by air conditioning. Sailor (2008) simulated the effects of albedo in the Florida urban environment and found that a higher in albedo using vegetation can result in a 2°C decrease in air temperature while extreme increase in albedo can result in a 4°C temperature reduction. Using high albedo materials decreases the amount of solar radiation absorbed resulting in a reduction of long wave radiation. Higher albedo materials can keep surfaces cooler having the potential to reduce energy consumption.

Surface temperatures on roofs can keep cooler by means of vegetation. Conventional roofs have higher surface temperatures than vegetated roofs. Teemusk and Mander (2009) studied the effects of daily temperature fluctuations on exposed roof membranes in Estonia finding that the imposed thermal stresses reduce the durability of the roof membrane. Using green roofs can prevent solar radiation exposure to the roof membrane adding to roof longevity. Teemusk and Mander (2009) found that the life span of a typical conventional roof is 20-25 years however from measurements on the green roof study in Estonia found that using green roofs and substrates can significantly reduce temperature fluctuation leading to an increased roof lifespan doubled to that of a conventional roof. Takebayashi et al. (2007) observed the surface temperature, net radiation, water content ratio of green roofs and high reflection roofs in Japan. By using a heat flux sensor the necessary parameters (solar heat flux, surface temperature and water content) were evaluated and compared with materials used on the reflective surfaces. It was concluded that further studies on evaporative efficiency should be conducted while other parameters analysed were confirmed. Okeil (2010) and Sailor (2008) studied the effects of solar radiation on covered and non-covered roofs and found that shaded areas radiate less heat than non-shaded areas. Rosheidat and Bryan (2010) performed simulation studies using ENVI-met on rural and urban context in Phoenix, Arizona to test the outdoor thermal comfort levels and found that vegetated canopy shading on surfaces decreased ambient temperatures by 22.91°C during the day achieving the lowest at 17.07°C early morning. Using reflective materials was also found to reduce surface temperatures when compared to asphalt and other hard surfaces that absorb heat. However when compared to reflective materials, vegetated canopies provide shading for soil layers which provide additional insulation and can effectively raise surface albedos depending on type of vegetation used.

Vegetated canopies irradiate solar heat gain. They provide shading for the substrate reducing green roof temperatures. Fioretti et al. (2010) studied the thermal performance of the green roof structure (vegetation, soil, and drainage layers) in Italy by comparing between the external surface temperature on the traditional roof and the temperature below the adjunctive green roof layers, using global radiometers positioned under the drainage layer, directly in contact with the waterproof membrane. By this analysis it confirmed that the shadow of foliage on the soil decreased the incident solar irradiance reducing heat gain (Fioretti et al. 2010). Wong et al. (2003) studied a commercial building in Singapore through field measurement with Yokogawa data loggers, DAQstation DX200, and thermocouple wires finding that surface temperatures were much lower under shading by plants and these temperature decreases could reach around 30°C. The study suggested that temperature varied depending on the type of vegetation and density LAI (Leaf Area Index of plants, thinker foliage resulted in lower temperatures than meagre foliage. Sailor (2008) using EnergyPlus simulation of green roof in Florida validated that an increase in vegetation density resulted in better building insulation reducing energy usage during the summer. Kumar and Kaushik (2005) conducted field studies in India using quantitative data and summarized that thermal performance is dependant on LAI and foliage height that can prevent penetrating heat flux by 4W/m2 thereby reducing indoor air temperatures and causing a cooling potential of 3.02kWh per day. The value of green roofs and vegetation canopies can result benefit outdoor thermal comfort, through evapotranspiration discussed in the next paragraph and indoor thermal comfort levels providing for ecological and energy efficient building and urban design.

Evapotranspiration (evaporation and transpiration) from vegetation can create oases that are 2-8°C cooler than their surroundings (Taha, 1997). In some scenarios the latent heat flux (flux of heat from the earth’s surface to the atmosphere associated with phase change, largely dependant on the dew point temperature) when large can cause the sensible heat flux (heat absorbed or lost during change in temperature, largely dependant on dry bulb) to become negative in vegetated and dry areas creating oases. The ratio of sensible heat to latent heat is known as the Bowen Ratio. When the Bowen ratio is negative or between 0.5 -2, oases conditions can be actualized. The total heat content of the air or enthalpy of air is a combination of latent heat and sensible heat. Rosheidat and Bryan (2010) simulated studies on an irrigated grass lawn and found that the moisture content enhanced cooling and reduced temperatures day time temperatures by 23.91°C reaching lowest at 19.91°C. Taha et. al (1997) found vegetated canopies in California reduced heat levels effectively by 2°C. Evapotranspiration effectively regulates heat flux leading to cooler ambient air temperatures.

Ambient air temperature when cool creates a better outdoor thermal environment and can benefit hot humid climates such as the UAE. Wong et al. (2003) measured the ambient air temperatures on the green roofs and hard surfaces at different heights and found that the cooling effect of plants was confirmed by ambient air temperatures. The ambient air temperatures were measured at 300mm, 600mm and 1000mm distances above hard surfaces and plants. The ambient air temperature was lower at 1000mm above the surface because of more ventilation than at 300mm which was higher. At night time however vegetated surfaces significantly reduced the ambient air temperature even at 300mm height than compared to the temperature on hard surfaces where the absorbed heat was reradiated back into the environment (the cause of the Urban Heat Island effect) resulting in warmer ambient air temperatures (Wong et al., 2003). The long-wave radiation in green roofs is much less than compared to that of hard surfaces and therefore green roofs is a much better alternative to mitigate heat island effect.

Mean Radiant Temperature (MRT) is calculated based on ambient air temperatures, global temperatures and air velocity. Wong et al. (2003) measured the MRT above hard surfaces and vegetated surfaces and found that hard surfaces when exposed to solar radiation during the day time absorb heat and emitted more long-wave radiation to the surrounding environment at night leading to uncomfortable thermal comfort levels. The MRT measured for vegetated roofs confirmed a reduced long-wave radiation emission since plants regulate the radiation levels absorbed to the roof surface. Kakon and Nobou, (2009) studied the effects of MRT on a modelled canyon and found that levels vary during the day time depending on air flow movements these can be effected by surrounding built environment such as, building heights, vegetation, climate, sky view factor (SVF) and global temperatures. Air flow also regulated the humidity levels in the built environment.

Humidity levels studied by Wong et al. (2003) on hard surfaces and vegetated surfaces were around the same levels. Kakon and Nobou, (2009) found that relative humidity (RH) levels in an urban canyon were higher during the day especially in places with a higher sky view factor (SVF). Higher SVF resulted in higher air temperatures (Ta) causing higher RH levels because of the amount of solar radiation absorbed. Increased building heights and tree canopies decreased the SVF resulting in lower Ta and RH levels. Again air flow and wind can affect RH levels on urban canyons and green roof environments.

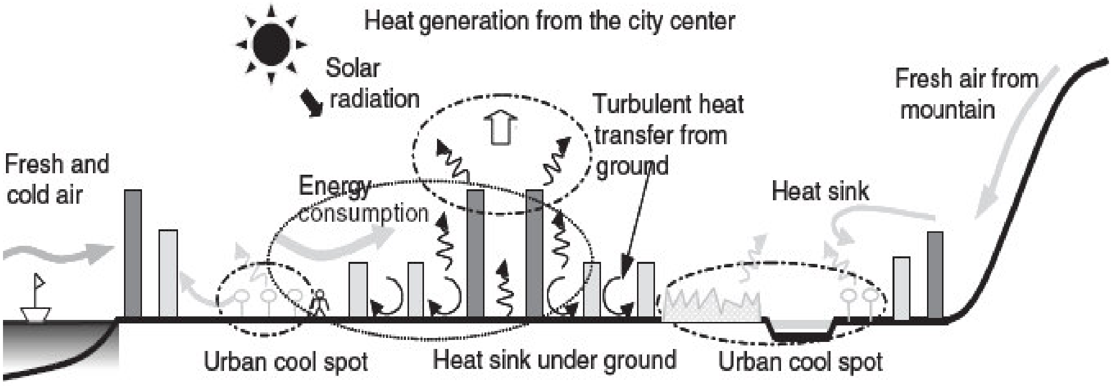


Figure 7: Urban heat exchange (Murakami, 2005 in Fahmy et al., 2008).

Airflow in the hot humid dense urban built environment of the UAE can be understood via figure 7 above. The diagram in figure 7 is taken from Fahmy et al. (2008) investigations of air flow pattern in an urban setting explaining an urban environment on how vegetation acts as heat sinks where as canyon scenarios with buildings and hard surfaces absorb and re-radiate heat creating uncomfortable UHI’s due to convections and anthropogenic heating. Air-Toudert and Mayer (2006) found that temperature decreases with increase in building height and width. Understanding airflow patterns is important factor in assessing urban thermal comfort and urban passive design strategies in the urban atmosphere.

The urban area atmosphere is made up of the urban boundary layer (UBL) and the urban canopy layer (UCL), see figure 8 below (Okiel, 2010). The boundary layer is the lowest at 100-3000m of the atmosphere. Figure 5 depicts the different constructs with the urban environment for air to pass through. Air flow in the urban boundary layer is less obstructed however air flow in the urban canopy layer is obstructed by buildings, tress and other infrastructure. The urban boundary layer is most affected by urbanism, heat exchange, carbon emissions, etc. An imaginary line separates the UBL from the UCL and right above the UCL is where the inertial surface roughness flow is not obstructed. Air exchange is dependant on relative spacing (building spacing/ building height) and relative building width (building width/ building height). Streets are considered urban canyons where interrupted air flow regimes take place depending on the nature of the built environment (Okiel, 2010).

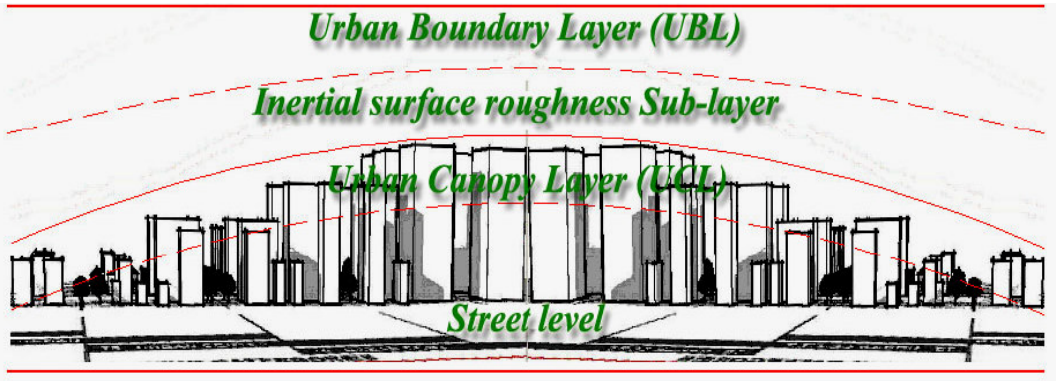
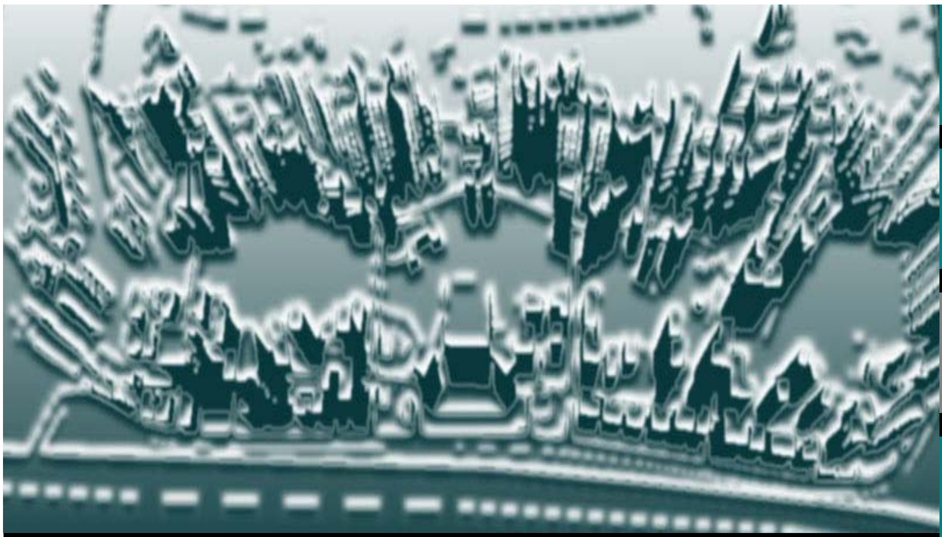


Figure 8: Urban area atmosphere (Fahmy et al., 2008).

Anthropogenic heating (heat generated from human activity) can affect near surface air temperatures in urban areas due to building energy consumption and motor vehicles that can add to the heat island effect. Taha et al. (1997) studied the meteorological simulations of US cities finding that Q values representing anthropogenic heating in addition to horizontal wave solar radiation was largest at the city core than the suburbs creating a 2-3°C temperature increase.

Green roof performance levels have been discussed in this section by evaluating the design benefits, design challenges, the impact of plants on thermal performance, influence of effective water management, life cycle analysis, importance of local rating systems on thermal performance of green roof in the UAE and the measures taken to evaluate thermal performance of green roofs from previous research case studies under hot, humid conditions. The main parameters evaluating thermal performance of green roofs in hot humid microclimates is dependant on the variables discussed above, surface albedo, surface temperature, vegetated canopies, evapotranspiration from vegetation, air flow, conditions in dense urban areas. Knowledge gaps from these studies include consistent simulated temperature profiles that can validate the research of thermal performance of green roofs in the UAE. Further study on the process for researching thermal performance of green roofs will be developed in Chapter 3 research methodology. A good background on the fundamentals, the influencing factors, the variables involved and standards in place can ensure a better design and optimal solution for urban conditions in the UAE. An investigation on a local site study in Dubai, UAE will determine the thermal performance levels of green roofs.



Chapter 3

Investigating Green Roof Research Methods

3.1 Introduction

Chapter 3 introduces the types of research methodology implemented when investigating thermal performance of green roof in the hot humid climate. From the examination of past research, codes and economics detailed in the previous chapter (2), chapter 3 carries the research question into further enquiry of the type of methods and parameters studied. It describes the methodologies used in the dissertation, i.e. case studies and simulated experiments from examples of past work. The two research methodologies are discussed detailing the observational approached conducted in chapter 2 and discussing the experimental chosen research method by simulation which will carry the research forward in the next few chapters using the selected research tool, ENVI-met. Chapter 3 concludes discussing the reason for ENVI-met selection, the parameters evaluated to assess the thermal performance of green roofs and the validity of the software.

3.2 Evaluating Research Methodologies for Green Roofs

Observational research is the first research methodology adopted in the green roof study. Observational research method uses an empirical technique and can be done through literature review of previous projects carried out (Brause, 2000). A detailed account of observational research conducted is chapter 2, in which several project case studies were observed and documented. Observational research is situation specific and therefore aims to test the theories arising out of the studied situation (Goddard and Melville, 2004). The case study approach is considered to be cost efficient and ethical. Although observational research is highly effective, the second research methodology by experiment will carry the research forward in the upcoming chapters.

Experimental research method is the second research method adopted in the green roof study. It is more fixed on results that can be easily quantified using the given tools. Experimental research is a scientific based model and can be categorized as field testing and simulation testing. Experimental research is primarily based on cause and effect assuming that a change in an independent variable will result in a change in a dependant variable (Goddard and Melville, 2004). Therefore the ultimate outcome of experimental research is to achieve better results. Experimental research can be costly depending on the type of equipment used (Brause, 2000). The feasibility of experimental research is also of concern depending on the research situation. In the next section a detailed review of the two research methods involved is examined.

3.3 Reviewing Methodologies from Previous Research

A number of research methodologies have been used in assessing the thermal performance levels of green roofs as seen in chapter 2. These included experimental studies via simulation and field studies, case studies, numerical studies and observational research. The most popular research methods documented in the literature review involved field testing, simulation modelling, literature review case studies and numerical analysis to obtain the tested results. The two main research approach reviewed is observational study approach and experimental via simulation approach.

3.3.1 Observational Approach

As discussed before, observation research is empirical in nature meaning that it is dependant on evidence. It is the primary type of research study conducted in the previous chapter. In evaluating thermal performance of green roofs in hot humid micro-climates using observational research evidence is collected using scientific theories, experimental observations, statistical data and numerical correlations.

An investigation by Wong et al. (2003) on the thermal benefits of a roof top garden in the tropical environment was conducted by studying a commercial building in Singapore through field measurement with equipment such as, Yokogawa data loggers, DAQstation DX200, and thermocouple wires to measure surface temperatures. Micro-climate parameters, ambient air temperature, global temperature, relative humidity and wind velocity were tested using a data acquisition device. A solar meter was used measure direct and indirect radiation on vegetated and non-vegetated surfaces (Wong et al., 2003). It was determined that long-wave radiation in green roofs in much less than compared to that of hard surfaces and therefore green roofs is a much better alternative to mitigate heat island effect. These instruments were effective tool in generating the required results to satisfy the tested premise.

Teemusk and Mander (2009) studied the green roof potential to reduce temperature fluctuations of the roof membrane, a case study in Estonia. The methodology used was statistical analysis where the correlation between air temperatures of green roof, green roof surfaces, reflective roofs and plants were measured. From the measurements conducted on the green roof study in Estonia it was found that using green roofs and substrates can significantly reduce temperature fluctuation leading to an increased roof lifespan doubled to that of a conventional roof.

Takebayashi and Moriyama (2007) hypothesised the surface heat budget on green roof and high reflective roof for mitigation of urban heat island. The method used for this study was observational research on a near by site using heat flux sensors. Air temperature, relative humidity, solar radiation, infrared radiation, precipitation, wind direction and velocity were observed. By using a heat flux sensor the necessary parameters were evaluated and compared with materials used on the reflective surfaces. It was concluded that further studies on evaporative efficiency should be conducted while other parameters analysed were confirmed.

The evaporative cooling effects on roof lawn gardens were studied by Onmura et al. (2001) by field measurements conducted in Japan. The parameters measured involved outdoor air temperatures, relative humidity, solar radiation and rainfall. A wind tunnel experiment was conducted measuring wind speed. Form the wind tunnel experiment Onumura concluded that there is a signification reduction in outdoor and indoor air temperature, however future study on moisture content of the external lawn area is required for comparative analysis.

Temperature decreases were investigated by Alexandri and Jones (2008) in an urban canyon due to green walls and green roofs in diverse climates. The experiment was conducted using a micro-scale model. The parameters studied air velocity, air temperature, relative humidity and wind speed. Varies cities in the world were observed and it was deducted that green roofs and walls had a positive impact on urban canyons resulting in a temperature decrease.

Green roofs and building energy savings and potential for retrofit was studied extensively by Castleton et al. (2010) using the literature review research method. The conditions observed were heat flux, solar reflectivity, thermal, soil thickness and moisture content, local temperature, air conditioning and costs. Theodosius (2003) studied the thermal performance of vegetated roofs based on solar radiation and effective insulation. Studies conducted demonstrated the potential of using specific material and re-using material for retro-fitting in order to maximize energy savings. The findings resulted in cooling potential and cost savings.

Green roof energy and water performance was observed by Fioretti et al. (2010) in the Mediterranean micro-climate. This research was conducted by field experiment using a quantitative and qualitative approach. Air temperature, heat flux, horizontal radiation, air temperature, benefits, thermal shading, canopy temperatures energy performance and storm water management were studied in Italy. Thermal comfort was studied by comparing between the external surface temperature on the traditional roof and the temperature below the adjunctive green roof layers, using global radiometers positioned under the drainage layer, directly in contact with the waterproof membrane. By this analysis it confirmed that the shadow of foliage on the soil decreased the incident solar irradiance reducing heat gain (Fioretti et al. 2010).

The analysis of green roof thermal properties was observed by Niacho et al. (2001) where the field experiment research was conducted using instruments to measure the temperature profile of an insulated versus non- insulated roof. An infrared camera was used to measure vegetation, air temperature and solar radiation of a building during different climatic seasons. It was concluded that the energy saving established given the executed parameters ranged between 2% to 37%. Additional research method by mathematical experiment was conducted to evaluate and confirm the air temperature profile attributed to thermal comfort.

Lazzarin et al. (2005) investigated the experimental and numerical research approach on green roofs. By using sensors in field experiments, the author was able to measure geometric, solar, physical and thermodynamic variables. A numerical model was used to measure the outside attributes of thermal accumulation in summer and winter months. The comparison between the summer and winter months found that there was a distinct change in thermal flux due to the difference in relative humidity which was higher during the winter months.

Thermal performance of green roofs in hot humid microclimates is dependant on the variables discussed above, surface albedo, surface temperature, vegetated canopies, evapotranspiration from vegetation, air flow, street canyon conditions in dense urban areas, building heights, humidity, anthropogenic heating from mobile and stationary sources. These variables will be invested on a local site study in Dubai, UAE to determine the thermal performance levels in this climate condition. Field experiment, literature review and statistical analysis were the primary observational methods used to confirm the hypothesis of the researcher. The methods were highly effective when using the right instruments to test the thermal comfort criteria; however other were found limited in their scope and simulation modelling is found to have a better capacity to test the various thermal comfort variables.

3.3.2 Simulated Study Approach

Simulation research is a highly effective tool for thermal comfort measurement. It is cost effective when compared to other research tools. In micro-climatic modelling, heat sensors and other instruments used were time consuming and costly where as simulation offer a better alternative to gather the required results.

The performance of green roofs for shading and thermal protection of buildings in India by Kumar and Kaushik (2005) using quantitative data depicted a numerical model using Matlab tested the LAI, heat flux, green roof canopy temperature and indoor air temperature. It was summarized that thermal performance is dependant on LAI and foliage height that can prevent penetrating heat flux by 4W/m2 thereby reducing indoor air temperatures and causing a cooling potential of 3.02kWh per day providing for ecological and energy efficient building and urban design.

Rosheidat and Bryan (2010) hypothesised optimizing the effects of vegetation for pedestrian thermal comfort and UHI mitigation in hot air urban environment. The simulation research method was chosen to measure MRT, surface temperature, air temperature and soil moisture content. Simulated studies on an irrigated grass lawn and found that the moisture content enhanced cooling and reduced temperatures day time temperatures by 23.91°C reaching lowest at 19.91°C.

Emphasis on Heat island mitigation and simulation programs to study potential energy savings was evaluated by Sailor (2008). A simulation conducted using EnergyPlus, determined the energy savings and reduction when measuring the vegetated roofs, surface temperature at monthly intervals. Sailor concluded that EnergyPlus is highly efficient in measuring thermal comfort and energy consumption parameters but has limitations on the types of green roof selections available for study.

A holistic approach to energy efficient design was studied by Okeil (2010) by using a comparative analysis research method of the urban built environment through simulation. The parameters measured were solar exposure in an urban/residential block and air flow. He confirmed that shaded vegetated areas radiate less heat than non-shaded areas and established that vegetated canopies provide shading for soil layers which provide additional insulation and can effectively raise surface albedos depending on type of vegetation used.

LAI based trees selection for mid latitude urban developments in a microclimatic study in Cairo, Egypt by Fahmy et al. (2008) conducted investigations of air flow patterns in urban settings. This depicts an urban environment documenting how vegetation acts as heat sinks where as canyon scenarios with buildings and hard surfaces absorb and re-radiate heat creating uncomfortable UHI’s due to convections and anthropogenic heating.

Spala et Al. (2008) observed green roof systems in Athens, Greece. A dynamic mathematical simulation model was used to observe plant selection, thermal properties and surface temperatures. It was deduced that increased LAI significantly reduced energy consumption levels of a school building in Athens Greece during the summer period by 15-58% resulting in environmental and economical savings.

Huttner et al. (2008) investigated the thermal stress in a typical European city using ENVI-Met simulation. The average building height was set up to 12m. The model contains houses, a church tower, a small park, gardens and courtyards (See figure 9). The summer temperature input was studied at 35°C worst case scenario and 30°C. Vegetation was distributed at different degrees and all streets were represented with East West orientation. It was found that differences in air temperature were caused due to inflow boundaries at specific periods. Cooler ambient air temperatures were found in areas of wet soil because of moisture content, where as dry soils portrayed the same albedo levels as hard surfaces (Huttner et al., 2008). Figure 9 represents the temperature profile of the two scenarios including a human thermal comfort index PET (Physiological Equivalent Temperature). Although the author has documented study with information about ENVI-Met testing, the lack of site information, reasoning for air flow patters, vegetation influence on wet and dry soils and other details were missing and further investigation into the summer time climate profile is needed.

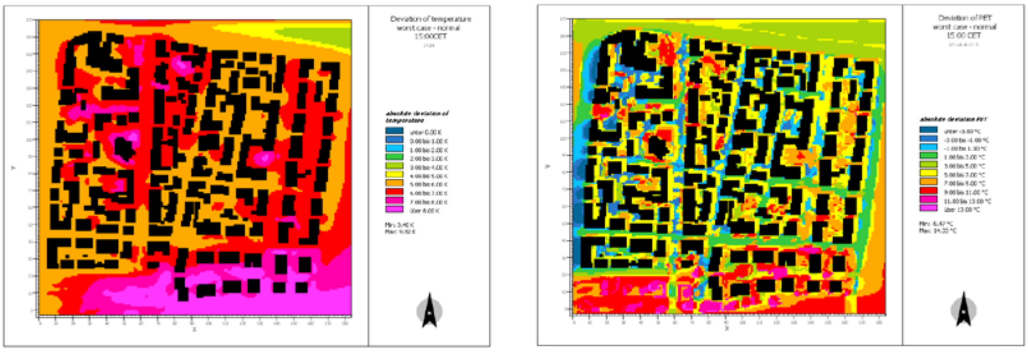


Figure 9: ENVI-Met study of comparative summer time temperatures (Huttner et al., 2009).

When identifying simulation research for micro-climate research it is necessary to specify location for climate profile, site surroundings, simulation tool inputs and surface profile to discuss the generated results. Simulation research is a highly effective tool for quick data testing and is cost effective when compared to other research tools. In micro-climatic modelling, sensors and weather stations used in previous study were costly and time consuming requiring regular site testing, if the research required annual study, then on - site testing had to be carried out for all twelve months. Simulation study contains weather profiles on a data base which can test parameters based on various scenarios and time frame. Further discussion on the simulation approach is discussed in the next section, chosen research methodology.

3.4 Choosing a Research Method

Although primarily two research methods were used in the research methods were used in this process the first being through literature review by case study and the second through simulation. The simulation method is the selected for the research design study to determine the thermal performance of green roofs on the hot humid micro-climate. This method was chosen among the other methods because it is resourceful and not limited in terms of scope. Once the initial site model is set up, it can measure a range of parameters available with in the software package. A simulation prototype of the built environment incorporating green roof practises is a dynamic component of the observational phase. It is a useful tool in analyzing on site conditions, impact of materials used, region specific analysis, the climatic profile, sun studies shading analysis, passive cooling strategies, air temperature interactions and wind studies.

Simulation is highly efficient and requires minimal resources in terms of cost, time and labour. It is flexible and beneficial when integrated in building design as its independent variables can be easily implemented, tried, tested and changed to allow for optimal performance and energy savings. Fixed variables can be established in the initial base model and will not requiring changing. Once the simulation is run, the dependent variables will be predicted and recorded in the report.

When compared to the other alternative research approaches such as field measurement, experimental and literature review, the simulation approach produces the necessary data and is not time intensive as the other approaches. Computer and software cost are not as expensive as equipment cost, easily available compare to the research equipment and does not require laboratory space to run prototype. It is not time consuming and the results for parameters at different, time, days and months can be easily produced on the simulation model at the touch of button. Daily site studies can be physically demanding and time intensive as, manpower is limited, the simulation model is best suited for the study and time frame set up.

The Simulation method will be used as it is flexible, dynamic and works well with limited resources, such as time, cost and manpower.

1. Site and climatic analysis – This is retrieved from IES data package in accordance with ASHRAE and ENERGY PLUS weather file. A detailed weather profile was also acquired from the National Center of Meteorology and Seismology in the UAE (2010). A summer climate profile will be the subject of analysis for assessment of hot and humid micro-climate performance. Comparative data can be retrieved of other months to compare variables and assess annual performance levels.
2. A model based on the Dubai Marina and JBR mixed-use development will be set up using ENVI-met software with and with out the green roof features incorporated.
3. Inclusion of different types of roof systems: standard roof and green roof. The roof systems evaluated include thickness, variation in soil (dry soil/ moisture content) and type of the proposed vegetation (leafy/non leafy).
4. Parameters to be measured:
    - Out door thermal comfort levels (surface albedo, exchange coefficient of heat, relative humidity, mean radiant temperature, predicted mean vote, percentage of people dissatisfied and wind speed).
5. Simulation modelling by importing development map (.bmp) into ENVI-met edditor that is imported to thermal modelling software, configuring the area input and measuring the parameters mentioned in step 4 are evaluated to assess the thermal performance levels of the dependent variables.
6. Recording and documenting results in the final report. A graphical and comparative analysis of the data can be investigated to find optimal heat island reduction and energy savings.

3.5 Selecting a Simulation Tool

In choosing the right software several software profiles were investigated to determine thermal comfort levels. Several pre-requites identified in the software selection process to quantify the thermal comfort performance of vegetated canopies under hot humid micro-climate conditions include:

- Determining configuring climatic conditions to fit the UAE temperate zone
- Measuring micro-climate thermal comfort levels on vegetated surfaces

- Flexible vegetation and soil selection to determine performance levels
- User friendly interface
- Easy/fast learning that fit architecture/ urban design user profile and given time restrictions
- Satisfactory graphic capabilities

After two and half months of software research, literature review, software workshop attendances and interaction with numerous software developers, it was concluded that ENVI-met satisfied the above conditions. ENVI-met was recognized as an innovative modelling tool that can progress urban information systems for the benefit of sustainable micro-climates during the International Cartographic Conference (ICC) held in Durban, South Africa in 2003 (ICA, 2010). International Cartographic Association (ICA) organization responsible for the ICC is actively involved in research and development of maps and geographic information (GI) to aid strategic decision making, crisis management and environmental development. Further development is still required to integrate ENVI-met and Geographic Information Systems for accurate measures.

Although the numerically modelling aspect of ENVI-met is highly accurate given the derived results, the graphic capabilities are limited and the vegetation database can be further developed to include a variety of plants form various regions. At present state the UAE plants varieties will require extra effort through manual input. The software is also limited in the as a conceptual model and a detailed development of any parameter will have to be programmed into the software, further limitations will be discussed in section 3.7 Validating the ENVI-met software.

3.6 Modelling with ENVI-met for Hot, Humid Micro-Climates

ENVI-met micro-climatic numerical modelling software developed by Michael Bruse and designed to assess the conditions in urban developments. ENVI-met has the capacity to easily translate numerical data founded on the fundamental laws of fluid dynamics and thermo-dynamics to simulate surface, vegetation and atmospheric exchanges with in the urban environment. Adding to ENVI-met's sophistication is the A-gs model input that can accurately simulate vegetative stomata in different environments when compared to the previous empirical Deardorff model used of which environmental conditions measurable were limited to plant canopy scale. The thermodynamic investigation at all surfaces, walls and vegetative canopies allows the software to analyze the complexity of the urban environment. The micro-scale non-hydrostatic model's resolution ranges from 0.5-10m with a time period of 24- 48 hours. The software runs on WINDOWS NT/2000/XP platforms with a minimum of 128MByte RAM however this is dependant on the number of grid points used.

ENVI-met calculates solar radiation (direct, reflected and diffused) and the surface temperatures and mean radiant temperature (MRT). The calculation of long term and short term radiation fluxes includes the plant shading, absorption and shielding of radiation as well as the re-radiation from other plant layers. Transpiration, evaporation and sensible heat flux can be measured for simulated plant parameters (Bruse, 2010). Ground, surface and walls for each grid point can be calculated at varied heights. Biometerological parameters like MRT or Fanger's Predicted Mean Vote (PMV) Value can measure human thermal comfort levels.

Temperature and humidity of surfaces is calculated ground surface and vegetation is incorporated using a source/sink term in both equations, building walls are only acting as a source/sink for temperature (Bruse, 1999). The distribution of temperature and specific humidity is then measured using an equation plugged into the software.

When considering turbulence or kinetic energy, calculated surfaces, walls and roof are defined as physical boundaries. When measuring turbulence ENVI-Met calculates the air flow patterns using physical obstructs modelled in the profile. Under windy conditions the magnitude of turbulence leads to increased convective exchange away from original source.

Soil properties are measured in ENVI-Met by calculating the thermal diffusivity of soil moisture. Water boils in soil are treated as an additional internal heat source which allows for absorption of shortwave radiation to be calculated in ENVI-Met (Bruse, 1999). When developing the ENVI-Met model the values of water can be represent and a heat source material to determine accurate heat exchange in the soil substrate.

Vegetation in ENVI-Met is measured by calculating foliage temperature. This temperature is influenced by the latent and sensible heat properties of the foliage dependant on actual plant physiological conditions. Radiative fluxes can be calculated based on plant geometry, shading and longwave radiation. These variables are dependant on foliage influence LAI and LAD. As mentioned before thicker foliage density and larger LAI results in solar radiative shielding.

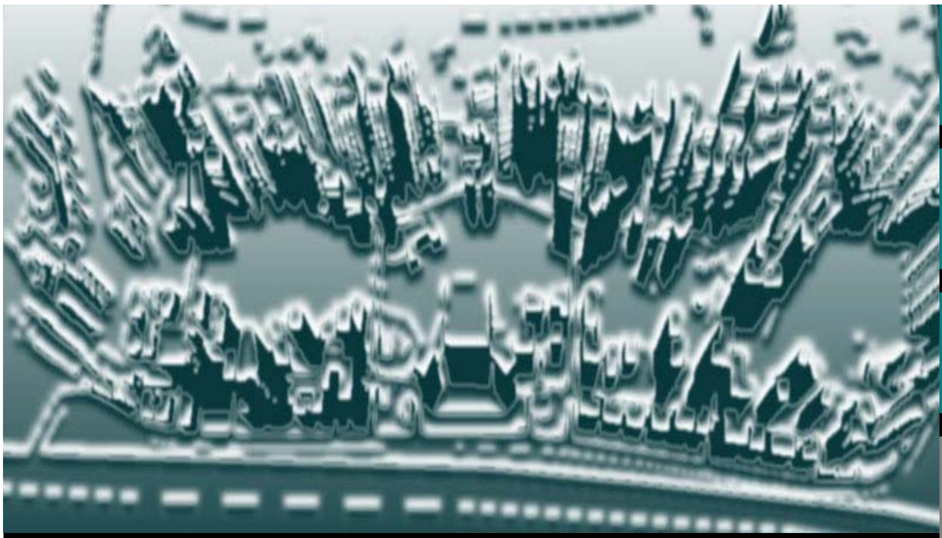
LAI can then be calculated based on angle of incidence. Sky View Factor (SVF) influence the output where SVF is 1 (free sky) and SVF is 0 (no sky). Building obstructions decrease SVF thereby shielding incoming solar radiation from hitting the foliage surface. Although horizontal longwave radiation may still exist, dense vegetation distribution and reduced ambient air temperatures can combat incoming fluxes. The rate of stomatal resistance is dependant on the type of plant and leaf density. In heated areas when wet foliage evaporates, dry vegetation transpires. Detailing Leaf Area Density (LAD) and Root Area Density (RAD) can be applied to grassy surfaces as well as trees. In ENVI-Met the energy budget is calculated at ground surface. Bruse (1999) calculated the atmospheric model (ground, surface and walls) and soil model (ground surface). Surface albedo takes into account longwave and shortwave flux from shielded and unshielded components. Walls and roofs are calculated with respect to surface orientation.

3.7 Validating the ENVI-met Software

What determines ENVI-met validity? Software validity falls under scrutiny of several scientific entities, government organizations and researchers. In researching the validity of the software, the three main contributions were acknowledged, developer capability and credentials, software capabilities, soundness (basis of model) and parameters investigated. Dr. Michael Bruse having a background in geography and climatology developed the ENVI-met software based on extensive research and mathematical formula such as the Navier–Stokes equations that calculate the required output for the parameters tested and a simple upstream advection scheme is used to calculate the pollutant dispersion. Huttner et. al, (1999) researched strategies to mitigate thermal stress on central European cities project KLIMES and documented simulations tested by ENVI-met and BOTWORLD to test climatic scenarios of cities. Bruse, (2009) recently documented a paper on the assessment of impact of urbanization on climate: An application of bioclimatic index is a recent study attesting to ENVI-met validity.

Certain limitations do exist, such as when calculating the pollutant dispersion since the numerical flow results in a deviation of the wind field calculations on a micro scale model. Further study on the numeric methods used is being tested for more accuracy. Emmanuel and Fernando (2007) found limitations in the flexibility of tools required to create the urban environment, such as shading devices and structures, however in developing the urban environment the surface type can be suggested depending on the expected albedo type. Evidence of several research literature conducted by Bruse and others validate the ENVI-met results.

As chapter 3 details the research methodology, the use of ENVI-met numerical simulation is validated. In the instance of a hypothetical scenario discussed in the following chapter, testing the thermal performance of green roofs in the Dubai Marina development, it was found that the use of ENVI-met is more than adequate and an extremely useful means to measure the necessary parameters. This will be further investigated in chapter 4, which defines the conventional and green roof scenario.



Chapter 4

Defining the Green Roof Experiment

4.1 Introduction

Chapter 4 focuses primarily on simulation research method for investigation using the ENVI-met software discussed and validated in Chapter 3. The simulation if based on a dense urban section of the Dubai Marina. The Dubai Marina located in the city of Dubai in the UAE comprises of high-rises and mid-rises in the development. The UAE is situated on the Persian Gulf (See figure 10 below) having the coordinates of 25˚N latitude and 55˚E longitude.

Figure 10: Map of the UAE (Google Earth, 2011).

4.2 Defining the Context of the Green Roof Experiment

The emirate of Dubai is situated in the North of the UAE (See figure 11). The Dubai Marina Master Plan (See figure 12) was developed by architectural firm HOK comprising of a total land area of approximately 578 ha (NRI, 2011). The initial concept was based on a city with in a city model. The architects used a canal city approached to design a waterfront community, the development houses people in luxury apartments, condominium and villas. The Dubai Marina not only caters to a high density residential community but offices and retail as well. Addressing the public realm and catering to a pedestrian environment is among the main ideals of the development (NRI, 2011).

Figure 11: Location of Dubai (Maps, 2011).

The Dubai Marina model is developed to test the outdoor thermal comfort levels of the pedestrian friendly environment. In this chapter a detail on ENVI-met model configuration, simulation inputs logged to test the urban thermal parameters and modelling process is developed and will be discussed further in the next section.

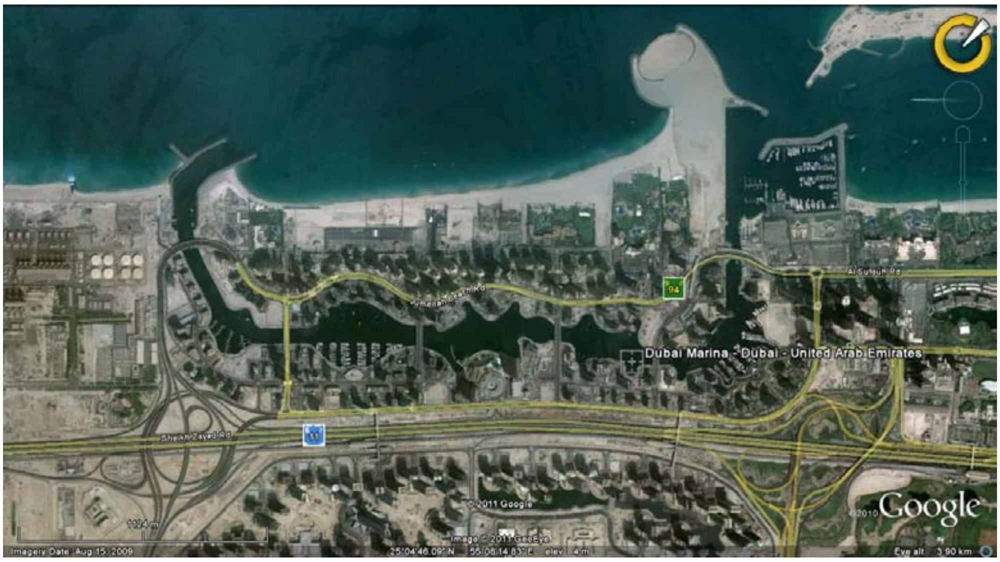


Figure 12: Location of Dubai Marina (Google Earth, 2011)

4.3 Documenting UAE Climate Data

The UAE climate as mentioned in chapter 1 is hot and humid, with mild winters and harsh summers. During the summer months temperatures elevate to extreme conditions.

A detailed look at the UAE climate is documented from IES-VE database representing the highs and lows on the graphs overleaf.

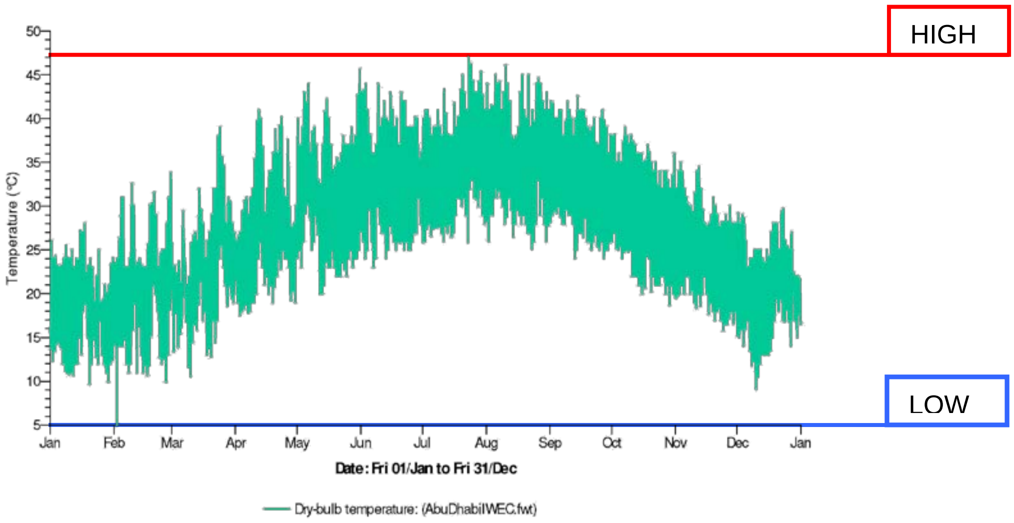


Figure 13: UAE Dry Bulb Temperature acquired from IES-VE database

Dry bulb temperature is the temperature of air usually representing the ambient air temperature. The UAE dry bulb temperature peaks during the months of June, July and August reaching a high of 47˚ C dropping to a low of 5˚C in February (See figure 13) .

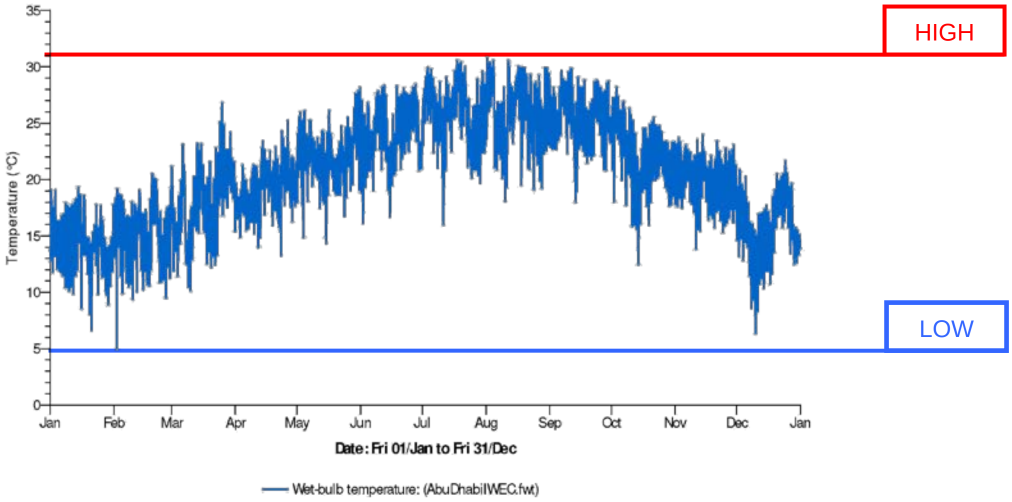


Figure 14: UAE Wet Bulb Temperature acquired from IES-VE database

Wet bulb temperature measures the amount of moisture in air. The wet bulb temperature peaks at 32˚C in the month of July dropping to a low of 5˚C in the month of February (See figure 14). The wind direction varies at different times of the year. Its azimuth is at high of 350˚C with a low of 0˚C (See figure 15).

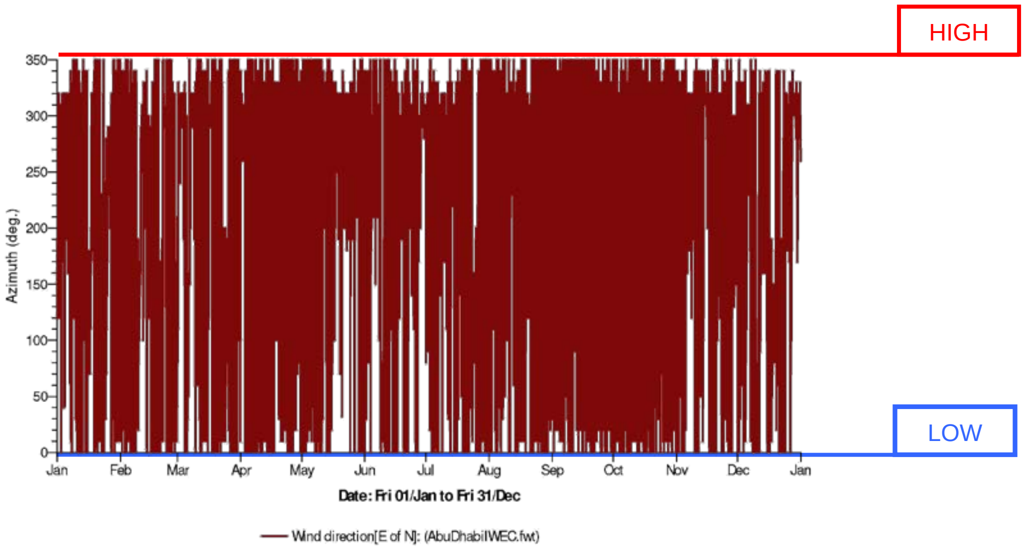


Figure 15: UAE Wind Direction acquired from IES-VE database

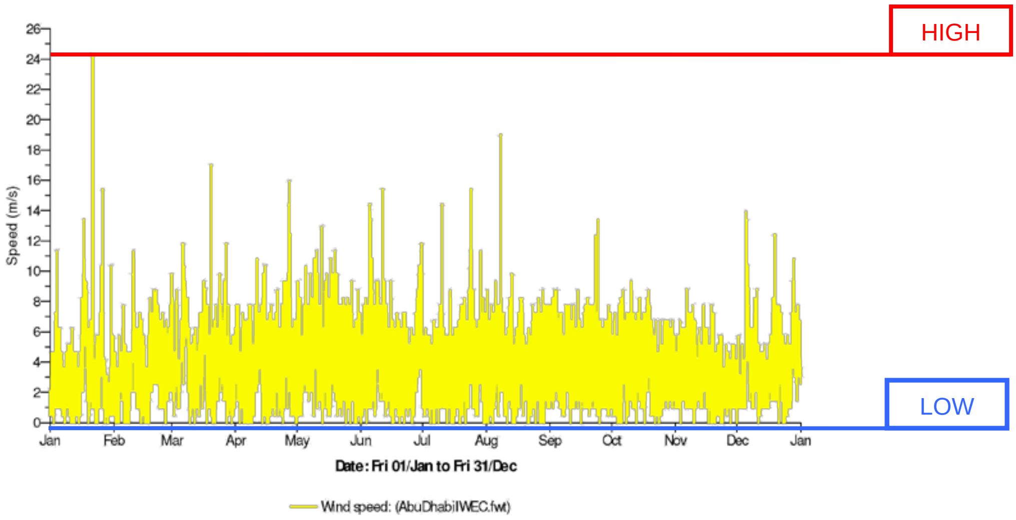


Figure 16: UAE Wind Speed acquired from IES-VE database

The wind speed measures the directions of the wind’s motion. It is at its peak in February reaching a high of 24˚C. The lowest speed is at 0˚C at different times of the year (See figure 16). The atmospheric pressure is at its peak in January reaching a high of 102000. The lowest speed is at 19000 during the month of June (See figure 17).

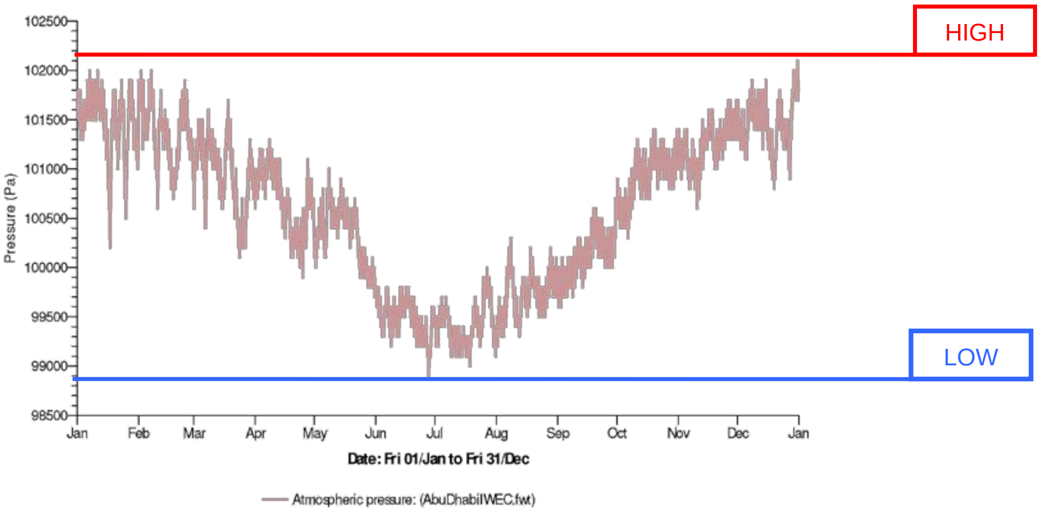


Figure 17: UAE Atmospheric Pressure acquired from IES-VE database

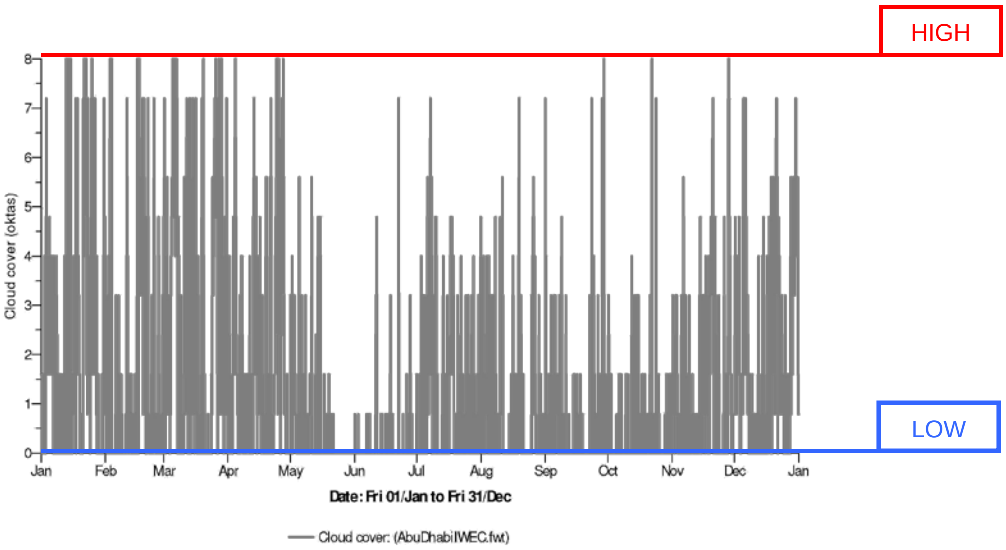


Figure 18: UAE Cloud cover acquired from IES-VE database

Cloud cover represents the fraction of the sky covered by clouds and varies at different times of the year. It is measured from a low of 0 to a high of 8 okais. (See figure 18). The diffuse radiation is solar radiation that reaches the earth after being diffused by molecules in the earth's atmosphere. It peaks during the month of April at 525 W/m^2 with a low 90 W/m^2 during the months of February and November (See figure 19).

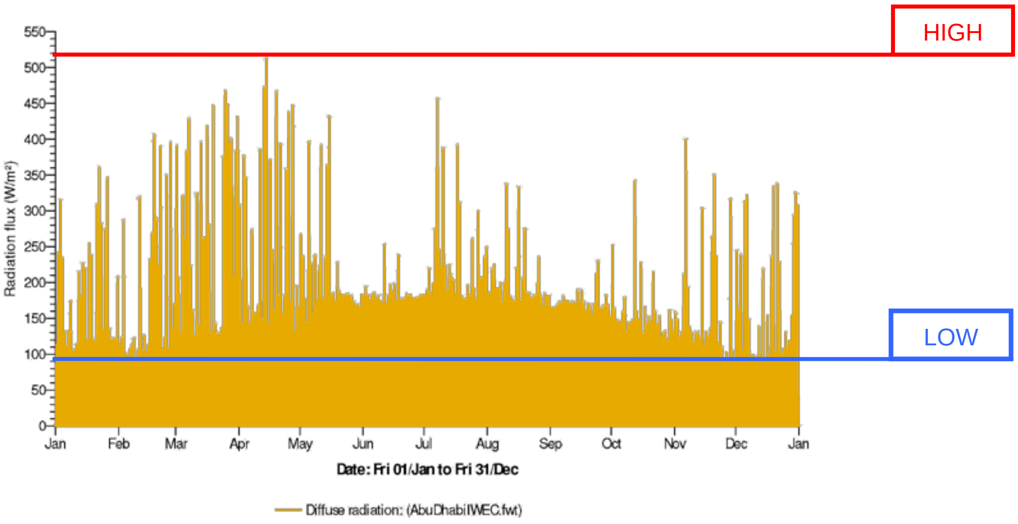


Figure 19: UAE Diffuse Radiation acquired from IES-VE database

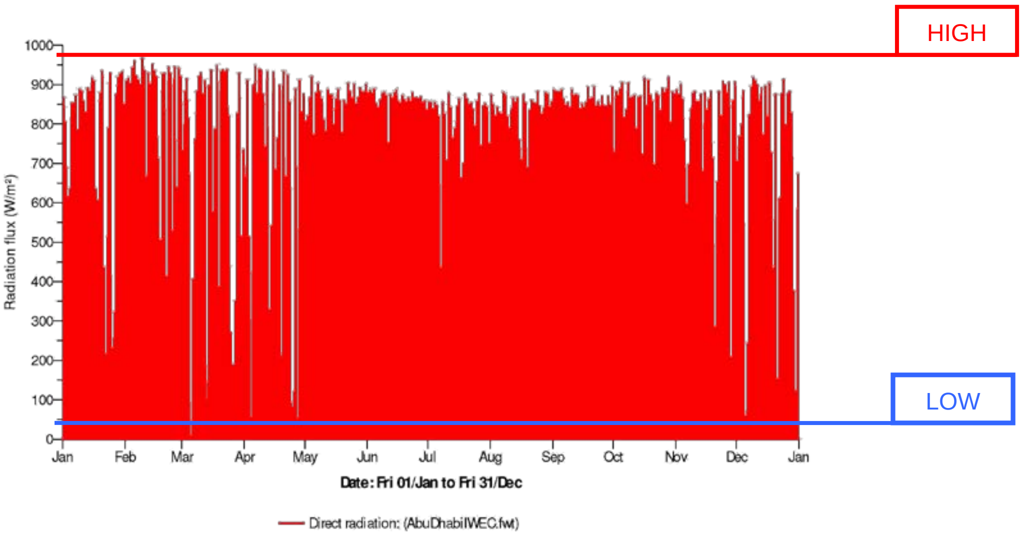


Figure 20: UAE Direct Radiation acquired from IES-VE database

Direct solar radiation is radiation not blocked by cloud cover. The UAE direct radiation varies at different times of the year with a peak rise is at 975 W/m^2 with a drop at 40 W/m^2 (See figure 20). Global solar radiation is the total amount of suns energy falling on the earth's surface. The UAE global radiation peaks during the month of April at 1050 W/m^2 with a low of 275 W/m^2 during the month of March (See figure 21).

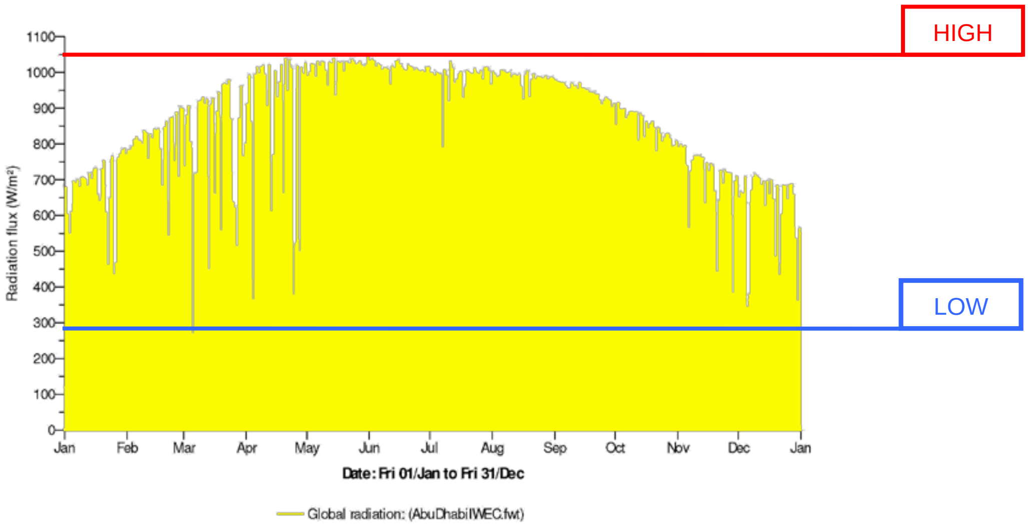


Figure 21: UAE Global Radiation acquired from IES-VE database

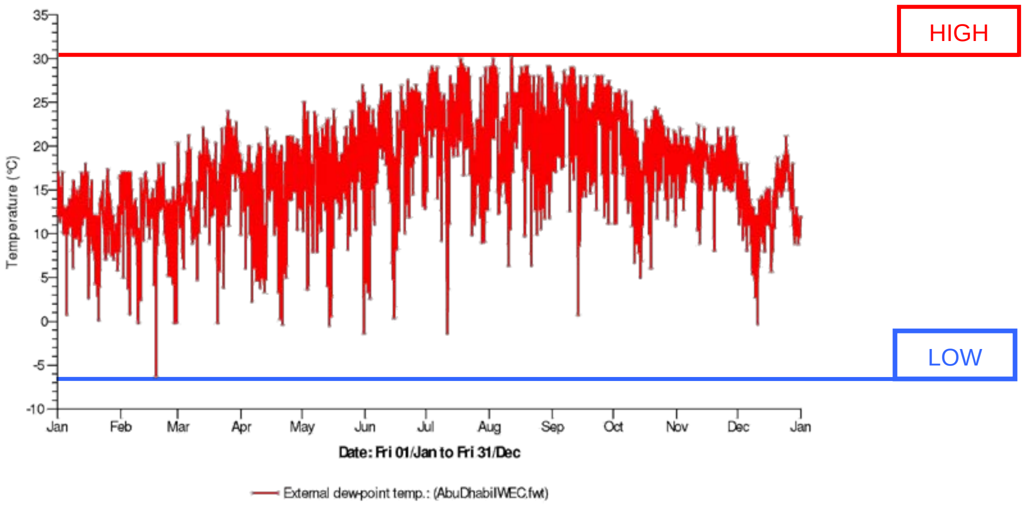


Figure 22: UAE External Dewpoint acquired from IES-VE database

The UAE external dew point is when water vapour in humid air condenses to water. It peaks in July and August at 31˚C dropping at 4˚C in February (See figure 22). External moisture content is the quality of water in properties such as soil. The UAE external moisture content peaks during the month of August at 0.020 kg/kg reaching a low of 0 kg/kg in February (See figure 23).

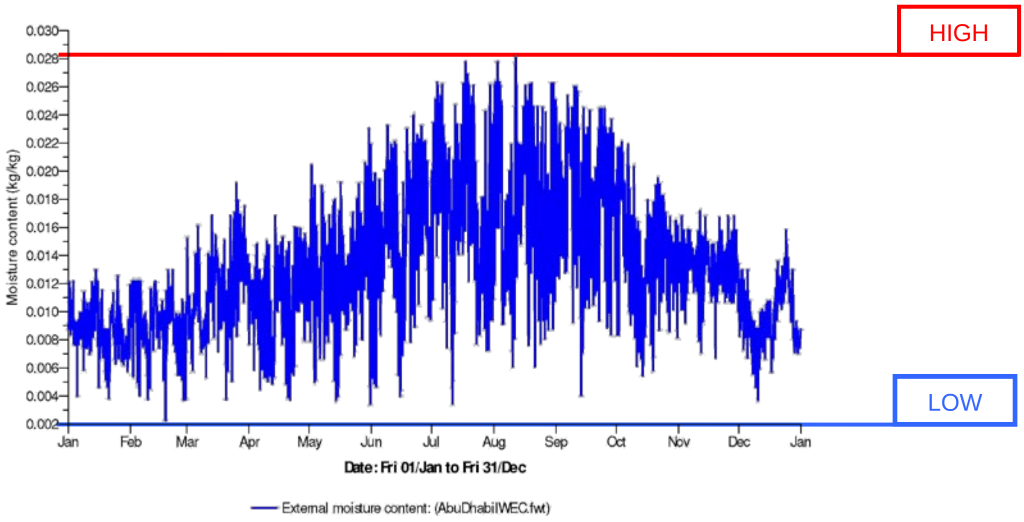


Figure 23: UAE External Moisture Content acquired from IES-VE database

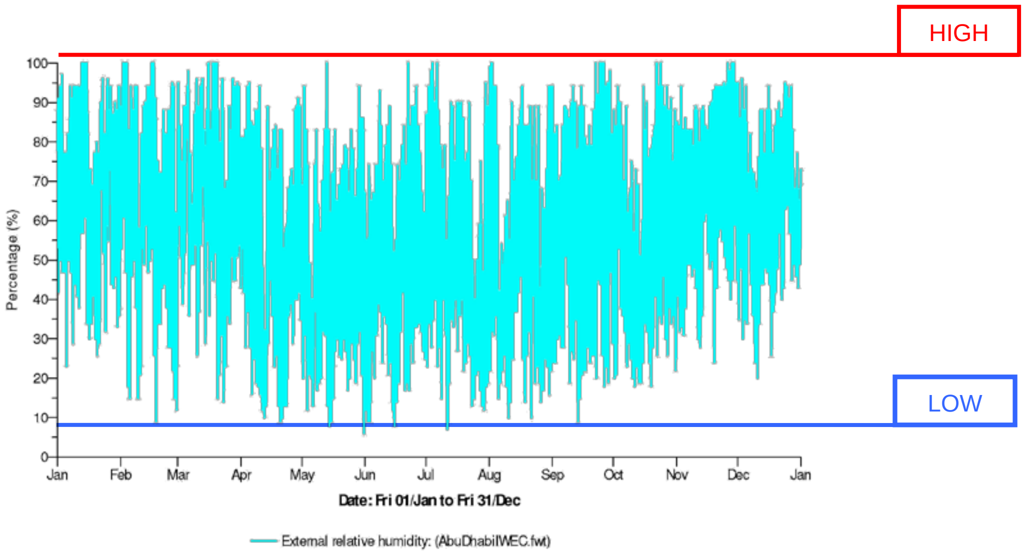


Figure 24: UAE External Relative Humidity acquired from IES-VE database

External relative humidity is the moisture content of water vapour and air. The UAE external relative humidity levels peaks during different months of the year reaching a high of 100% dropping to 8% during the month of June (See figure 24). Solar altitude is the angular height of the sun measured from the horizon. The UAE solar altitude is at an angle of 85˚ in May dropping to 42˚ in January (See figure 25).

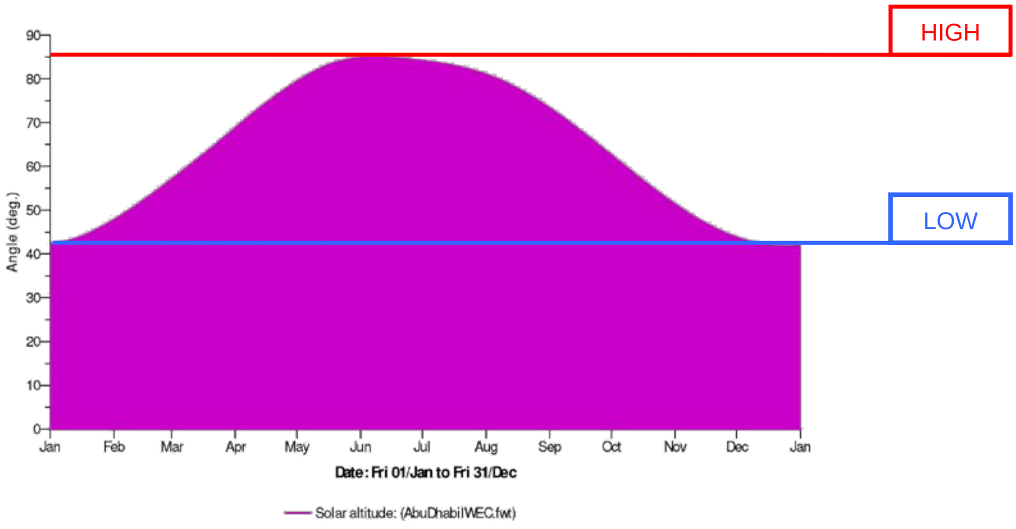


Figure 25: UAE Solar Altitude acquired from IES-VE database

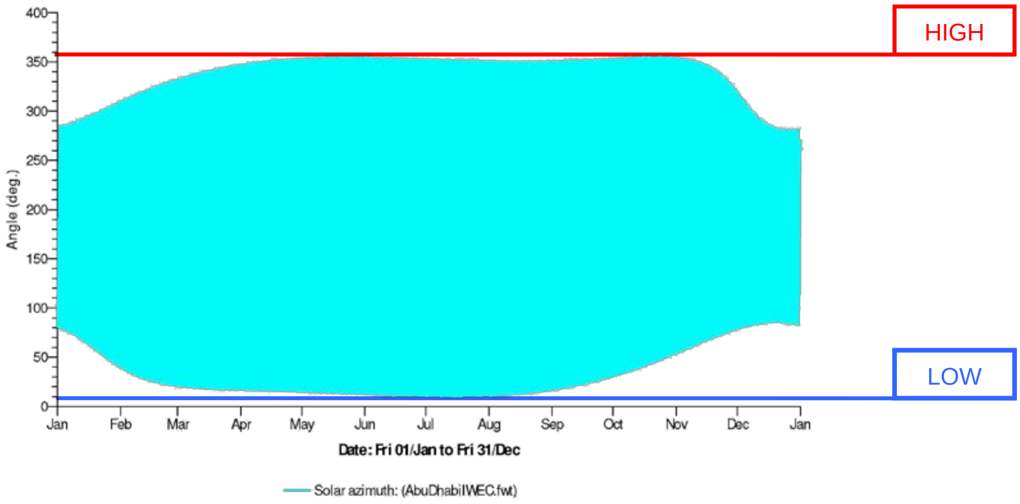


Figure 26: UAE Solar Azimuth acquired from IES-VE database

Solar azimuth or sun angle is found from due north in a clockwise direction. In the UAE, it is elevated at an angle of 350̊ during the months of April to November. The sun's declination angle is at the lowest of 9˚ from the months of June through August (See figure 26).

4.4 Modelling the Context with ENVI-met

Modelling the Dubai Marina context using ENVI-met involves a calculation of fluid dynamics and thermodynamic processes at surfaces/ walls/ roofs and plants (Bruse, 1999). It can be detailed by four distinctive processes during the simulation phase model area inputs, model configuration, model runs/ output and leonardo visualization. The four processes are defined below:

- **Model Area Inputs**
  The area input setting is intuitive and based on the model size, location, dimension and building environment (Bruse, 1999). Building heights, soil types, plants and surface conditions can be defined in the area input editor.

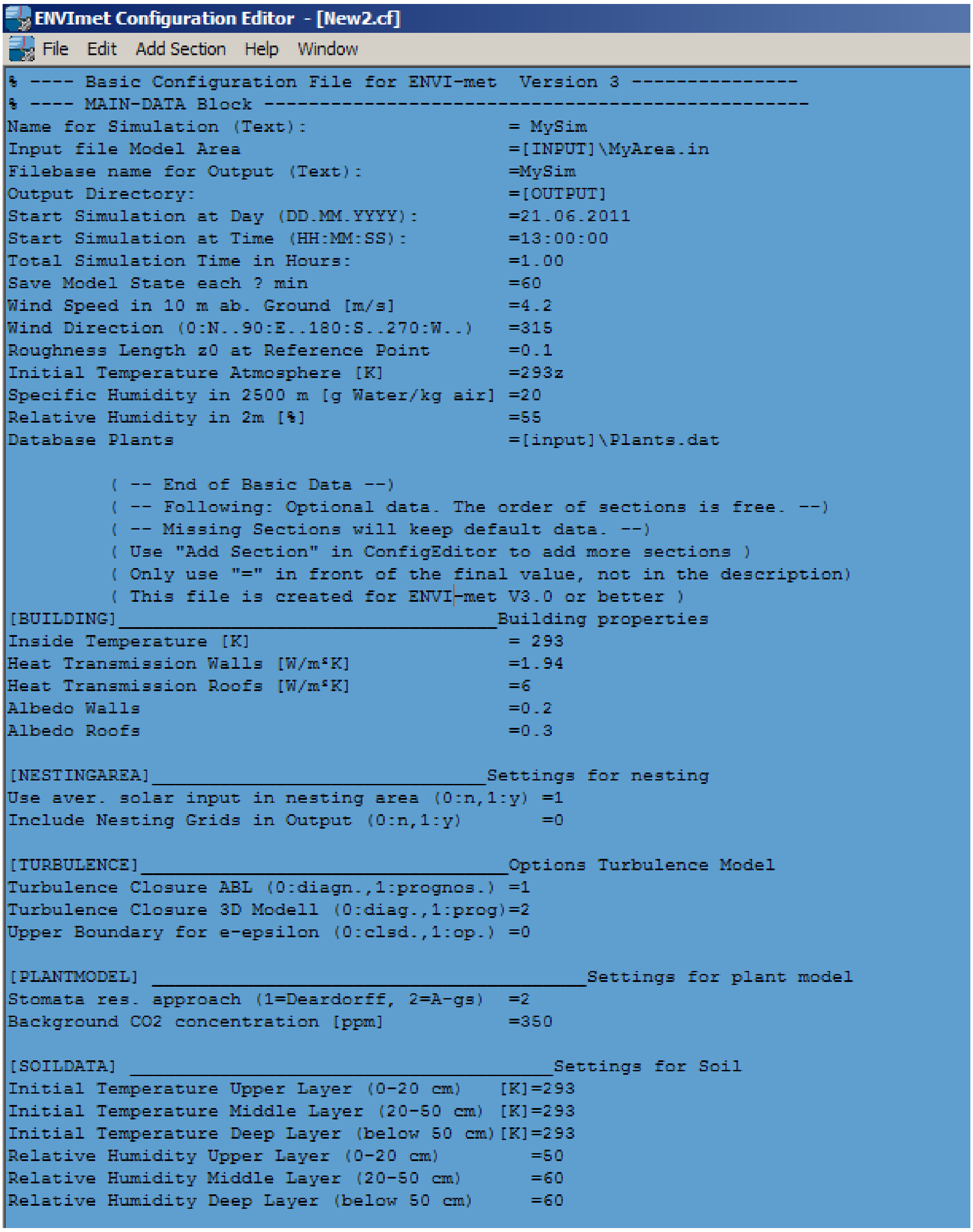
- **Model Configuration**
  A model configuration file is set up to include the meteorological profile of the UAE for a specified date (Bruse, 1999). Including this information helps the model run an analysis for that period to test the thermal comfort levels. In this case the measured performance parameters include wind direction, speed, humidity, temperature and surface albedo.

- **Model Run and Outputs**
  Model run is a phase where the built model from the ENVI-met editor (eddi) is tested and run following the necessary input conditions mentioned above (Bruse, 1999). The model run procedure follows the assigned time frame inputted in the configuration and generates the necessary output filed for the tested parameters specified in model configuration.

- **LEONARDO Visualization**
  LEONARDO visualizes the output files generated from the Model run. The three main output data folders documented for LEONARDO visuals are atmosphere, surface data and soil conditions (Bruse, 1999). Visuals for each parameter can be viewed on hourly basis depending on the assigned time sequence specified in the configuration.

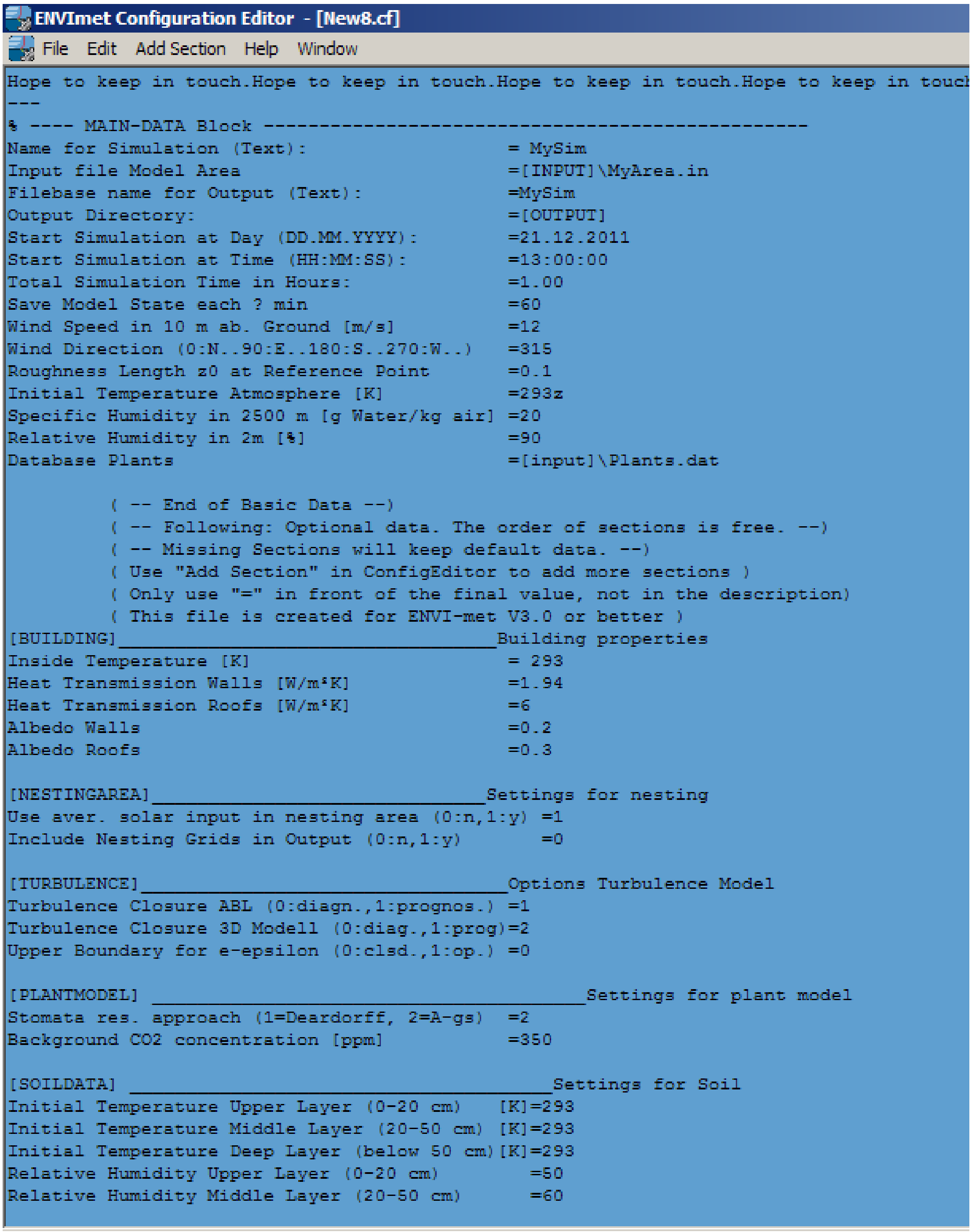
4.5 Detailing the Model Setup

The simulation is set up based on a core configuration (See figure 27 and 28) for the Dubai Marina development. The inputs for the configuration include the area inputs, time frame, UAE weather profile, building surface temperature, plant data and soil data.



```
% ---- Basic Configuration File for ENVI-met  Version 3 ---------------
% ---- MAIN-DATA Block -------------------------------------------------
Name for Simulation (Text):                  = MySim
Input file Model Area                        =[INPUT]\MyArea.in
Filebase name for Output (Text):             =MySim
Output Directory:                            =[OUTPUT]
Start Simulation at Day (DD.MM.YYYY):        =21.06.2011
Start Simulation at Time (HH:MM:SS):         =13:00:00
Total Simulation Time in Hours:              =1.00
Save Model State each ? min                  =60
Wind Speed in 10 m ab. Ground [m/s]          =4.2
Wind Direction (0:N..90:E..180:S..270:W..)   =315
Roughness Length z0 at Reference Point       =0.1
Initial Temperature Atmosphere [K]           =293z
Specific Humidity in 2500 m [g Water/kg air] =20
Relative Humidity in 2m [%]                  =55
Database Plants                              =[input]\Plants.dat

         ( -- End of Basic Data --)
         ( -- Following: Optional data. The order of sections is free. --)
         ( -- Missing Sections will keep default data. --)
         ( Use "Add Section" in ConfigEditor to add more sections )
         ( Only use "=" in front of the final value, not in the description)
         ( This file is created for ENVI-met V3.0 or better )
[BUILDING]__________________________________Building properties
Inside Temperature [K]                       = 293
Heat Transmission Walls [W/m²K]              =1.94
Heat Transmission Roofs [W/m²K]              =6
Albedo Walls                                 =0.2
Albedo Roofs                                 =0.3

[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

[TURBULENCE]_________________________________Options Turbulence Model
Turbulence Closure ABL (0:diagn.,1:prognos.) =1
Turbulence Closure 3D Modell (0:diag.,1:prog)=2
Upper Boundary for e-epsilon (0:clsd.,1:op.) =0

[PLANTMODEL] ______________________________________Settings for plant model
Stomata res. approach (1=Deardorff, 2=A-gs)  =2
Background CO2 concentration [ppm]           =350

[SOILDATA] ______________________________________Settings for Soil
Initial Temperature Upper Layer (0-20 cm)   [K]=293
Initial Temperature Middle Layer (20-50 cm) [K]=293
Initial Temperature Deep Layer (below 50 cm)[K]=293
Relative Humidity Upper Layer (0-20 cm)        =50
Relative Humidity Middle Layer (20-50 cm)      =60
Relative Humidity Deep Layer (below 50 cm)     =60
```

Figure 27: ENVI-Met Configuration Set-Up for June 21st, 2011.



```
Hope to keep in touch.Hope to keep in touch.Hope to keep in touch.Hope to keep in touc
---
% ---- MAIN-DATA Block -------------------------------------------------
Name for Simulation (Text):                  = MySim
Input file Model Area                        =[INPUT]\MyArea.in
Filebase name for Output (Text):             =MySim
Output Directory:                            =[OUTPUT]
Start Simulation at Day (DD.MM.YYYY):        =21.12.2011
Start Simulation at Time (HH:MM:SS):         =13:00:00
Total Simulation Time in Hours:              =1.00
Save Model State each ? min                  =60
Wind Speed in 10 m ab. Ground [m/s]          =12
Wind Direction (0:N..90:E..180:S..270:W..)   =315
Roughness Length z0 at Reference Point       =0.1
Initial Temperature Atmosphere [K]           =293z
Specific Humidity in 2500 m [g Water/kg air] =20
Relative Humidity in 2m [%]                  =90
Database Plants                              =[input]\Plants.dat

         ( -- End of Basic Data --)
         ( -- Following: Optional data. The order of sections is free. --)
         ( -- Missing Sections will keep default data. --)
         ( Use "Add Section" in ConfigEditor to add more sections )
         ( Only use "=" in front of the final value, not in the description)
         ( This file is created for ENVI-met V3.0 or better )
[BUILDING]__________________________________Building properties
Inside Temperature [K]                       = 293
Heat Transmission Walls [W/m²K]              =1.94
Heat Transmission Roofs [W/m²K]              =6
Albedo Walls                                 =0.2
Albedo Roofs                                 =0.3

[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

[TURBULENCE]_________________________________Options Turbulence Model
Turbulence Closure ABL (0:diagn.,1:prognos.) =1
Turbulence Closure 3D Modell (0:diag.,1:prog)=2
Upper Boundary for e-epsilon (0:clsd.,1:op.) =0

[PLANTMODEL] ________________________________________Settings for plant model
Stomata res. approach (1=Deardorff, 2=A-gs)  =2
Background CO2 concentration [ppm]           =350

[SOILDATA] ______________________________________Settings for Soil
Initial Temperature Upper Layer (0-20 cm)   [K]=293
Initial Temperature Middle Layer (20-50 cm) [K]=293
Initial Temperature Deep Layer (below 50 cm)[K]=293
Relative Humidity Upper Layer (0-20 cm)        =50
Relative Humidity Middle Layer (20-50 cm)      =60
```

Figure 28: ENVI-Met Configuration Set-Up for December 21st, 2011.

The model is allotted a 24 hour time frame thus recording the parameter inputs on hourly basis. In doing this, a profile is set up for temperature deferential at different times of the day for a more accurate assessment of the scope. However the chosen time frame for the model discussing the thermal performance is set for June 21st at 13:00 and

December 21st at 13:00. The surface albedo and internal building properties are assigned for all buildings with in the model area and cannot be varied on individual account. The simulation is set for clear sky conditions on the ENVI-met program assuming no cloud cover is recorded.

The simulation date is set during the summer solstice June 21st, 2011 and the winter solstice December 21st, 2011. The sun is at peak intensity on June 21st as showing in the diagram, figure 29. During the winter period, the sun is at a lower angle, also shown in figure 29. Seasonal variation is tested to validate thermal performance levels purely because during winter months, the earth surface does not receive as much solar energy from the sun in the Northern hemisphere when compared to the summer months.

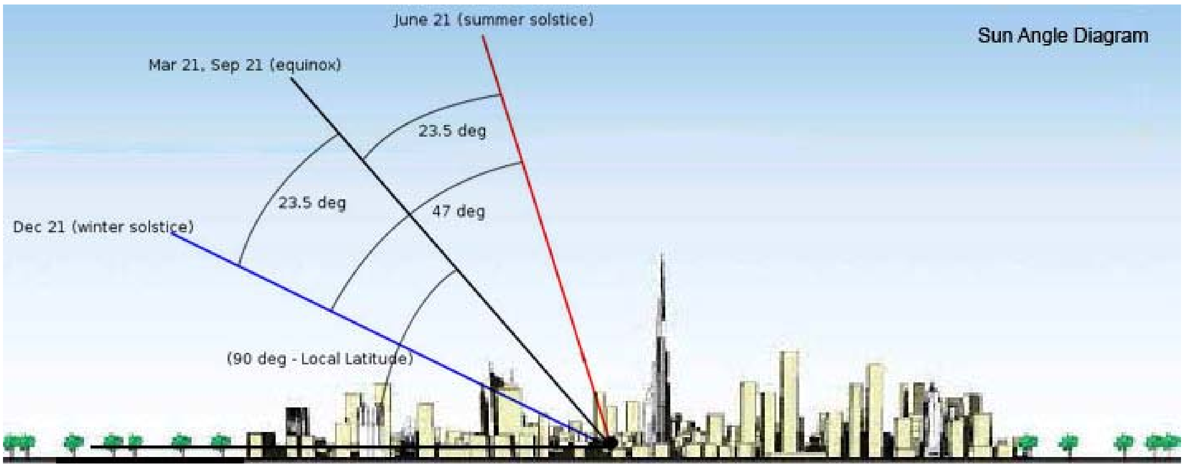


Figure 29: Sun Angle Diagram (Author, 2012).

Wind speed, direction, relativity humidity levels are based on UAE weather data recorded in Appendix A. The ENVI-met configuration in figures 27 and 28 is used for two model scenarios, the first is a base case documenting existing conditions and the second represent the inclusion of green roof strategies. The area inputs are discussed in the next section.

4.6 Sizing the Site Domain

The below figure 30 represents the Dubai Marina and Jumeirah Beach Residence development density. The numbers represented on the legend are floor levels. There are about 200+ buildings with varied heights, the tallest building having over hundred floors. Most buildings are about with the yellow and orange colour category. In order to simply the height for the ENVI-met simulation, the buildings are grouped into four categories depending on the number of floors for each building (See figure 30). Floor levels 0-25 is represented in yellow, levels 26-50 is assigned orange, levels 51-75 is red and 76 + levels is highlighted in maroon. It is assumed each level is 3 meters in floor height. The area highlighted wit a red border will be evaluated for ENVI-met simulation. More about the site area for ENVI-met simulation will be detailed in the next sections discussing the base model set up and base model with green roof strategies.

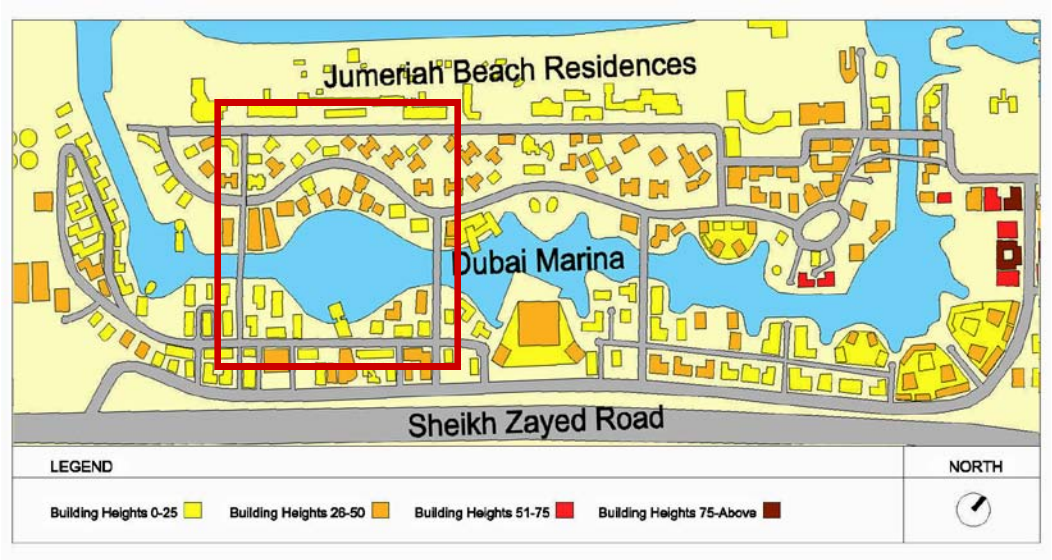


Figure 30: Site area and density of the Dubai Marina and Jumeirah Beach Residence on AutoCAD (Author, 2011).

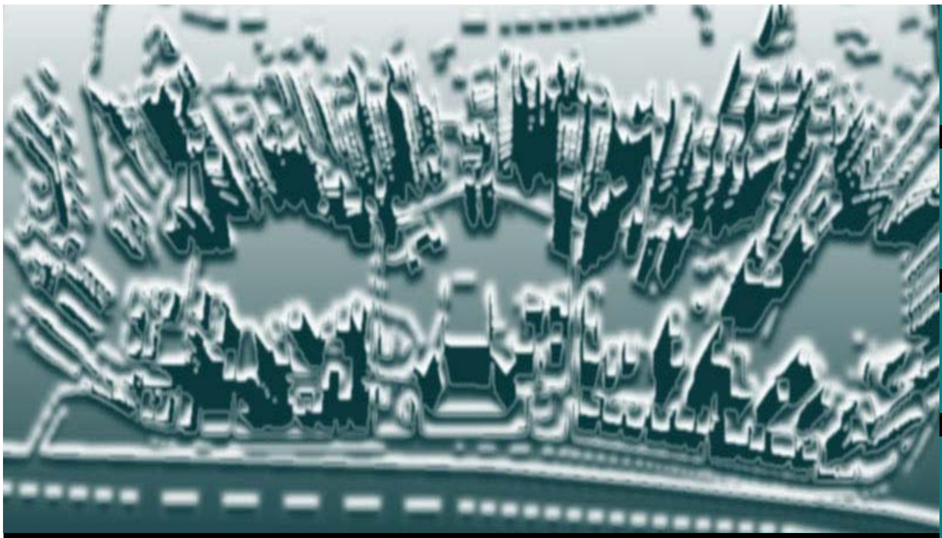
4.7 Setting up the Original Base Model

The original ENVI-met base mode was built using a 100x100x30 domain. The individual cells were modelled at 3m in height. The red highlighted outlined section in Figure 29 is the site area chosen for the ENVI-met simulation. The modelled buildings differentiate in shapes, heights and sizes as built. After inserting the base map and modelled buildings, the surfaces were defined (Refer to Appendix D for details). There were primarily, concrete pavement, asphalt roads, water bodies and soil conditions. The model was then set to run on the 21st June 2011 and 21st December 2011 for a 24 hour period, to test conditions at different times of the day.

4.8 Setting up the Base Model with Green Roof Strategies

The green roof scenario model incorporates the initial base case inputs with vegetation available in the ENVI-met database. The vegetation inputs include, grass, shrubs and tress (Refer to Appendix E for details). Landscaping inputs involve additional soil conditions for green roof. The simulation configuration settings follows the same as described by base case, where the simulation time selected is the summer and winter solstice, the 21st June 2011 and 21st December 2011 respectively and set to run for a 24 hour time period. All measurements are calculated on clear sky conditions. In chapter 5, a look at the outputs and results of the base case simulation and green roof simulation will be discussed.

In conclusion, the Dubai Marina sight was chosen as an ideal location to run the green roof experiment because of climatic factors, building proximity, the variation in building height, the nearness to the sea and a highly concentrated asphalt environment. Chapter 4 discusses the set up and inputs of two ENVI-met model scenarios, an existing condition and a proposed condition. In chapter 5, the results will be examined based on the measured parameters to determine the impact green roofs on thermal comfort.



Chapter 5

Results on Green Roof Thermal Studies

5.1 Introduction

Chapter 5 discusses in detail the ENVI-met results of the base case model and the green roof model mentioned in Chapter 4. The base model will be a non-vegetated roof also referred to as a conventional/ typical roof and will be explained in section 5.2 (summer) and 5.3 (winter) the base case scenario. In the green roof model, a vegetated roof will be further detailed in section 5.4 and 5.5 the green roof scenario.

These results will be tested at 13:00 hours on June 21st, 2011 and December 21st, 2011. June 21st, the summer solstice represents the peak of the sun's intensity on the earth. During this simulated period the two models will be tested the following parameters to test the thermal performance levels i.e., surface albedo, exchange-coefficient of heat, mean radiant temperature, relative humidity, predicted mean vote, percentage of people dissatisfied, wind speed.

A complete analysis will be completed based on the above tested parameters. This analysis will be an in-depth study on the inputs into the model programs and the generated results thereby creating a dialogue comparing the effectiveness of the base case roof scenario and green roof scenario.

5.2 The Base Roof Scenario @ 13:00 hrs June 21st, 2011

The base case scenario represents a conventional roof input (See Appendix D) used typically in the Dubai Marina development, a concrete roof membrane with insulation. The typical roof is not assigned any specific colour or details such as, parapets or canopies. The ENVI-met model is a highly conceptual development in which the following parameters are measured:

- Parameter 1: Surface Albedo
- Parameter 2: Exchange Coefficient of Heat
- Parameter 3: Mean Radiant Temperature
- Parameter 4: Relative Humidity
- Parameter 5: Predicted Mean Vote (PMV)
- Parameter 6: Percentage of People Dissatisfied (PPD)
- Parameter 7: Wind Speed

Parameter 1: Surface Albedo

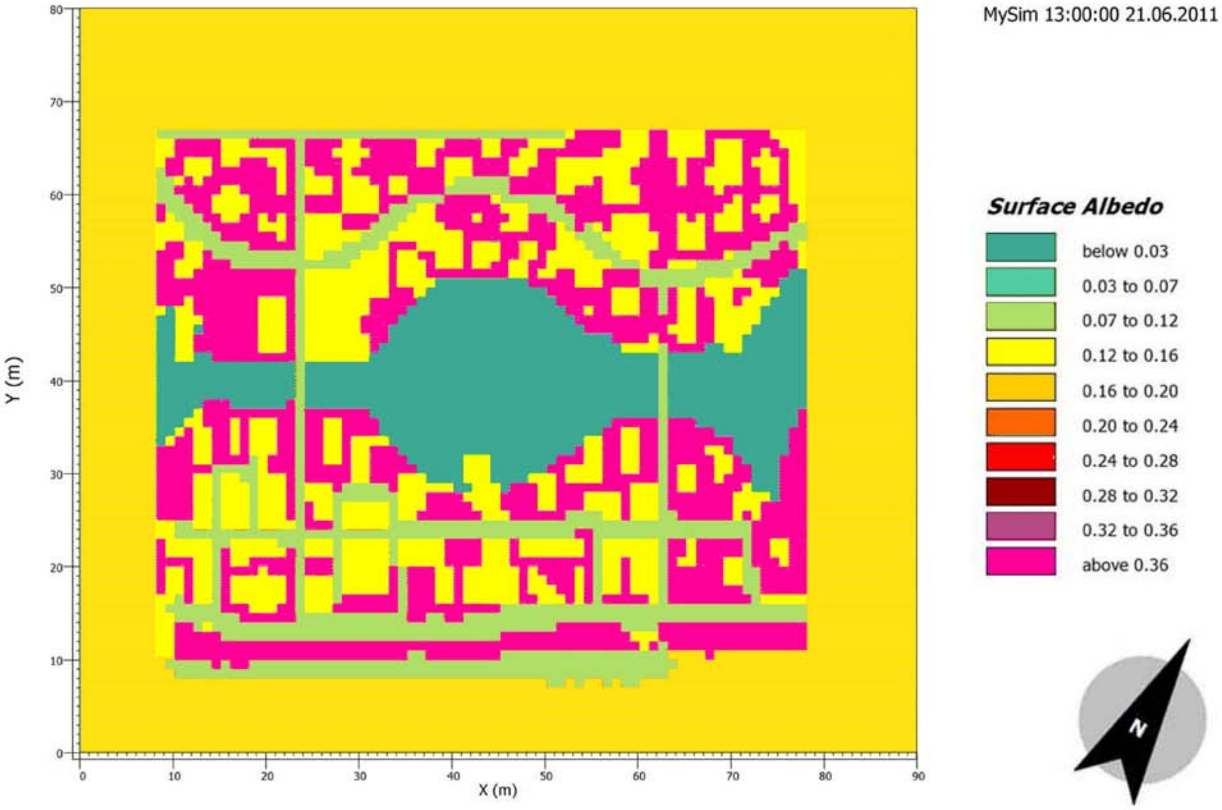


Figure 31: Surface Albedo June 21st 2011 rendered by ENVI-met V3

The surface albedo ENVI-met simulation (See figure 31) confirmed that as no vegetation was assigned in the scenario of a typical roof, the surface albedo is measured in the range of 0.12 to 0.16. Water is depicted as having the lowest surface albedo under 0.03 due to reflectivity. As mentioned in chapter 2, this is dependant on the suns angle and therefore calculated under mid-day sun conditions. The highest surface albedo was found in the concrete pavement having a surface albedo of 0.36 and above. The asphalt road contained a surface albedo ranging from 0.7 to 0.12.

A higher surface albedo reflects the suns rays creating better thermal comfort conditions in the built environment. Having higher surface albedo on roofs help reduce building cooling loads will is beneficial to the built environment. The potential impact of green roofs on thermal performance will be tested in the next section.

Parameter 2: Exchange Coefficient of Heat

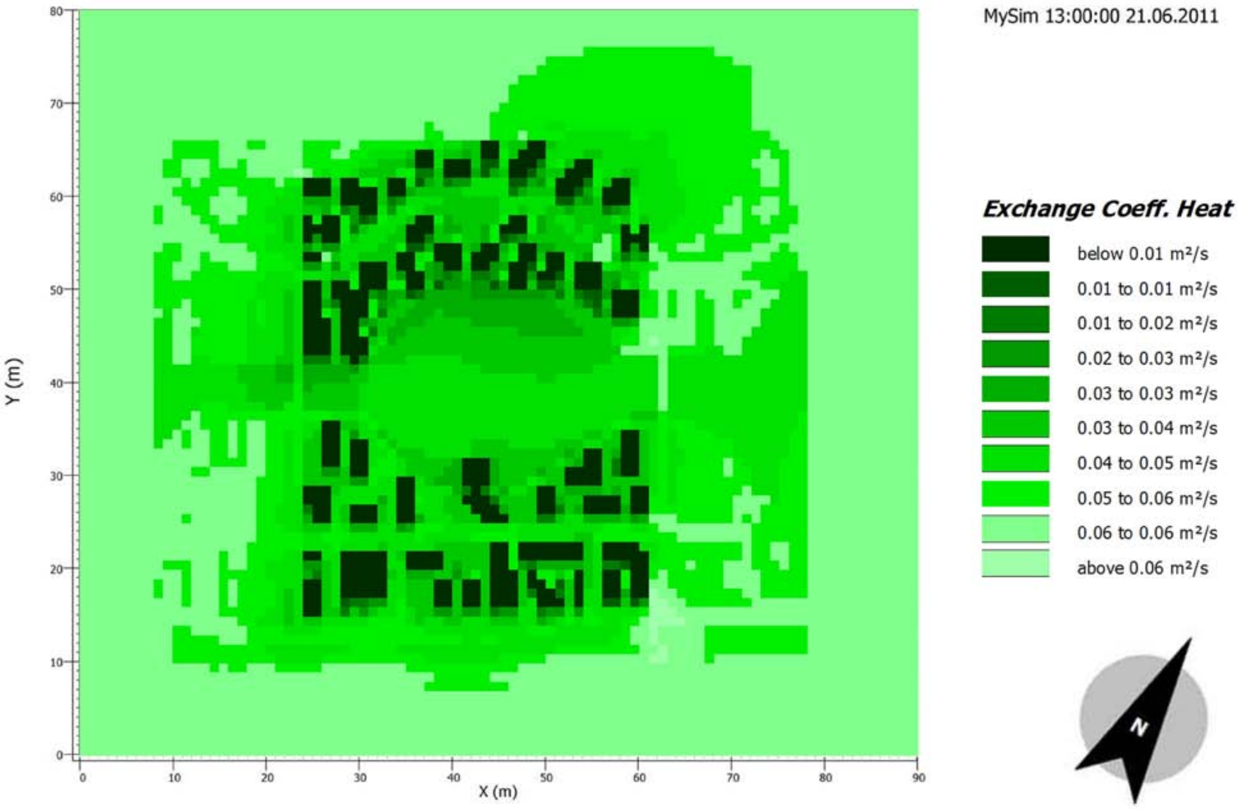


Figure 32: Exchange Coefficient of Heat June 21st 2011 rendered by ENVI-met V3

The exchange coefficient of heat (See figure 32) measured using ENVI-Met found that roofs are subjects to heat transfer from internal building temperature and solar radiation from the suns rays. The typical base roof does not have surface protection such and vegetation strata and soil which acts as point of collection, process and energy release system for heat flow. Therefore the heat interaction between surface and air in this environment is a between 0.01 m^2/s to 0.05 m^2/s.

A green roof study will be conducted in the next section 5.4 (The green roof scenario) to determine any change in the above indicated values. Any change in the above values can be considered beneficial to the outdoor thermal environment.

Parameter 3: Mean Radiant Temperature

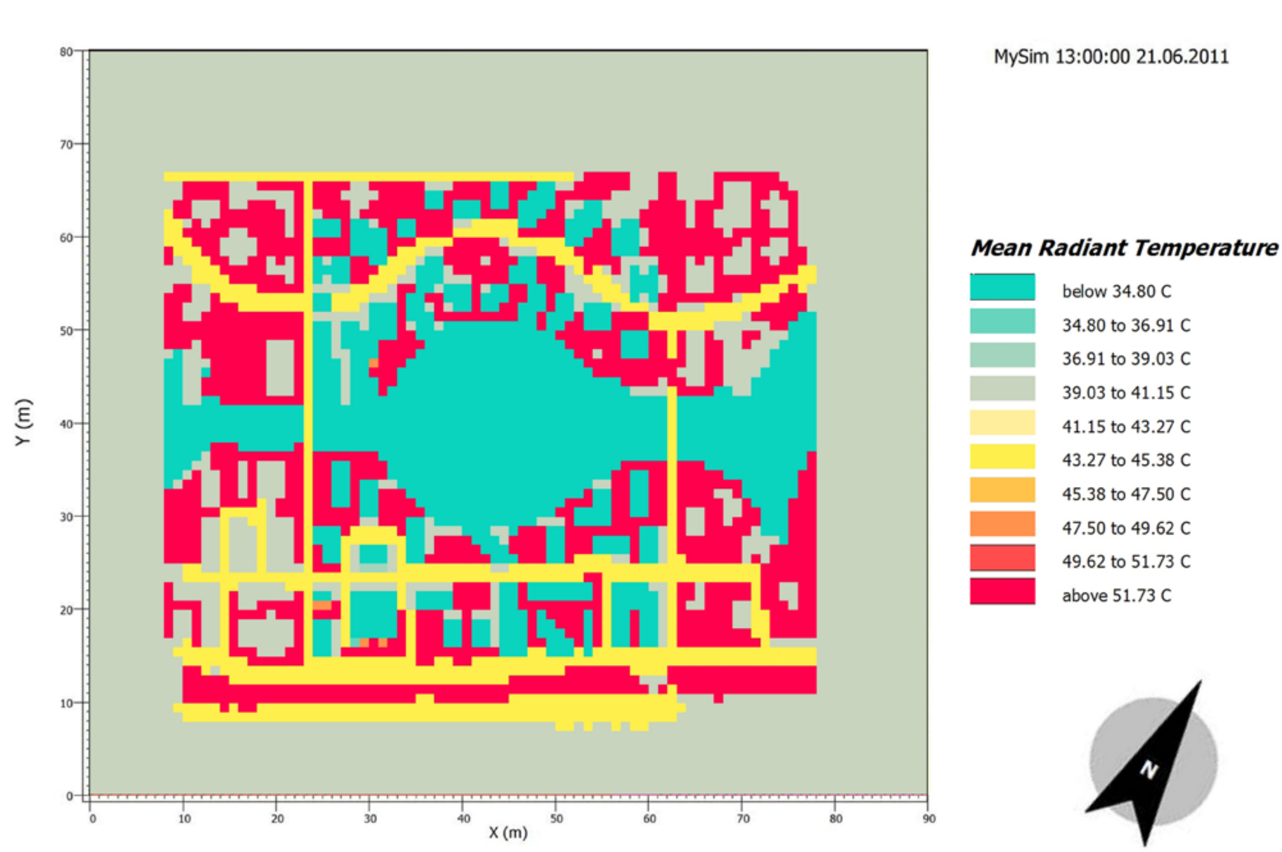


Figure 33: MRT June 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 33) confirmed that the Mean Radiant Temperature measuring the heat emissivity from long wave radiation around the surrounding roof surfaces is the highest on the ENVI-met scale at 49.62˚C – 51.73˚C. This confirms that hard surfaces when exposed to solar radiation during the day time absorbs heat and emits more long-wave radiation to the surrounding environment leading to reduced outdoor thermal comfort.

A green roof study will be modelled in the next section 5.4 (the green roof scenario). This will determine any change in possible change or improvement in thermal comfort will the green roof installation when compared to the based roof modelled above.

Parameter 4: Relative Humidity

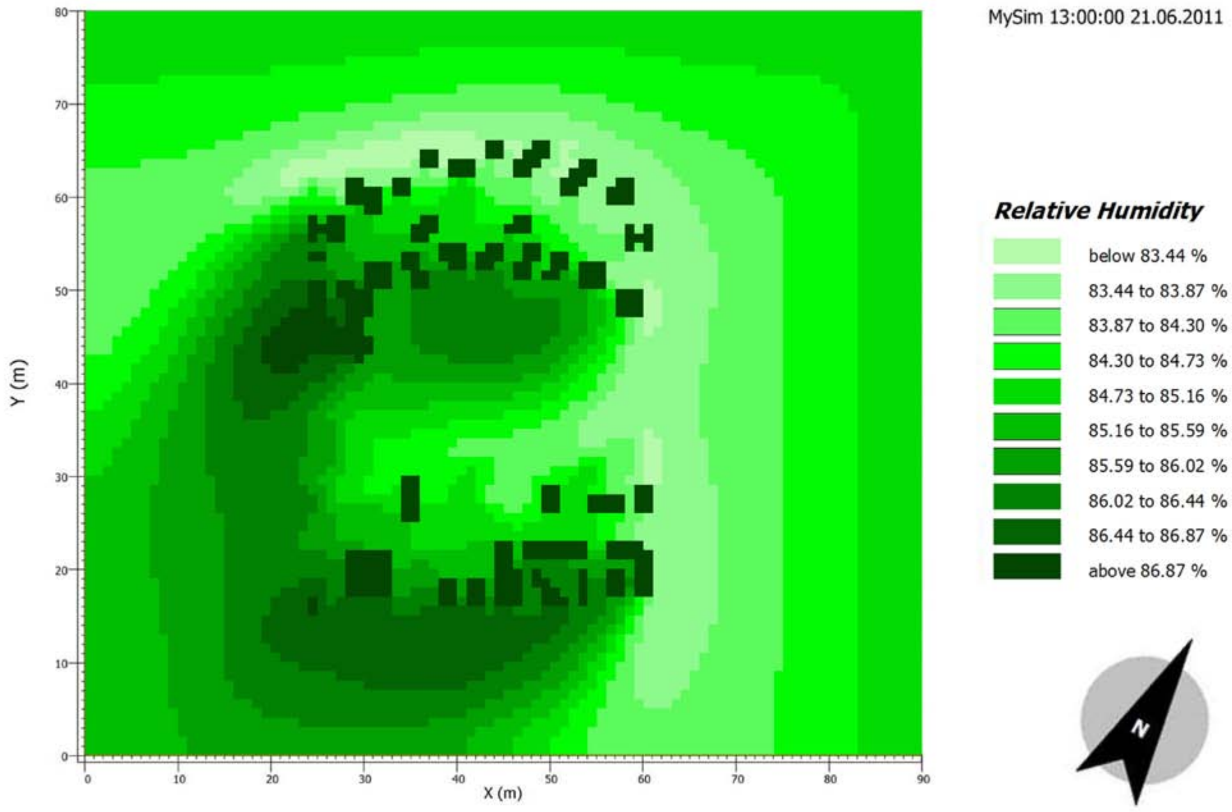


Figure 34: RH June 21st 2011 rendered by ENVI-met V3

Relative humidity (RH) measures the moisture content in air. Thermal comfort levels in the built environment are largely affected by RH levels. When RH is low the human body experience a drop in temperature levels even though the air temperature is at a constant. However, when RH is high the human body experiences an increase in temperature levels. RH (See figure 34) is measured at a range of 83.44% to 86.87% in the Dubai Marina section studied. At an average RH is measure at 85% in the dense urban context at 13:00 hours.

The above ENVI-met study found that RH levels reduced by water bodies and in areas of decreased building heights. However wind speed and airflow also contribute to the variation in RH levels and this will be discussed further in the next two sections.

Parameter 5: Predicted Mean Vote

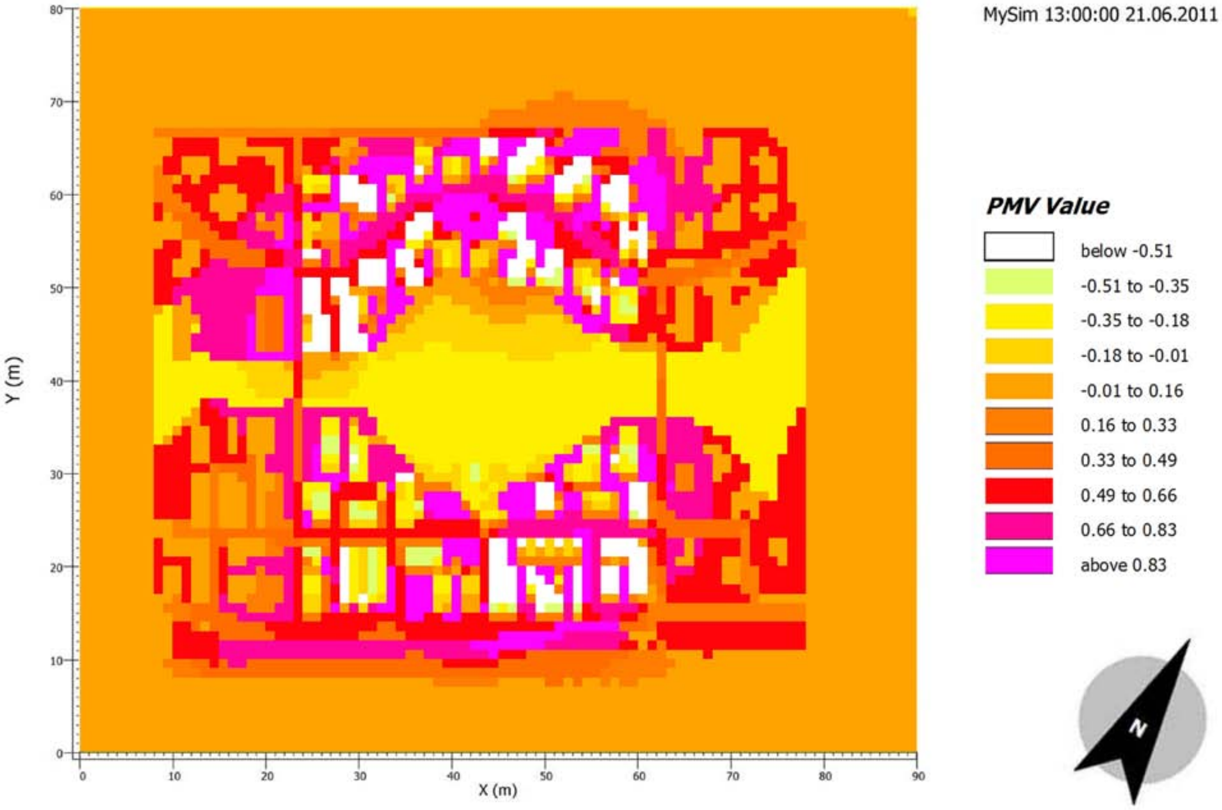


Figure 35: PMV June 21st 2011 rendered by ENVI-met V3

The Predicted Mean Vote (PMV) model is based on close observation of the four physical variables i.e., air temperature, mean radiant temperature, relative humidity and air velocity. Clothing and activity levels can be quantified to form an accurate measure of PMV.

In the above ENVI-met simulation (See figure 35) of the Dubai Marina built environment and the conventional roof context of that area, the PMV value is measured at -0.51 to -0.35. In areas of tall buildings with less SVF, the PMV at 13:00 hours is measured at 0.83 and above. According to ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) the human thermal comfort range of - 0.5 to +0.5 is considered neutral.

Parameter 6: Percentage of People Dissatisfied

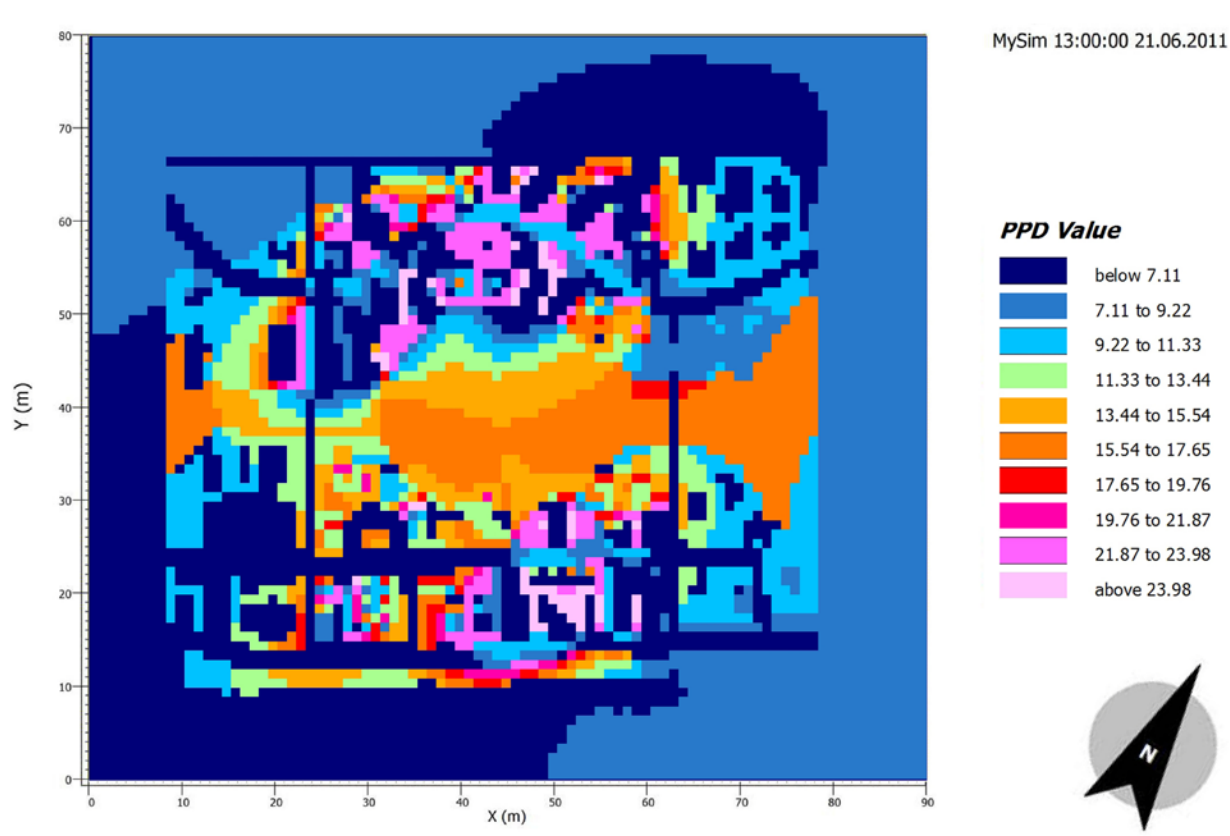


Figure 36: PPD June 21st 2011 rendered by ENVI-met V3

ISO standard 7730 (ISO, 1994) has stated that the Percentage of People Dissatisfied (PPD) expresses a person’s thermal comfort based on air temperature, velocity and turbulence. The PPD is dependant on the calculation of PMV and measure the percentage of people dissatisfied with the outdoor thermal environment.

According to the ENVI-met model simulation (See figure 36) the PPD ranges from 7% to 23%. A satisfaction range of 77%-93% is generally considered acceptable. However variation in the specified parameters can lead to a variation of PPD and a green roof variation will be studied in the next section 5.4 (The green roof scenario).

Parameter 7: Wind Speed

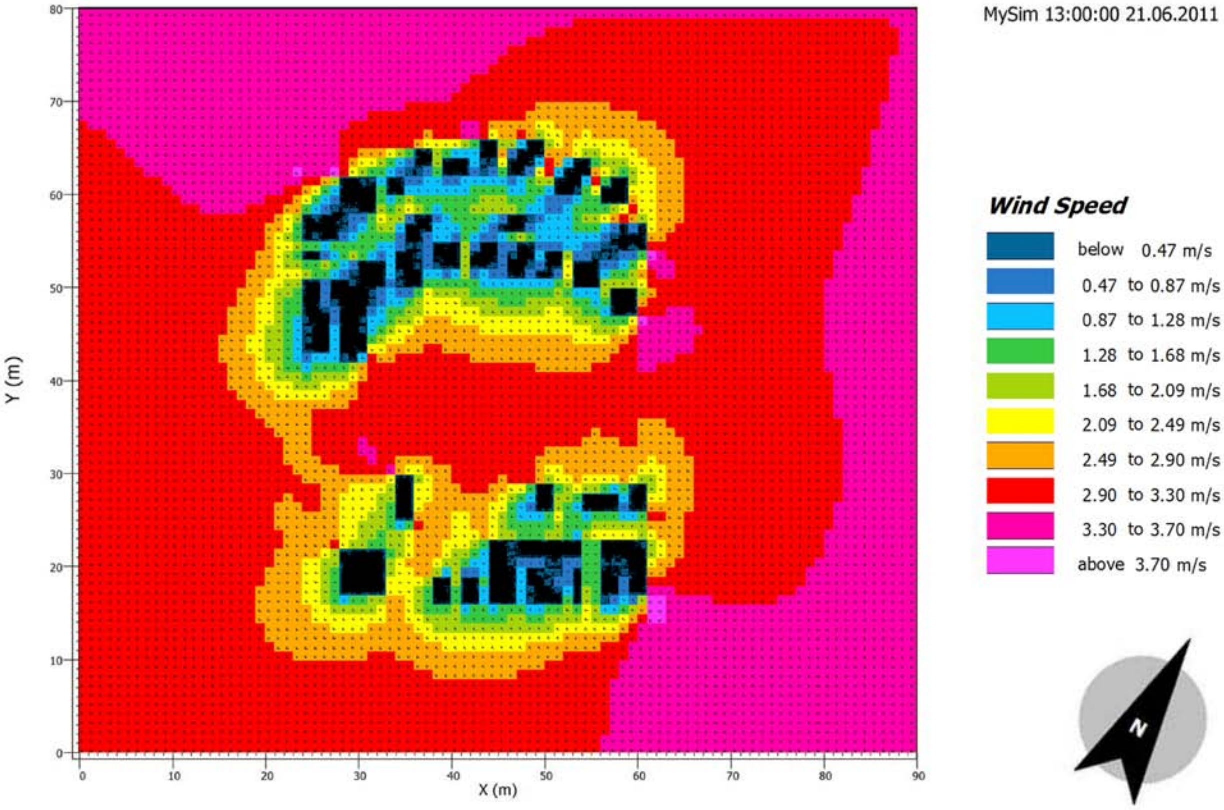


Figure 37: Wind Speed June 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation (See figure 37) confirmed that the wind speed ranges from 0.47 m/s to 1.68 m/s. A low wind speed of 0.5 m/s to 2 m/s is considered acceptable. However with mean radiant temperature at 13:00 hours on June 21st (summer) ranging from 49.62˚C – 51.73˚C, human thermal sensation in the outdoor environment is still considered hot.

A green roof study in the next section 5.4 (The green roof scenario) will determine any reduction/ change in temperature which might effect human thermal sensation based on low wind speed. The study will also determine is wind speed is affected/ hindered by the inclusion of green roof plants.

5.3 The Base Roof Scenario @ 13:00 hrs December 21st, 2011

The base case scenario test the conventional roof scenario at 13:00 December 2011 (See Appendix F). The ENVI-met model measures the following parameters:

- Parameter 1: Surface Albedo
- Parameter 2: Exchange Coefficient of Heat
- Parameter 3: Mean Radiant Temperature
- Parameter 4: Relative Humidity
- Parameter 5: Predicted Mean Vote (PMV)
- Parameter 6: Percentage of People Dissatisfied (PPD)
- Parameter 7: Wind Speed

Parameter 1: Surface Albedo

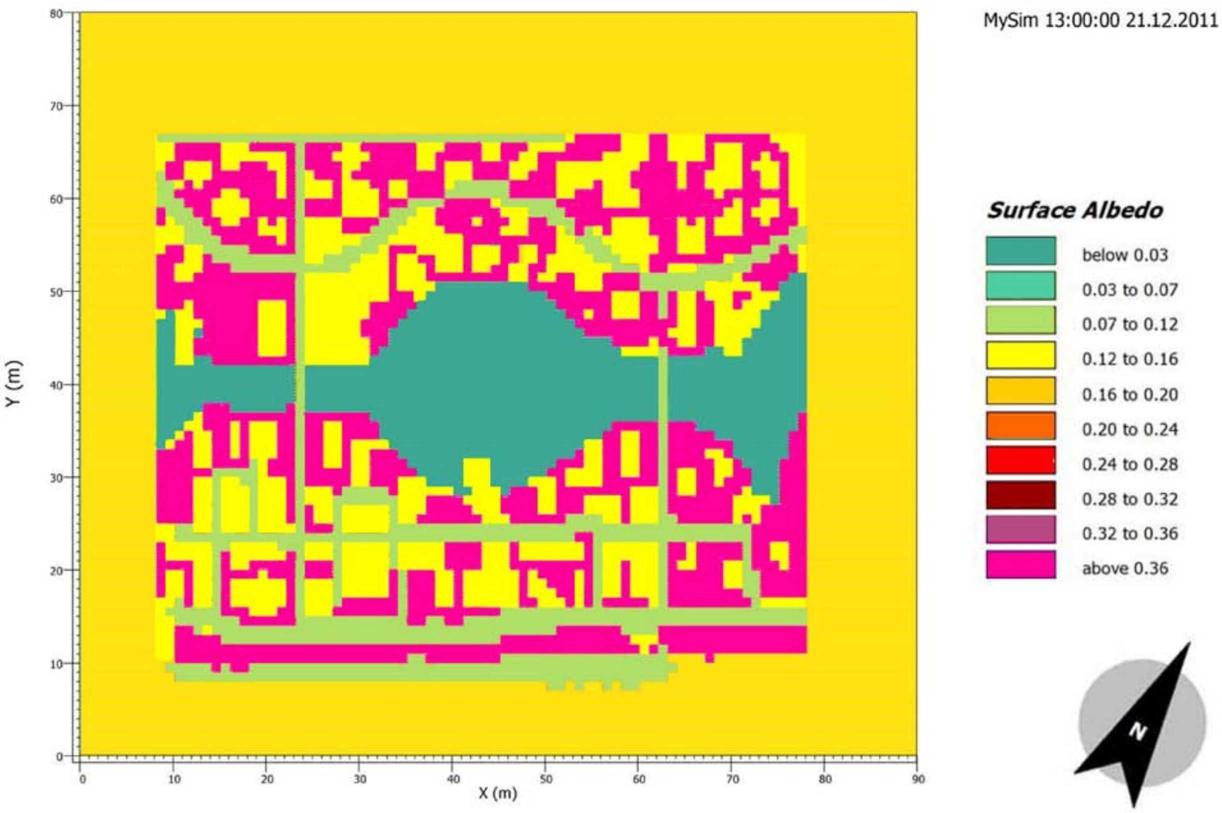


Figure 38: Surface Albedo December 21st 2011 rendered by ENVI-met V3

The surface albedo ENVI-met simulation (See figure 38) as measured during the summer is measured in the range of 0.12 to 0.16. Water is depicted as having the lowest surface albedo under 0.03 due to reflectivity. No change in surface albedo has been noticed in the winter and summer period.

Parameter 2: Exchange Coefficient of Heat

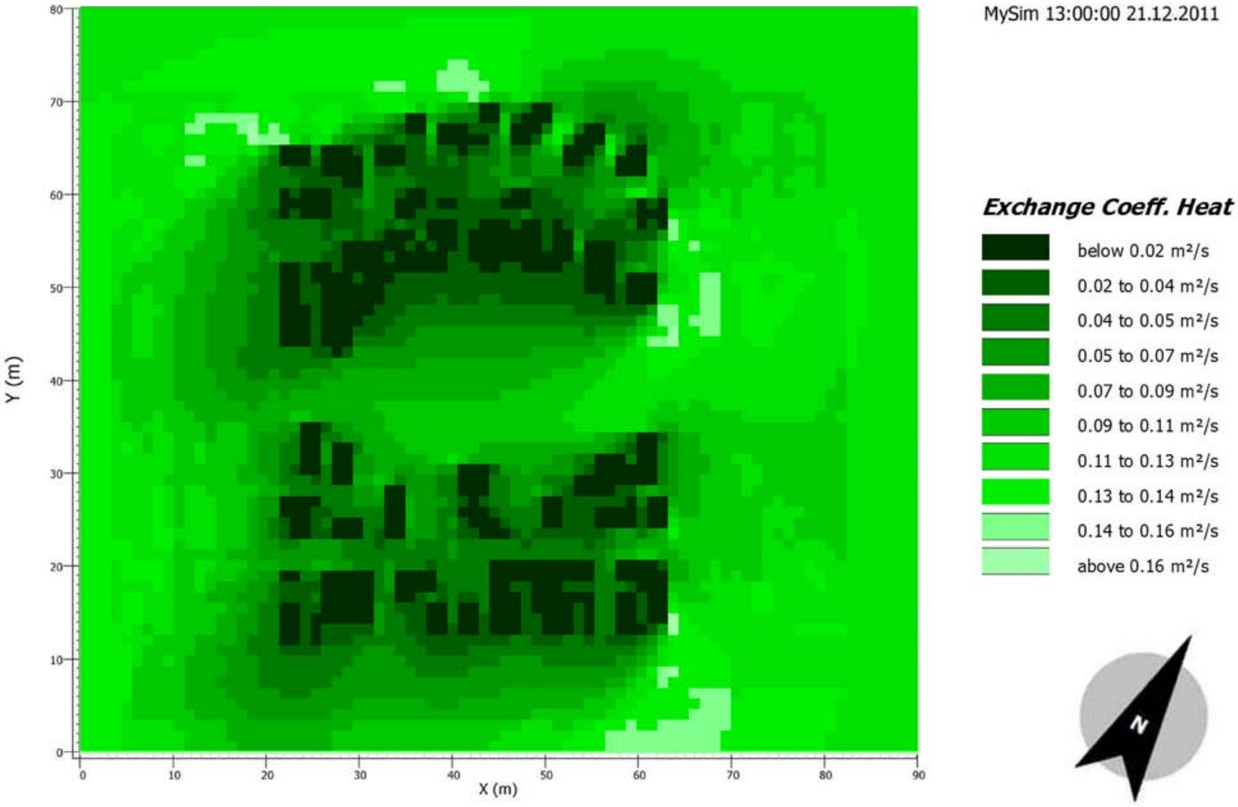


Figure 39: Exchange Coefficient of Heat December 21st 2011 rendered by ENVI-met V3

The exchange coefficient of heat (See figure 39) measured using ENVI-Met found that the heat interaction between surface and air in this environment is below 0.02 m^2/s and can range from 0.02 m^2/s to 0.07 m^2/s.

A green roof study will be conducted in the next section 5.5 (The green roof scenario) to determine any change in the above indicated values. Any change in the above values can be considered beneficial to the outdoor thermal environment.

Parameter 3: Mean Radiant Temperature

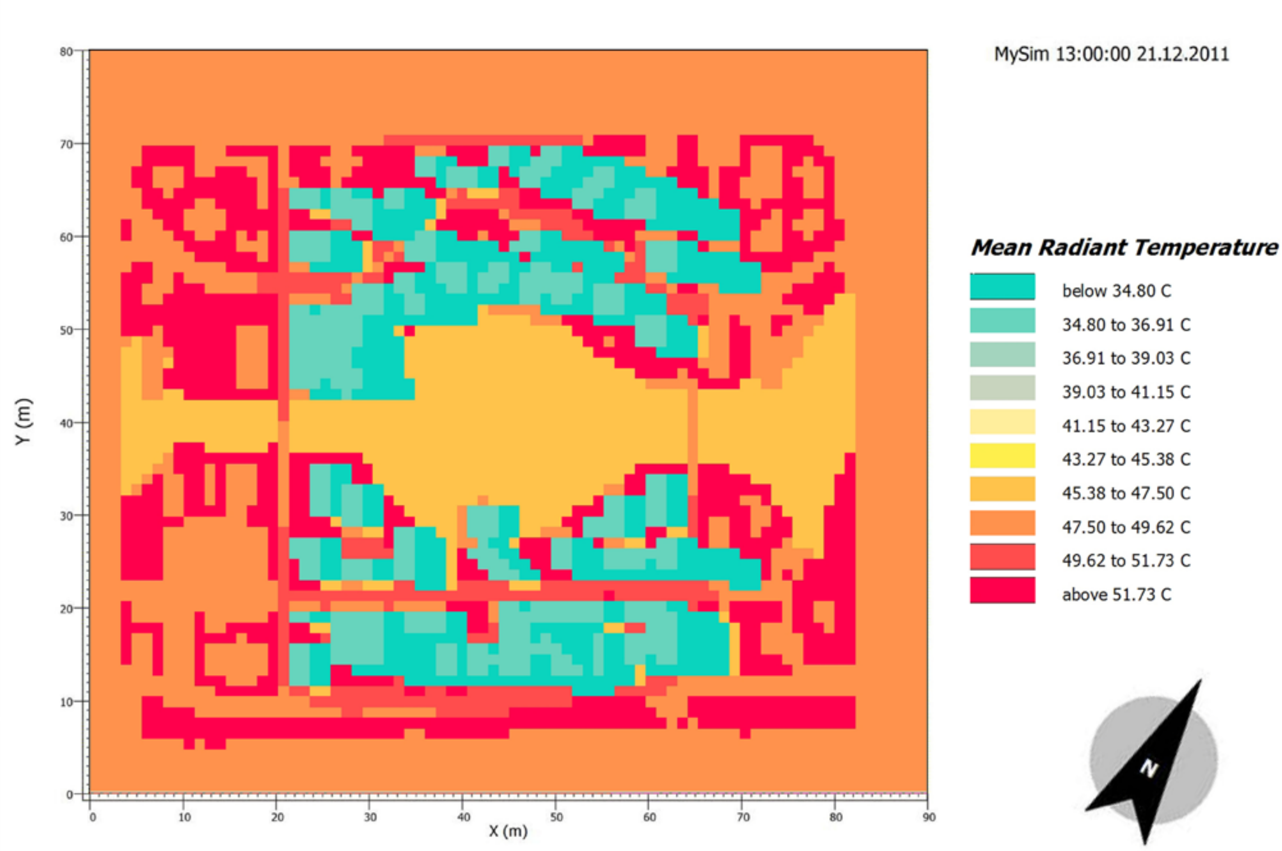


Figure 40: MRT December 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 40) confirmed that the Mean Radiant Temperature measuring the heat emissivity from long wave radiation around the surrounding roof surfaces is the highest on the ENVI-met scale at 34.80˚C – 36.91˚C. Consequently, during winter periods MRT is lower than compared to summer periods.

The ENVI-met simulation above (See figure 40) confirmed that the Mean Radiant Temperature around the surrounding roof surfaces of the green roof is measured at 49.62˚C – 51.73˚C. There is no change in temperature when compared to the base case scenario.

Parameter 4: Relative Humidity

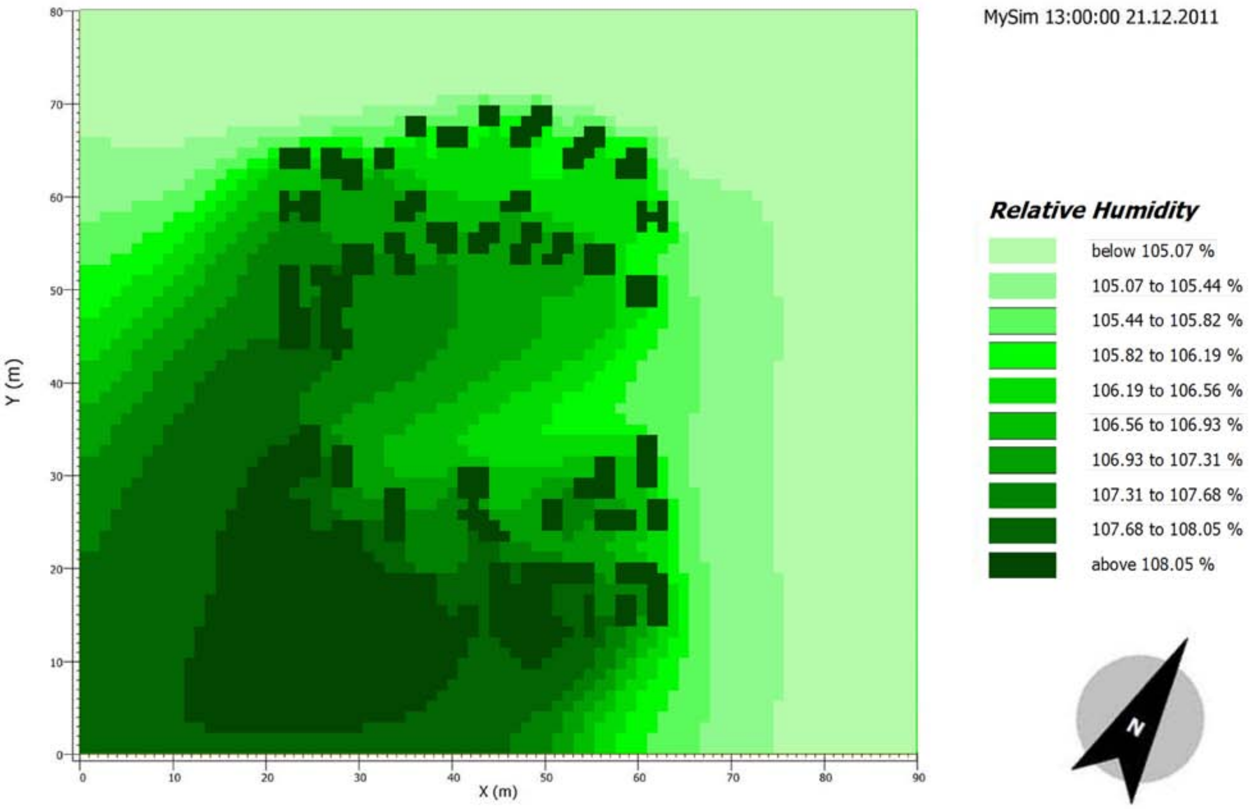


Figure 41: RH December 21st 2011 rendered by ENVI-met V3

Relative Humidity (RH) (See figure 41) is measured at a range of 105.07% to 106.93% in the Dubai Marina section studied. At an average RH is measure at 85% in the dense urban context at 13:00 hours. This represents a shift in RH levels when compared to summer temperature where average RH is 85%.

As mentioned before when RH is low the human body experience a drop in temperature levels even though the air temperature is at a constant. However, when RH is high the human body experiences an increase in temperature levels. Changes in wind speed and airflow also contribute to the variation in RH levels and this will be discussed further in the next two sections.

Parameter 5: Predicted Mean Vote (PMV)

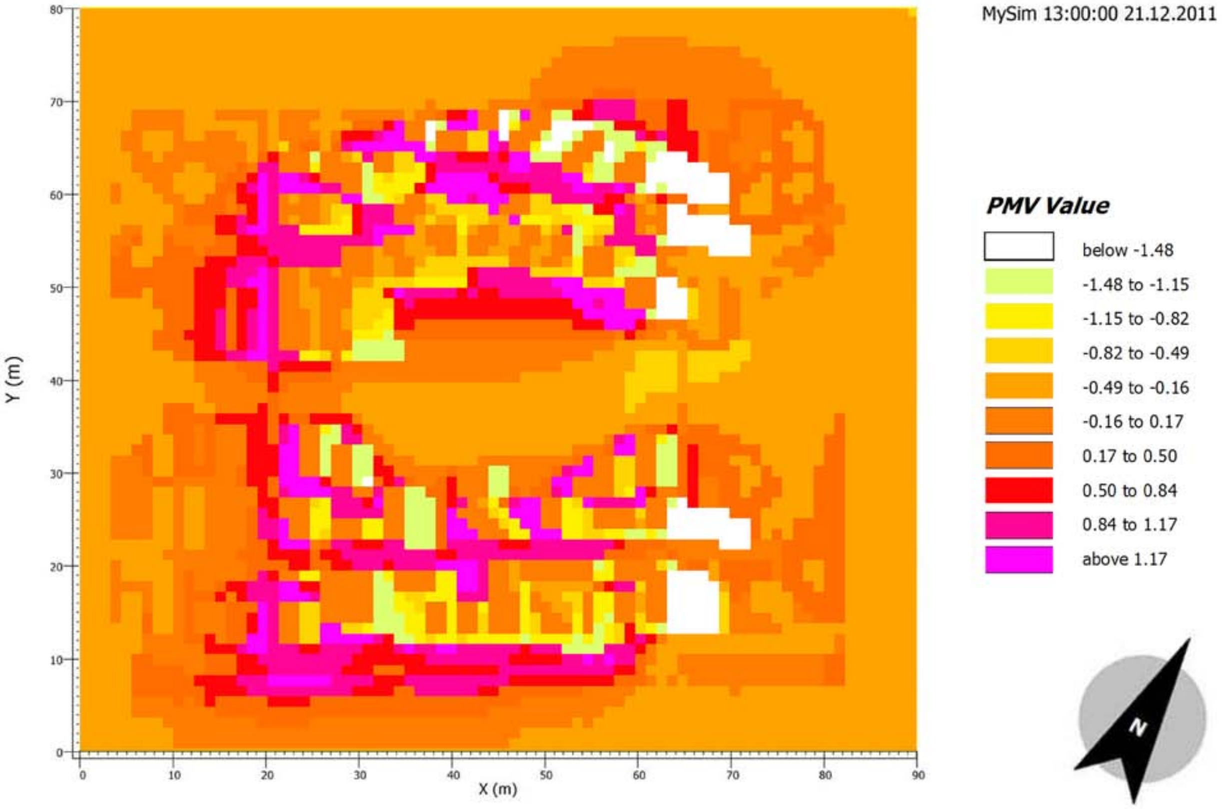


Figure 42: PMV December 21st 2011 rendered by ENVI-met V3

In the above ENVI-met simulation (See figure 42) of the Dubai Marina built environment and the conventional roof context of that area, the PMV value is measured at -1.48 to -0.82. As a result, the surrounding environment is measured at 0.17 to 0.50.

As according to ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994), the human thermal comfort range is measured from - 0.5 to +0.5 (neutral), and below -0.5 (cooler). During the winter periods it was found that some areas a more cooler than others.

Parameter 6: Percentage of People Dissatisfied (PPD)

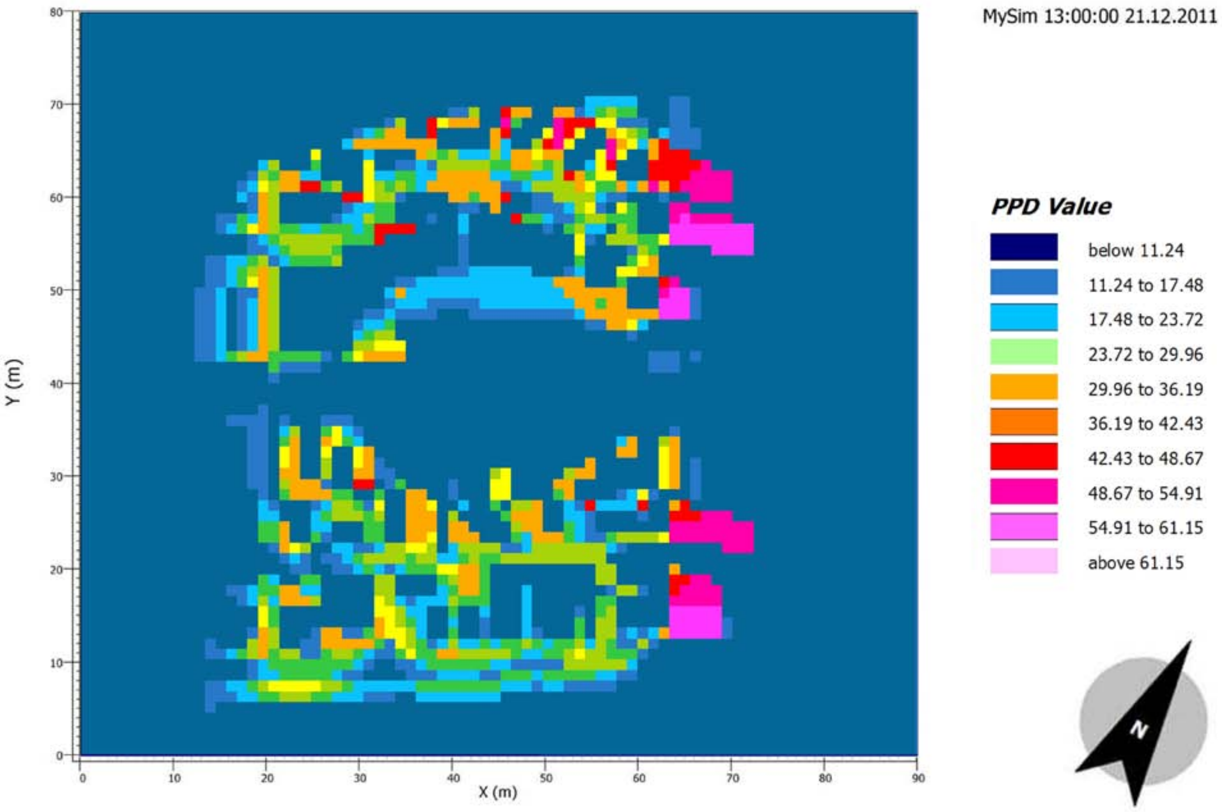


Figure 43: PPD December 21st 2011 rendered by ENVI-met V3

ISO standard 7730 (ISO, 1994) has stated that the Percentage of People Dissatisfied (PPD) expresses a person's thermal comfort based on air temperature, velocity and turbulence. The PPD is dependant on the calculation of PMV and measure the percentage of people dissatisfied with the outdoor thermal environment.

According to the ENVI-met model simulation (See figure 43) the PPD ranges is below 11.24% when compared to the summer time conventional roof from 7% to 23%. Therefore since the satisfaction range falls into the 77%-93% category, it is considered acceptable. However variation in the specified parameters can lead to a variation of PPD and a green roof variation will be studied in the next section 5.3 (The green roof scenario).

Parameter 7: Wind Speed

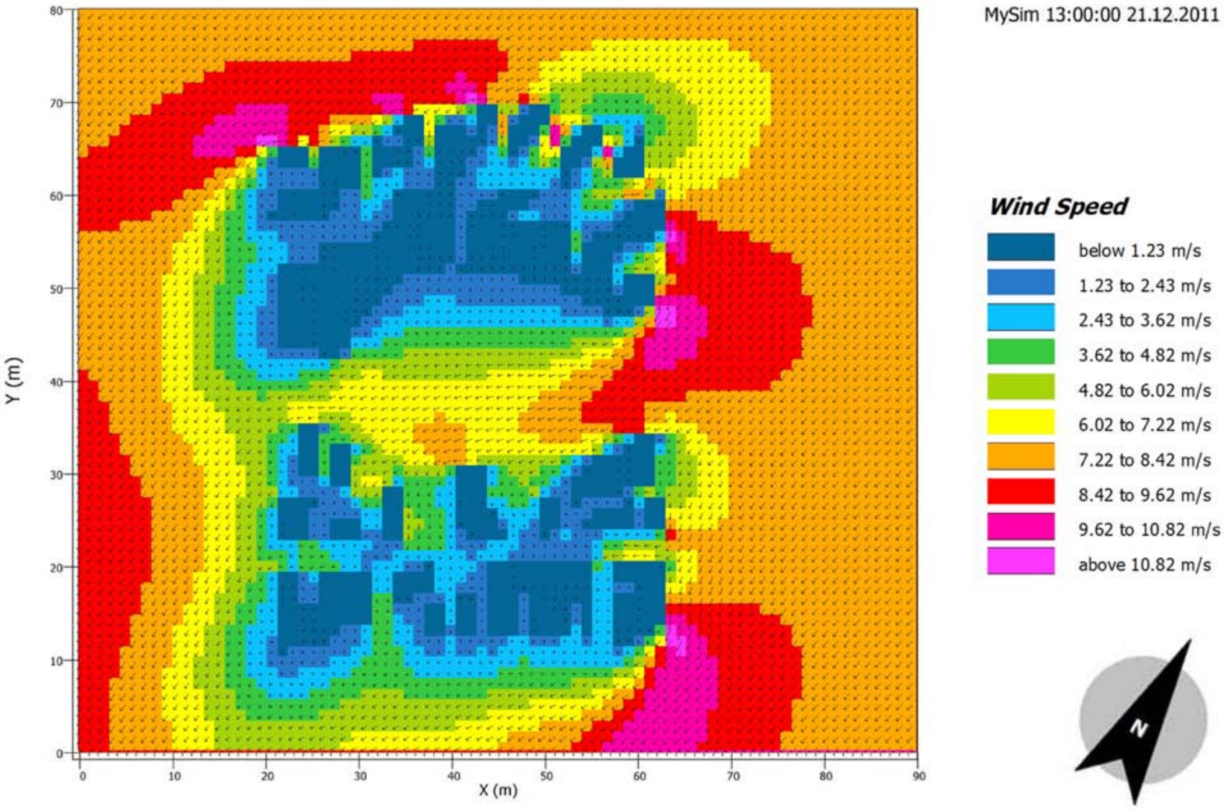


Figure 44: Wind Speed December 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation (See figure 44) confirmed that the wind speed ranges from 1.23 m/s to 3.62 m/s during the winter periods. A low wind speed of 0.5 m/s to 2 m/s is considered acceptable. However with mean radiant temperature at 13:00 hours on June 21st (winter) ranging from 34.80˚C – 36.91˚C, human thermal sensation in the outdoor environment is considered cool.

A green roof study in the next section 5.5 of the winter period (The green roof scenario) will determine any reduction/ change in temperature which might effect human thermal sensation based on low wind speed. The study will also determine is wind speed is affected/ hindered by the inclusion of green roof plants.

5.4 The Green Roof Scenario @ 13:00 hrs June 21st, 2011

At 13:00 hours June 21st 2011, an inclusion of green roofs plants were inputted into the dynamic ENVI-met simulation model. The inputs (See Appendix E) include soil (heavy extensive media) and green roof plants included in the software database. The ENVI-met plant inputs include grass, trees and shrubs. A detailed list of green roof plants for development use can be acquired from the green roof plant database documented by Dubai Municipality (DM) and listed in Appendix C.

For the purpose of the ENVI-met study the green roof plants selected are primarily from the ENVI-met database and although these are fairly generic standardised properties are programmed into the software as observed in Chapter 3. A detailed Leaf Area Index (LAI) assessment is not undertaken for the purpose of this study. Although detailed research on this topic can possible affect the results of the green roof experiment.

Regardless of the LAI assessment, the inclusion of green roofs can possibly eliminate high temperatures in urban areas range from 2-8 °F than the surrounding areas. The intensity of UHI can be reduced through the inclusion of grass and substrate. By doing so, a reduction in roof surface temperature is expected to help mitigate heat islands in the highly urbanized Dubai Marina development.

The ENVI-met simulation model will measure the following parameters to determine if the inclusion of green roofs will result in any change of output to improve the outdoor thermal environment:

- Parameter 1: Surface Albedo
- Parameter 2: Exchange-Coefficient
- Parameter 3: Mean Radiant Temperature
- Parameter 4: Relative Humidity
- Parameter 5: Predicted Mean Vote (PMV)
- Parameter 6: Percentage of People Dissatisfied (PPD)
- Parameter 7: Wind Speed

Parameter 1: Surface Albedo

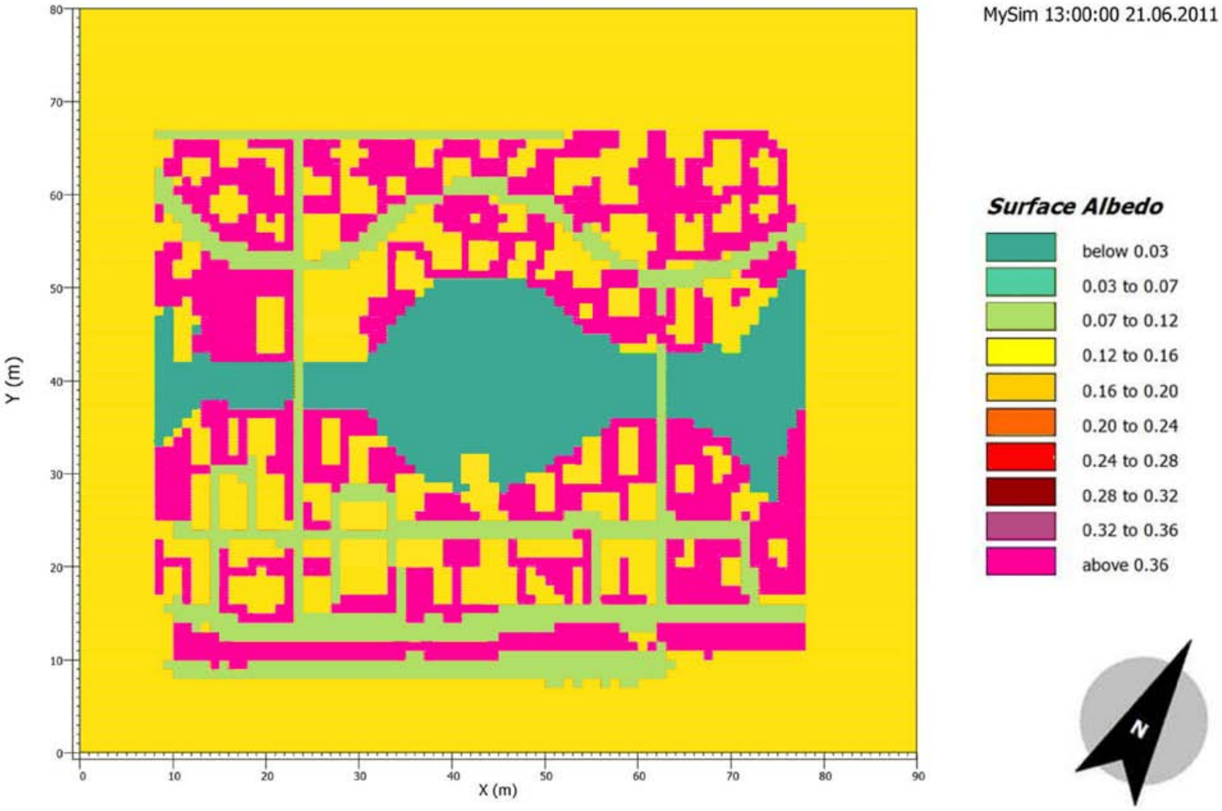


Figure 45: Green Roof Surface Albedo June 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 45) found that with vegetation assigned to the typical roof, the surface albedo has increased from the range of 0.12 to 0.16 in the base case scenario to 0.16 to 0.20. The increase in surface albedo shows that green roofs can mitigate heat islands by reducing air temperature caused by solar reflectivity.

The ability to further reduce surface albedo depends on the type of plants and materials used. The simulation is currently the measure of a section of Dubai Marina where as the large scale application of green roofs when measured can have increased temperature reduction benefits.

Parameter 2: Exchange Coefficient of Heat

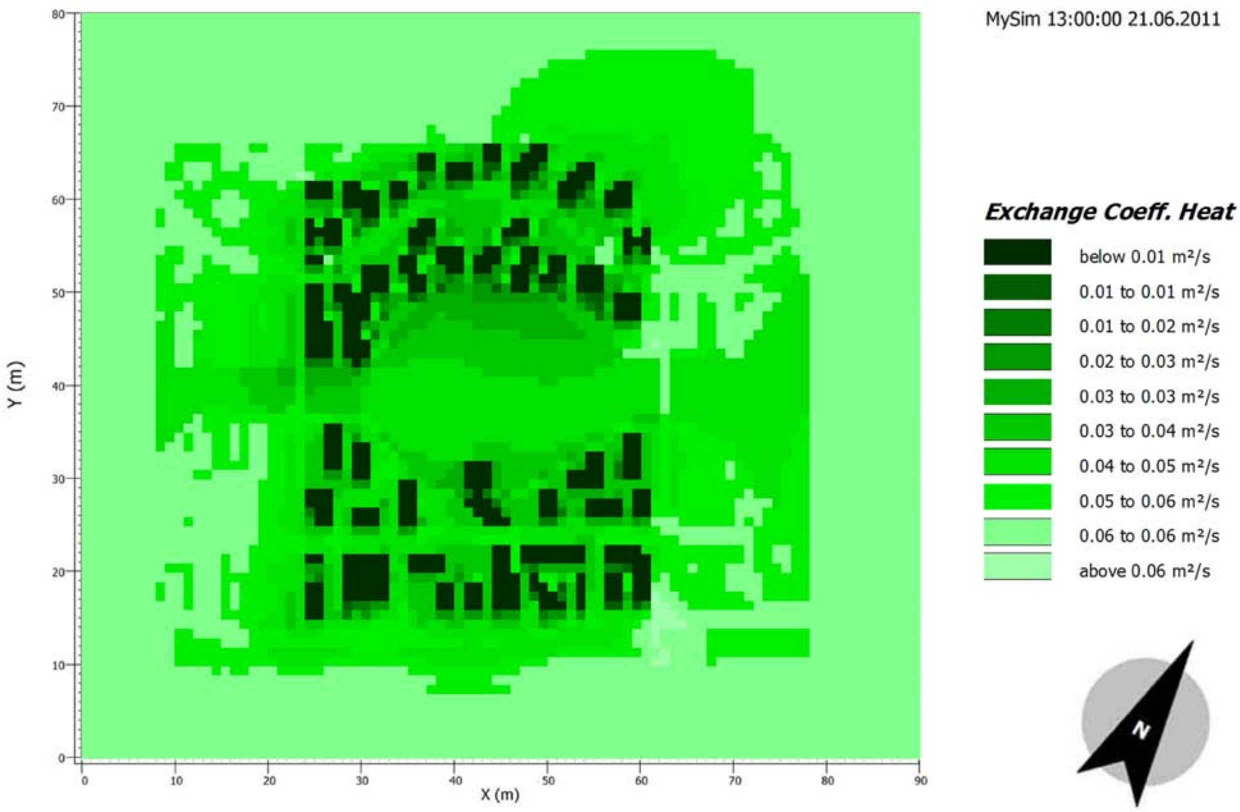


Figure 46: Green Roof Exchange Coefficient of Heat June 21st 2011 rendered by ENVI-met V3

The exchange coefficient of heat measured using ENVI-Met simulation of the green roof scenario (See figure 46) found that there is no major difference in the surface and air interaction from green roofs as compared to the base case roof scenario. The exchange coefficient of heat value still remains in the range of 0.01 m^2/s to 0.05 m^2/s.

Due to limitations in the ENVI-met software, an accurate assessment of the exchange coefficient of heat can not be determined as a more detailed indication of plants and substrate placement could possible result in a change in the exchange coefficient of heat when compared to the base roof scenario.

Parameter 3: Mean Radiant Temperature

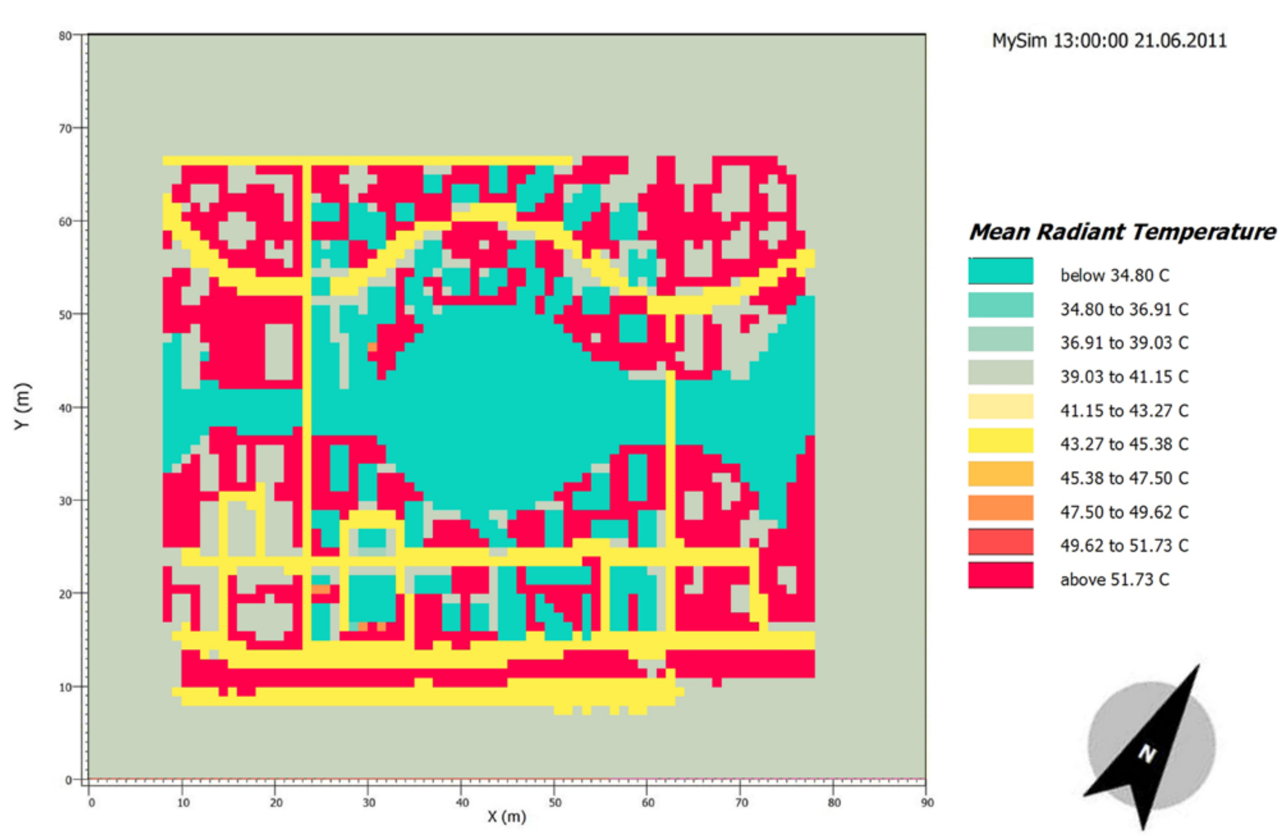


Figure 47: Green Roof MRT June 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 47) confirmed that the Mean Radiant Temperature around the surrounding roof surfaces of the green roof is measured at 49.62˚C – 51.73˚C. There is no change in temperature when compared to the base case scenario.

However, ENVI-met software limitations does not allow for a detailed assessment of plant and substrate details to determine whether a reduction in MRT temperature can be measured. Therefore the potential benefits of green roofs cannot be determined on the ENVI-met Dubai Marina conceptual model and a more detailed study is recommended.

Parameter 4: Relative Humidity

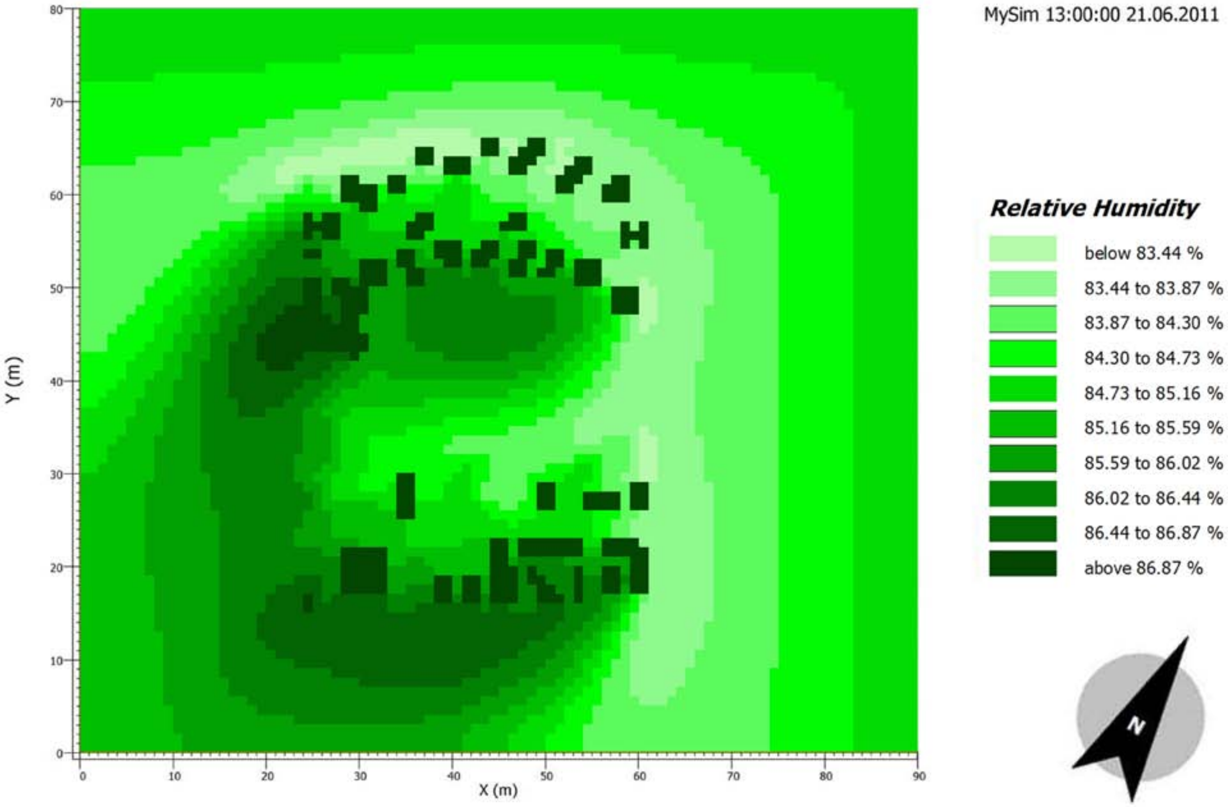


Figure 48: Green Roof RH June 21st 2011 rendered by ENVI-met V3

Relative humidity (RH) model (See figure 48) remains at a range of 83.44% to 86.87% as measured in the base case scenario. The average RH is measured at 85% in the dense urban context at 13:00 hours.

As factors such as wind speed and airflow effect RH levels the installation of green roofs may have little or no impact on RH levels. The type of green roof in depth may have little or no impact dependant on scale and typology of green roof.

Parameter 5: Predicted Mean Vote

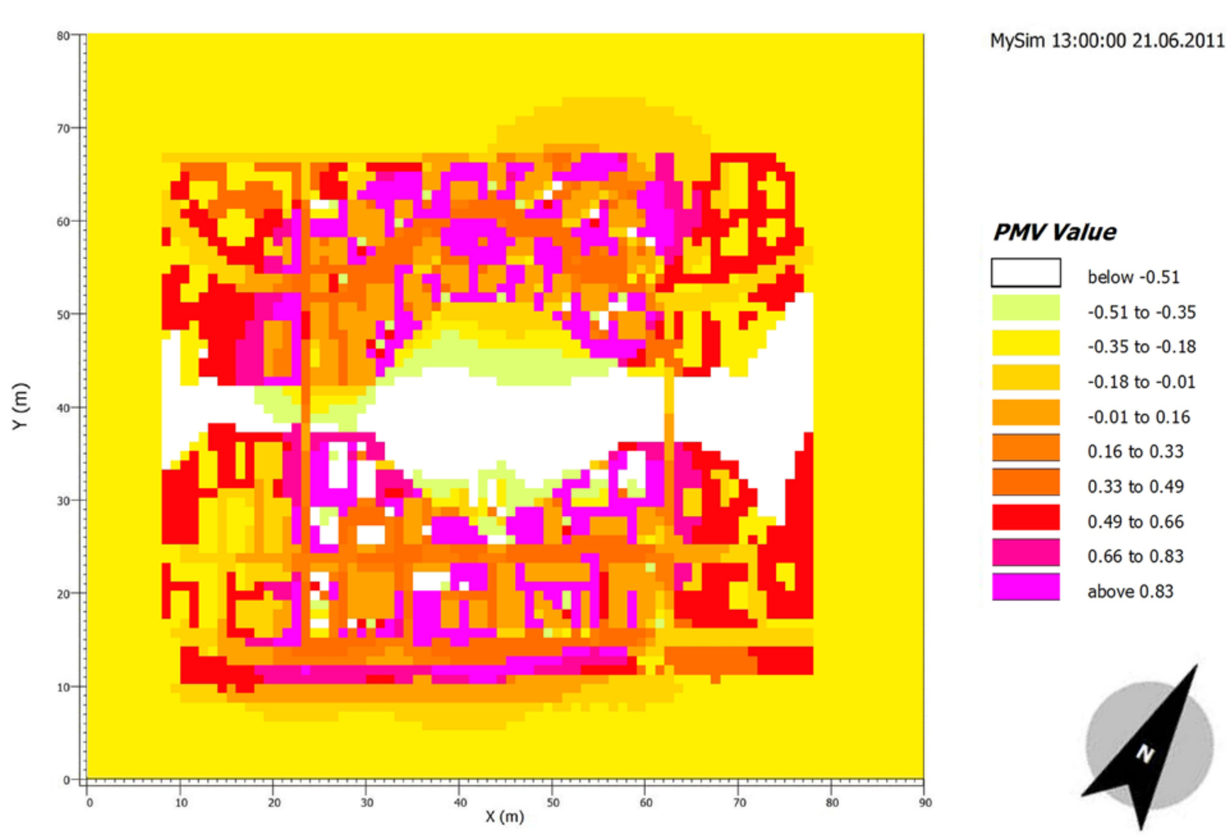


Figure 49: Green Roof PMV June 21st 2011 rendered by ENVI-met V3

The Predicted Mean Vote (PMV) simulated by ENVI-met green roof model above (See figure 49) measures a slight change in PMV numbers from the base case scenario. In the base case scenario the PMV was measured at -0.51 to -0.35. However in the ENVI-met green roof scenario, the PMV increase measured at -0.01 to 0.33. This signifies a slight increase in comfort but still satisfying the ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) of human thermal comfort range - 0.5 to +0.5 (neutral).

Parameter 6: Percentage of People Dissatisfied

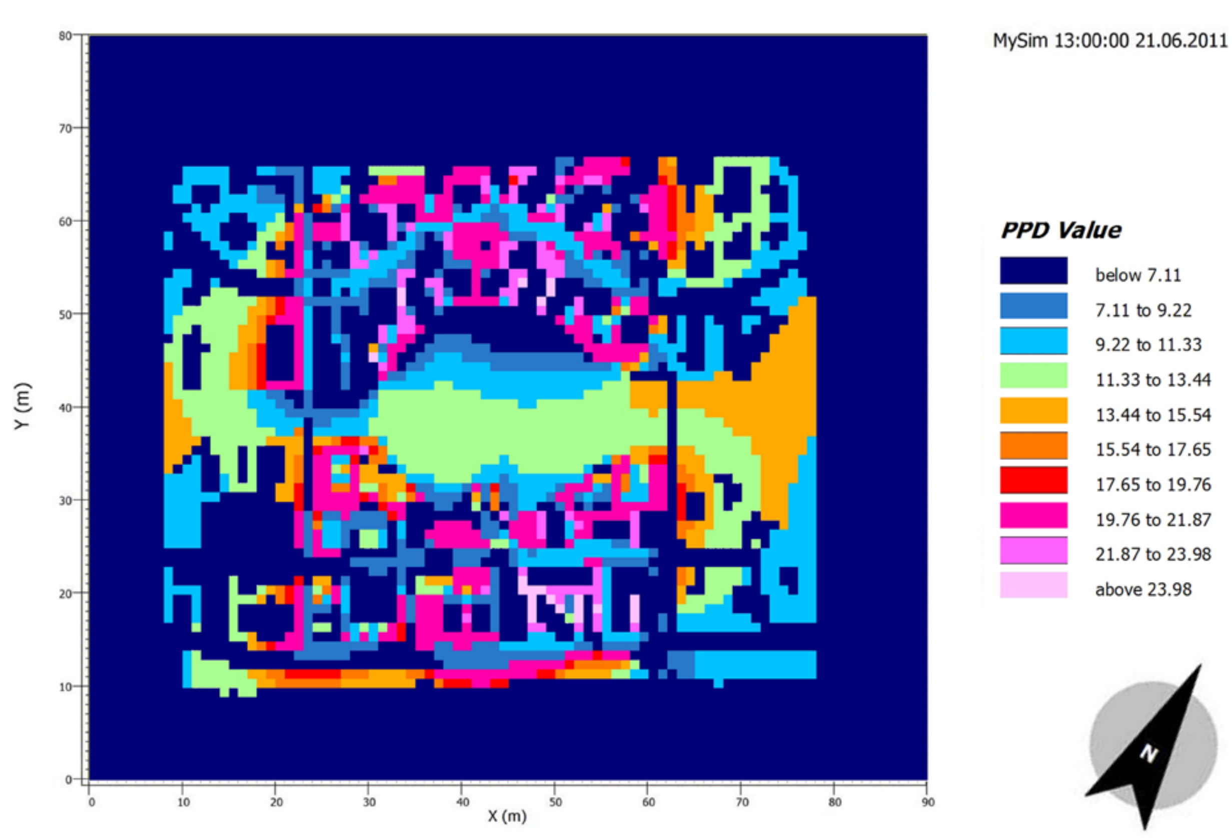


Figure 50: Green Roof PPD June 21st 2011 rendered by ENVI-met V3

According to the ENVI-met model study (See figure 50) the Percentage of People Dissatisfied (PPD) ranges from 0% to 11.33% compared to the 7% to 23% value specified in the base case scenario. The satisfaction range therefore has slightly increased compared to the base roof scenario and is now at 89%-100%. The slight increase in the satisfaction range is considered acceptable for human thermal comfort.

Parameter 7: Wind Speed

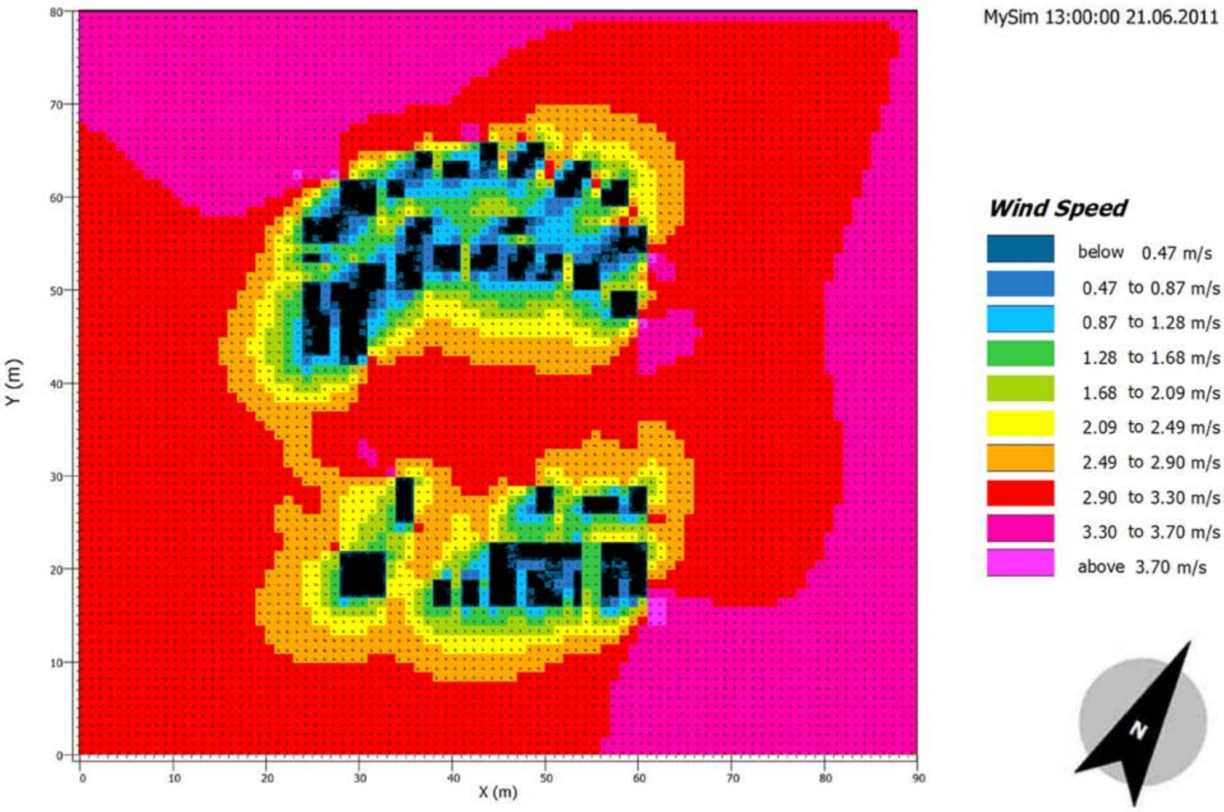


Figure 51: Green Roof Wind Speed June 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 51) confirmed that no changes in the wind speed value is represented with the installation of green roofs and therefore still remains at 0.47 m/s to 1.68 m/s. Again as mentioned in the base case scenario a low wind speed of 0.5% to 2% is considered acceptable.

However, ENVI-met software limitations does not allow for a detailed assessment of plant and substrate details to determine whether changes in wind speed can be measured. Therefore the potential benefits of green roofs cannot be determined on the ENVI-met Dubai Marina conceptual model and a more detailed study is recommended.

5.5 The Green Roof Scenario @ 13:00 hrs December 21st, 2011

The green roof scenario evaluates thermal comfort at 13:00 December 2011 (See Appendix G). The ENVI-met model measures the following parameters:

- Parameter 1: Surface Albedo
- Parameter 2: Exchange Coefficient of Heat
- Parameter 3: Mean Radiant Temperature
- Parameter 4: Relative Humidity
- Parameter 5: Predicted Mean Vote (PMV)
- Parameter 6: Percentage of People Dissatisfied (PPD)
- Parameter 7: Wind Speed

Parameter 1: Surface Albedo

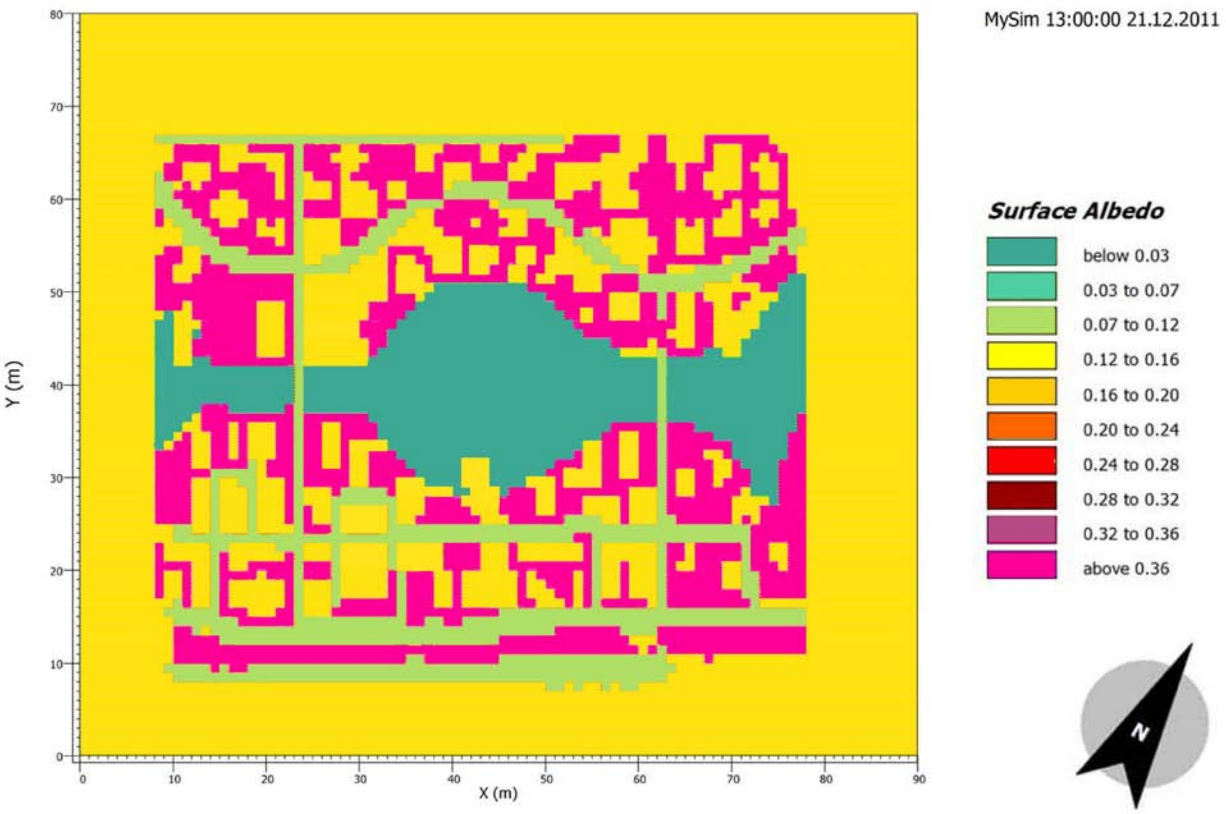


Figure 52: Green Roof Surface Albedo December 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 52) found that with vegetation assigned to the typical roof, the surface albedo has increased from the range of 0.12 to 0.16 in the base case scenario to 0.16 to 0.20. However, as discussed before surface albedo will depend on the type of plant and materials used.

As in the previous green roof study there is no change of the results during the summer and winter months. Again as mentioned before, the ability to further reduce surface albedo depends on the type of plants and materials used.

Parameter 2: Exchange-Coefficient

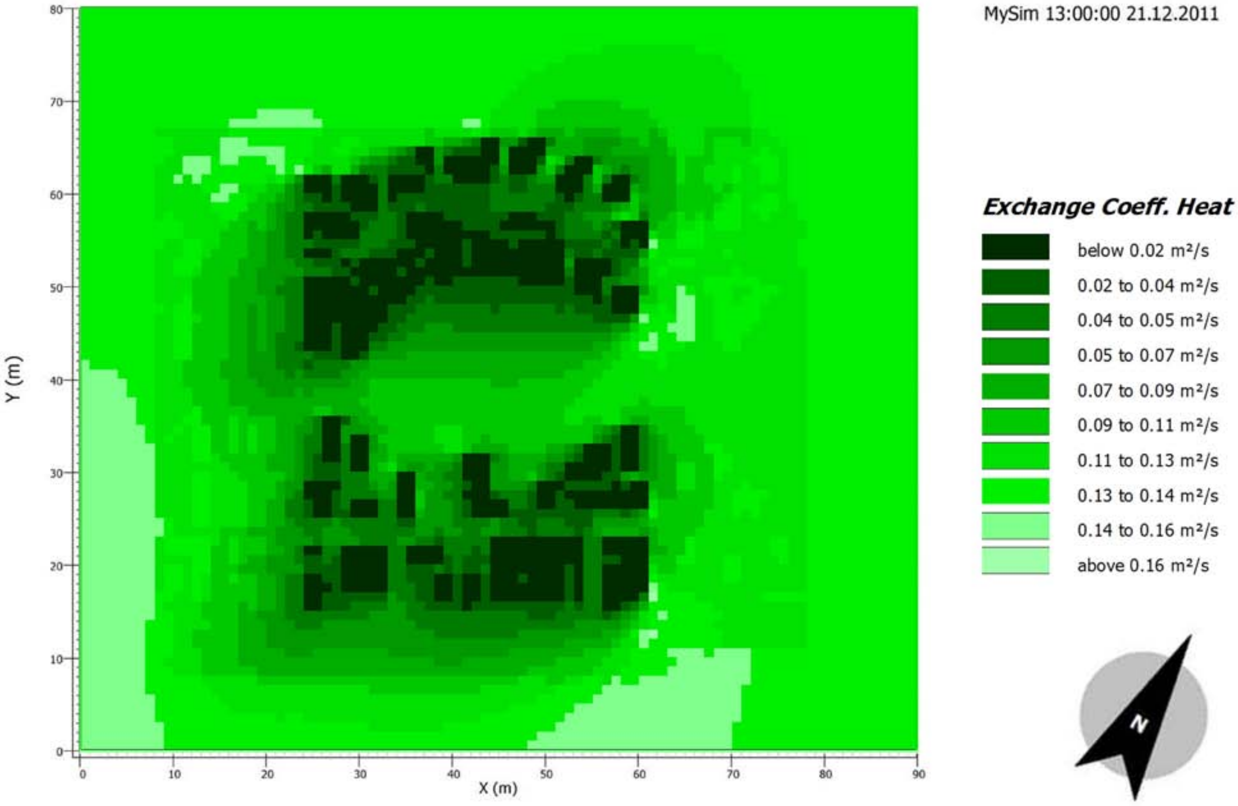


Figure 53: Green Roof Exchange Coefficient of Heat December 21st 2011 rendered by ENVI-met V3

The exchange coefficient of heat measured using ENVI-Met simulation of the green roof scenario (See figure 53) found that there is no major difference in the surface and air interaction from green roofs as compared to the base case roof scenario. The exchange coefficient of heat value still remains in the range of 0.01 m^2/s to 0.05 m^2/s.

The exchange coefficient of heat measured using ENVI-Met found that the heat interaction between surface and air is found below 0.02 m^2/s and can range from 0.02 m^2/s to 0.07 m^2/s.

Parameter 3: Mean Radiant Temperature

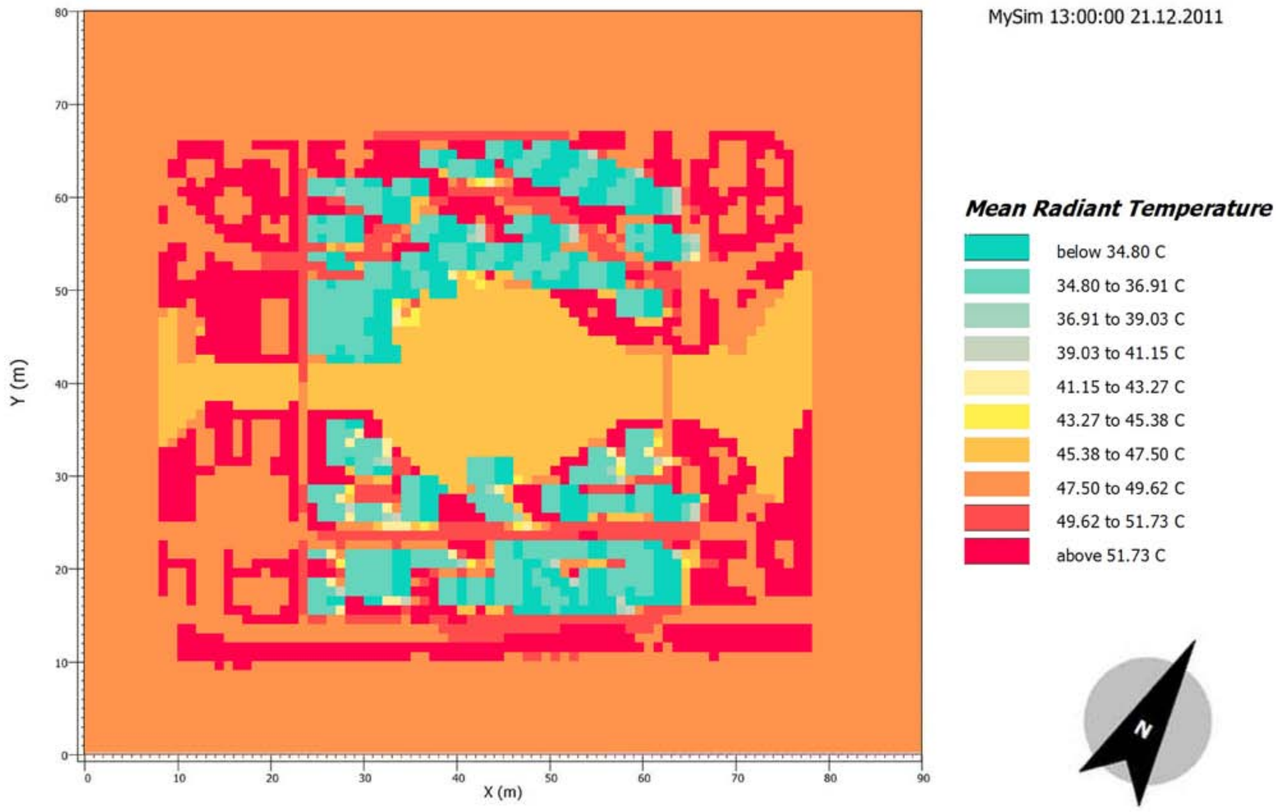


Figure 54: Green Roof MRT December 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 54) confirmed that the Mean Radiant Temperature around the surrounding roof surfaces of the winter time green roof is measured at 36.91˚C – 39.03˚C when compared to the summer time MRT of 49.62˚C –

51.73˚C. There is not much change in temperature when compared to the base case winter time roof scenario.

However as discussed before, ENVI-met software limitations does not allow for a detailed assessment of plant and substrate details to determine whether a reduction in MRT temperature can be measured. Therefore the potential benefits of green roofs cannot be determined on the ENVI-met Dubai Marina conceptual model and a more detailed study is recommended.

Parameter 4: Relative Humidity

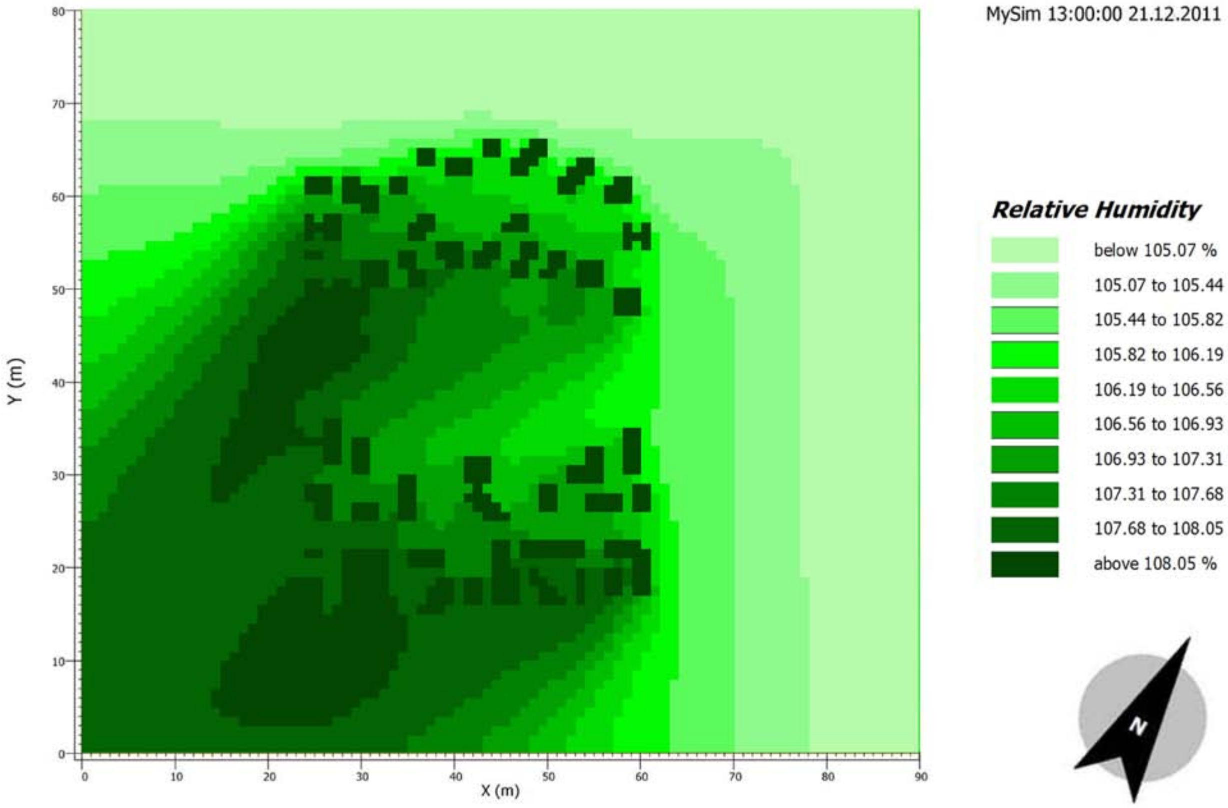


Figure 55: Green Roof RH December 21st 2011 rendered by ENVI-met V3

Relative humidity (RH) model (See figure 55) is above 108.05%, slightly higher when compared to the base case conventional roof scenario. The average RH is measured at 85% in the dense urban context at 13:00 hours during the summer.

As factors such as wind speed and airflow effect RH levels the installation of green roofs may have little or no impact on RH levels. The type of green roof in depth may have little or no impact dependant on scale and typology of green roof.

Parameter 5: Predicted Mean Vote (PMV)

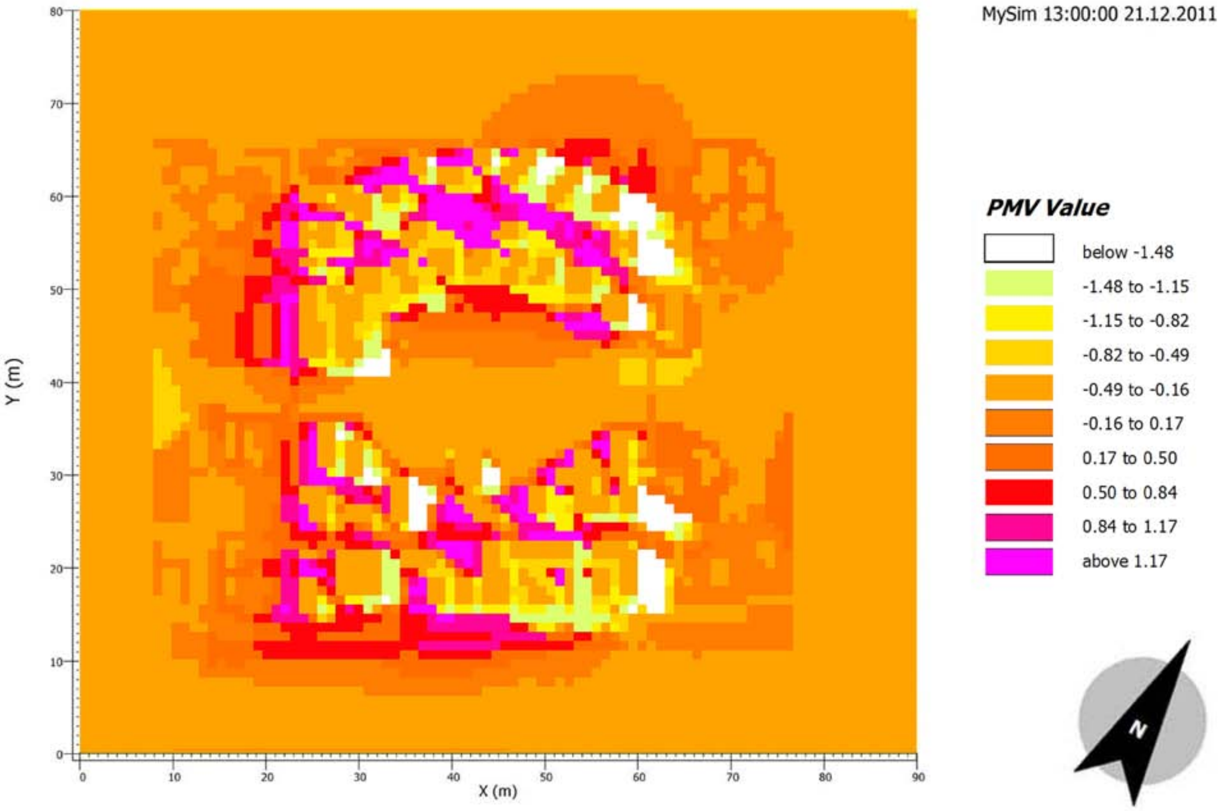


Figure 56: Green Roof PMV December 21st 2011 rendered by ENVI-met V3

The Predicted Mean Vote (PMV) simulated by ENVI-met green roof model in December 21st 2011 above (See figure 56) measured at -1.15 to -0.16 which resulted in a slight change in PMV numbers from the base case winter time roof scenario measured at -1.48 to -0.82.

Compared to the summer time green roof number which is measured at -0.01 to 0.33, the winter time PMV range is cooler. According to ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) of human thermal comfort range - 0.5 to +0.5 (neutral) and anything below -0.5 is considered cool. Above +0.5 is considered warm.

Parameter 6: Percentage of People Dissatisfied (PPD)

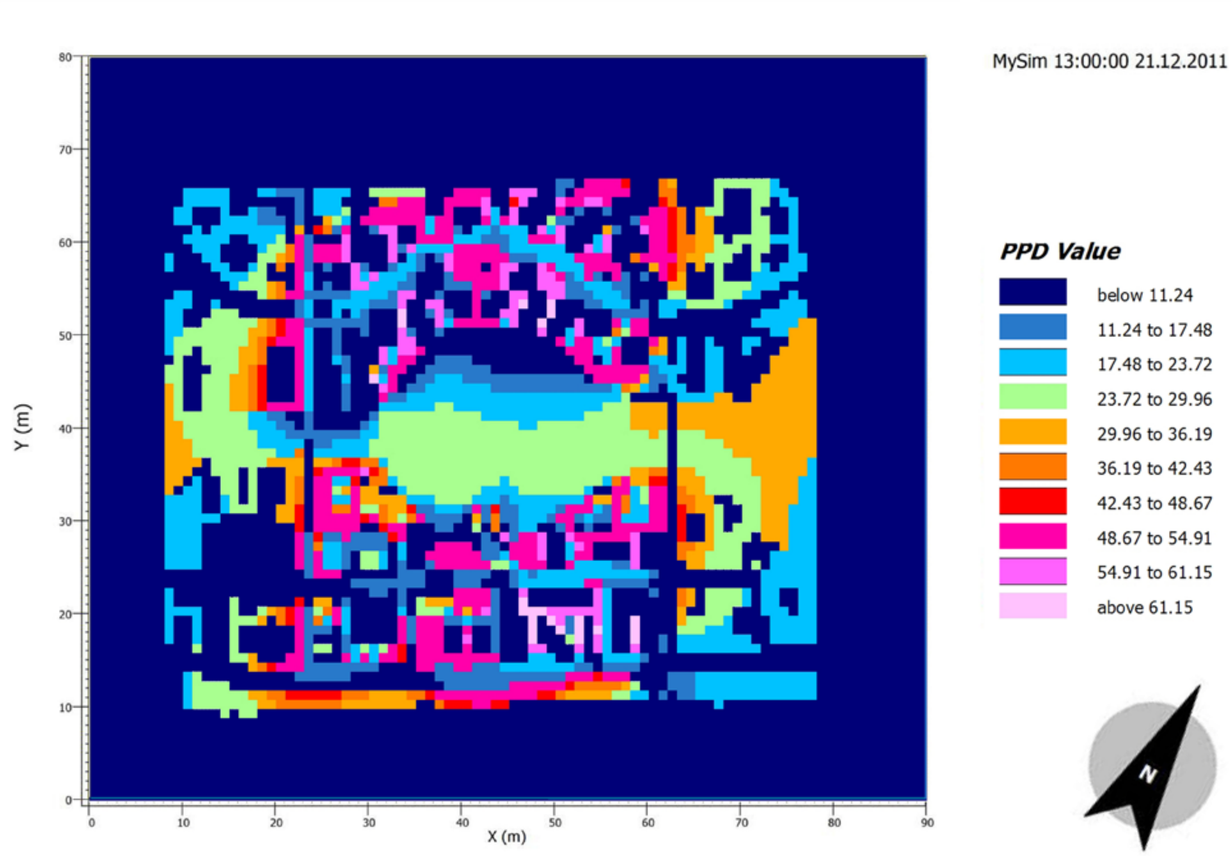


Figure 57: Green Roof PPD December 21st 2011 rendered by ENVI-met V3

According to the ENVI-met model study (See figure 57) the Percentage of People Dissatisfied (PPD) ranges from 0% to 11.24% compared to the 7% to 23% value specified in the base case winter time scenario. The satisfaction range therefore has slightly increased compared to the base roof scenario and is now at 89%. A slight increase in the satisfaction range is considered acceptable for human thermal comfort.

Parameter 7: Wind Speed

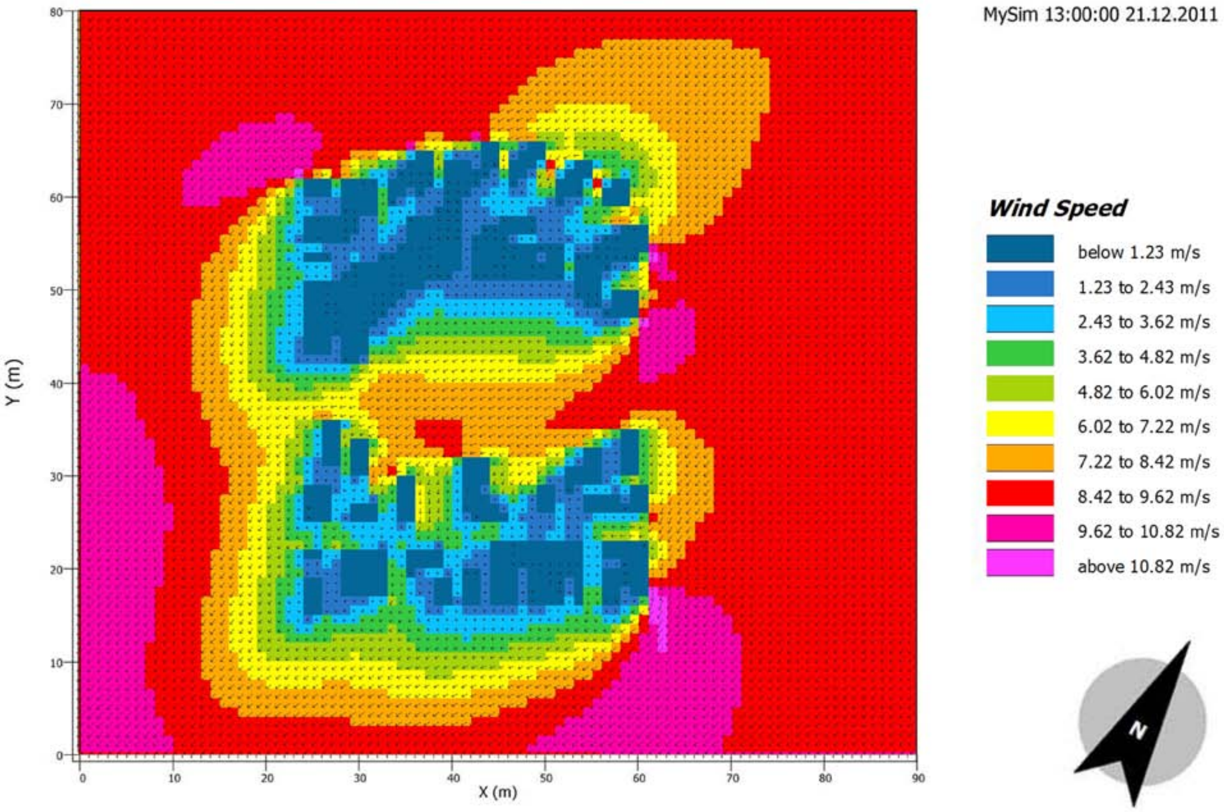


Figure 58: Green Roof Wind Speed December 21st 2011 rendered by ENVI-met V3

The ENVI-met simulation above (See figure 58) confirmed that no changes in the wind speed value is represented with the installation of green roofs and therefore still remains below 1.23 m/s. Again as mentioned in the base case winter and summer time scenario, a low wind speed of 0.5% to 2% is considered acceptable.

As mentioned before, ENVI-met software limitations does not allow for a detailed assessment of plant and substrate details to determine changes in wind speed. Therefore the potential benefits of green roofs cannot be determined on the ENVI-met Dubai Marina conceptual model and a more detailed study is recommended.

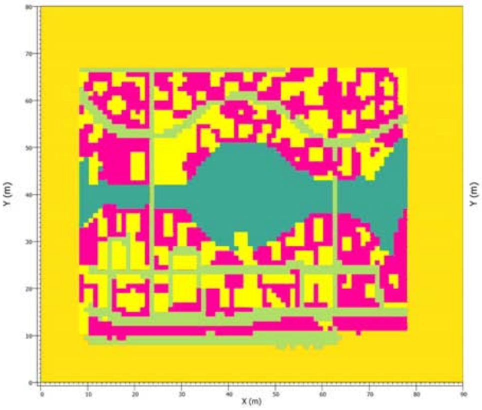
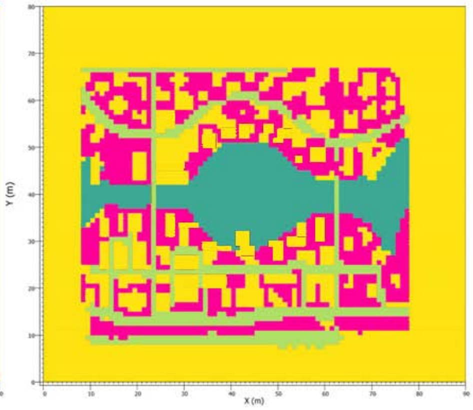
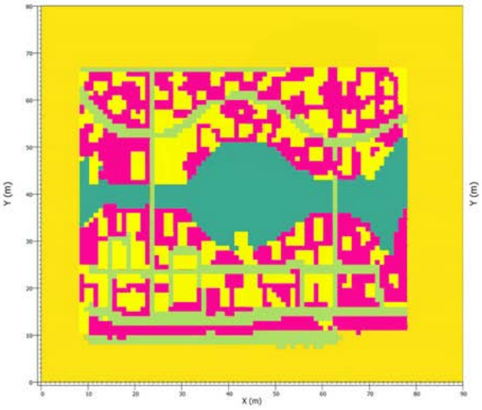
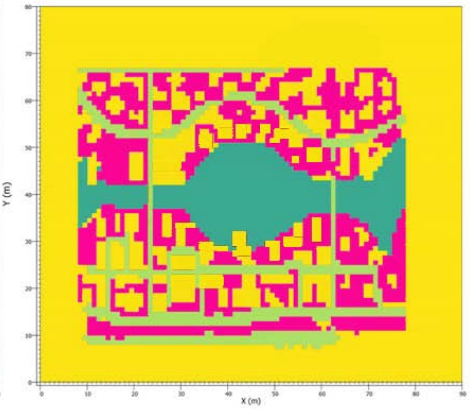
5.6 Analyzing the Conventional and Green Roof Results

ENVI-met results in the previous section 5.2 and 5.3 documented results of the numeric simulation test done to measure thermal performance levels of a conventional roof and a green roof. This was done by programming the inputs in Chapter 4 into the base roof and green roof model of a built up section of the Dubai Marina (See chapter 4, figure 30). The major difference between the two models include different inputs in the base model and green roof model, please refer to chapter 4 and Appendix E-G for an in depth detail on the two scenarios in summer and winter conditions. These different climatic inputs were then programmed into the base model along with location and building details. In the green roof scenario, additional inputs such as plant and soil inputs were programmed based on the ENVI-met database selection available. A comparison of the changes is documented in the tables below. A conventional roof when compared to the green roof has reported considerable changes in the following parameters Surface Albedo, Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD). Parameters that were not affected by the installation of green roofs in the ENVI-met simulation were Exchange Coefficient of Heat, Mean Radiant Temperature (MRT), Relative Humidity (RH) and Wind Speed. All seven parameters are discussed in detail below.

A surface albedo assessment was conducted using ENVI-met to measure the difference in albedo levels during the summer period for the base and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived; it was taken to the Leonardo program to define the results. The legend in table 4 depicts the findings of the ENVI-met model. By including green roofs in the Dubai Marina ENVI-met sectional model, the surface albedo (parameter 1) increased from a low of 0.12-0.16 in the summer and winter conventional roof model to 0.16-0.20 in the summer and winter green roof model (See table 4). There is no major difference in the surface albedo increase as the test inputs did not yield significant changes. This could be due to several factors which influence the surface albedo of green roofs, such as the type of plants used for the roof and the materials used in installation.

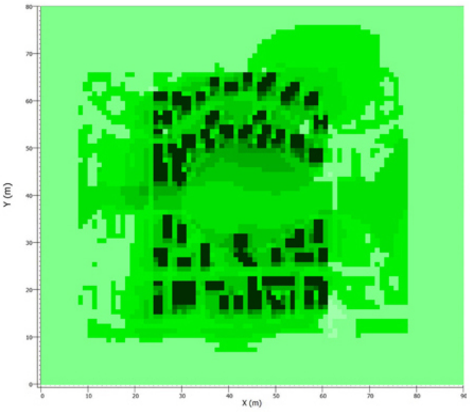
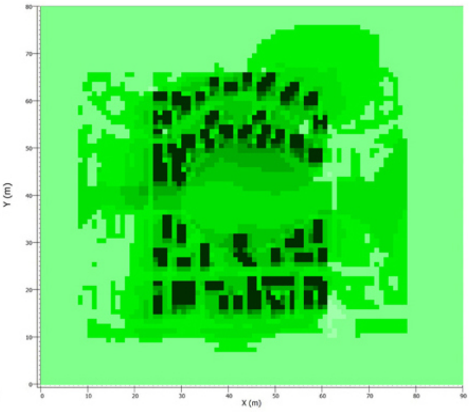
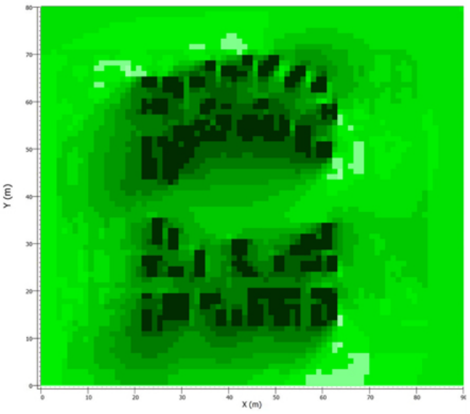
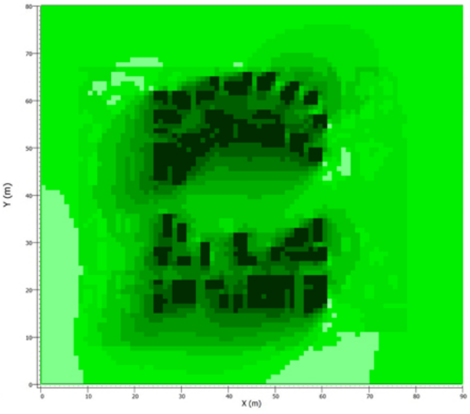
In the study represented on table 4, a rise in surface albedo was indicated in both seasons by inclusion of green foliage. This rise represents the potential for green roofs to reduce surface temperature and long wave radiation emitted from the roof surface. Also this rise is only represented on a section (See chapter 4, figure 30) of the Dubai Marina, However a reduction in surface albedo over a large scale city wide area can have positive effects in mitigating urban heat islands by surface temperature reduction. Taha (1997) studied a mesoscale model of Los Angeles and found that alebdo from vegetation reduced surface temperature by 2°C- 4°C and Sailor (2008) noted a similar study in Florida which concluded that vegetation increase surface albedo and thereby reduce surface temperature by 2°C. Taha (1997) noted that most cities albedo range from 0.10-0.20. By using green roofs the albedo levels have increased. As mentioned before further increase is dependant on the type of materials and plants used. An in-depth study is recommended on materials and plants for further assessment.

Table 4: Surface Albedo results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
		MySim 13:00:00 21.06.2011 Surface Albedo 🟩 below 0.03 🟩 0.03 to 0.07 🟩 0.07 to 0.12 🟨 0.12 to 0.16 🟨 0.16 to 0.20 🟧 0.20 to 0.24 🟥 0.24 to 0.28 🟥 0.28 to 0.32 🟪 0.32 to 0.36 🟪 above 0.36	21-06-2012
		MySim 13:00:00 21.12.2011 Surface Albedo 🟩 below 0.03 🟩 0.03 to 0.07 🟩 0.07 to 0.12 🟨 0.12 to 0.16 🟨 0.16 to 0.20 🟧 0.20 to 0.24 🟥 0.24 to 0.28 🟥 0.28 to 0.32 🟪 0.32 to 0.36 🟪 above 0.36	21-12-2012

An exchange coefficient of heat analysis was conducted using ENVI-met to measure the difference in levels during the summer period for the base and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived; it was taken to the Leonardo program to define the results. The legend in table 5 represents the findings of the ENVI-met model. The exchange coefficient of heat (parameter 2) is measured using the ENVI-Met simulation (See table 5) for the summer green roof scenario and no major difference in the air/surface interaction was found between the base roof and green roof scenario. In both senarios, the summer time exchange coefficient of heat value remained between 0.01m^2/s - 0.05m^2/s, where as the winter time surface and air interaction was found to be below 0.02 m^2/s in some cases and in others it was found between the 0.02 m^2/s to 0.07 m^2/s.

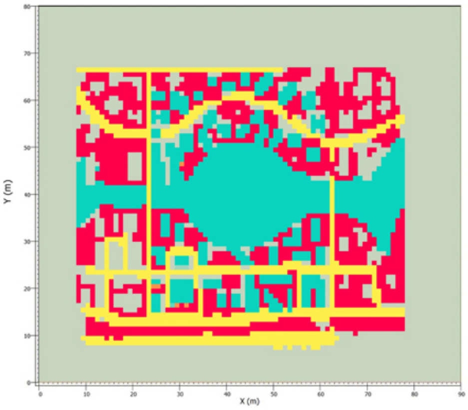
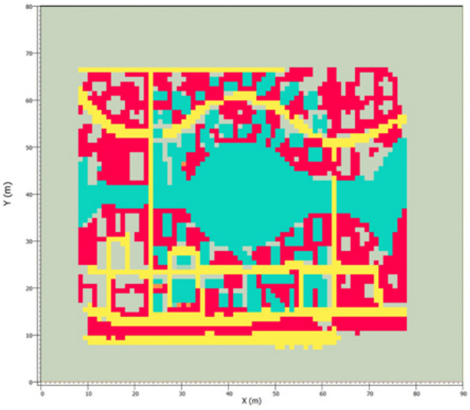
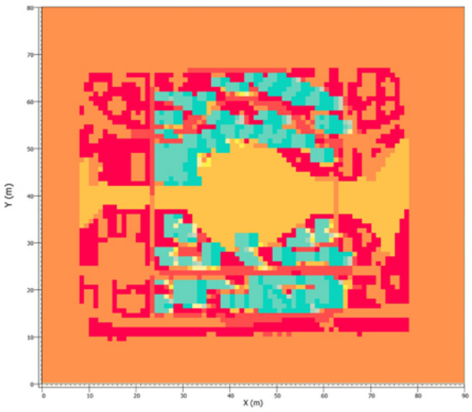
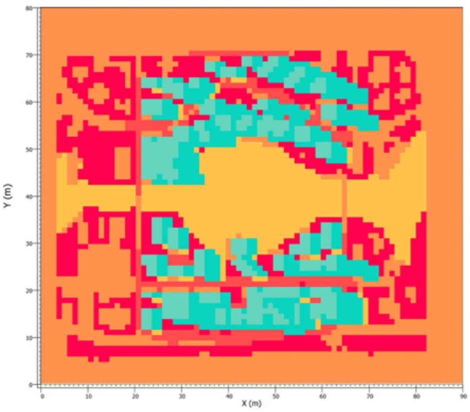
Table 5: Exchange Coefficient of Heat results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
		MySim 13:00:00 21.12.2011 *Exchange Coeff. Heat* below 0.01 m²/s 0.01 to 0.01 m²/s 0.01 to 0.02 m²/s 0.02 to 0.03 m²/s 0.03 to 0.03 m²/s 0.03 to 0.04 m²/s 0.04 to 0.05 m²/s 0.05 to 0.06 m²/s 0.06 to 0.06 m²/s above 0.06 m²/s	21-06-2012
		MySim 13:00:00 21.12.2011 *Exchange Coeff. Heat* below 0.02 m²/s 0.02 to 0.04 m²/s 0.04 to 0.05 m²/s 0.05 to 0.07 m²/s 0.07 to 0.09 m²/s 0.09 to 0.11 m²/s 0.11 to 0.13 m²/s 0.13 to 0.14 m²/s 0.14 to 0.16 m²/s above 0.16 m²/s	21-12-2012

A detailed plant typology, foliage type and Leaf Area Index (LAI) can influence the exchange coefficient of heat in plants. A plant type with highly dense foliage or longer leaves can provide adequate shading to the roof surface thereby delaying and deflecting the solar radiation from reaching the roof surface. In this case the plant type was limited to the selection available in the ENVI-met database and selected plant type is detailed in Appendix E & G. Fahmy et al. (2010) evaluated the thermal performance of trees in the Cairo, Egypt and found that higher temperatures were noted with sparse foliage. Similarly, Sapala et al., (2008) found that LAI reduced energy consumption in building in Athens, Green during summer periods. Stable solar heat flux temperatures were noted with thicker LAI (Kumar and Kaushik, 2005). A high level of detail is not tested in the ENVI-met research study conducted for this parameter and that is why no change was depicted in the results, however further study is recommended to monitor any noticeable changes. Also, this same result was noted by Takebayashi et al., (2007) who tested the role of vegetation on roofs by using field sensors to determine changes in heat flux. It was found that further studies on evaporative efficiency were necessary to determine the results of base and green roof compared.

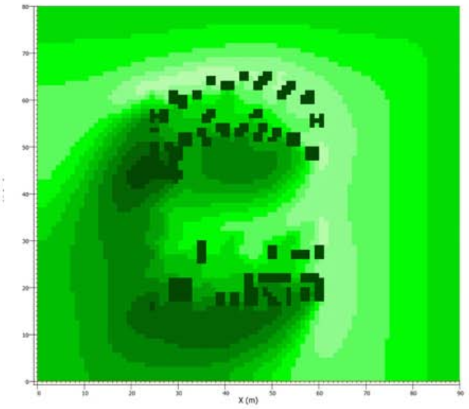
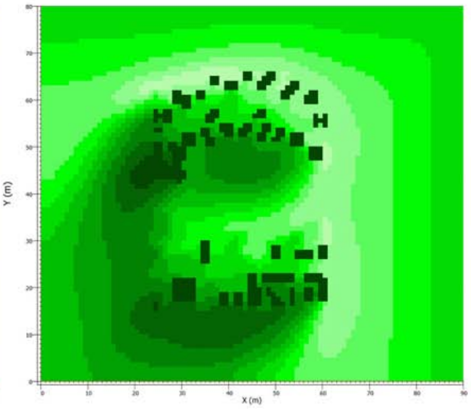
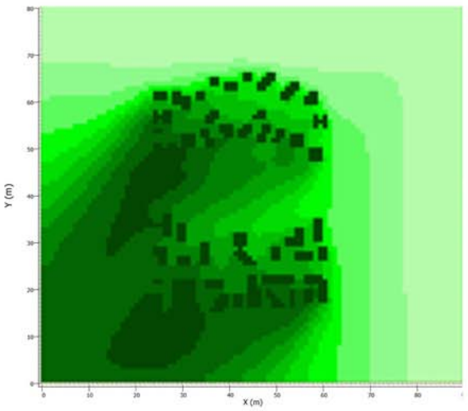
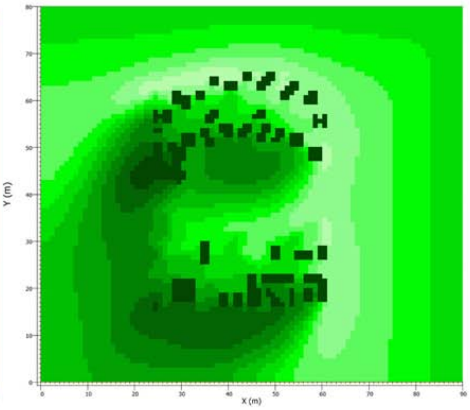
A Mean Radiant Temperature analysis was conducted using ENVI-met to measure the difference in levels during the summer period for the base and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived, it was taken to the Leonardo program to define the results. The legend in table 6 depicts the finding of the ENVI-met model. The Mean Radiant Temperature (MRT) (parameter 3) in the summer time ENVI-met simulation remains between 49.62˚C – 51.73˚C in the base roof and green roof scenario. The winter time base roof and green roof scenario was measured at 36.91˚C – 39.03˚C when compared to the summer time MRT of 49.62˚C – 51.73˚C (See table 6 next page). There is not much change in temperature when compared to the base case winter time roof scenario. Changes in MRT can occur due to green roof installation as green roof soft surface emitted less long wave radiation when compared to hard surfaces such as in the base roof. In literature review, chapter 2 it was found that MRT was reduced on vegetated roofs when compare the based roof because heat transfer took place faster on ground than a vegetated surface as depicted in research by Wong et al. (2003 a & b) of Singapore and Kakon and Nobou, (2009) in Bangladesh. Sailor’s study of a green roof in Florida using Energyplus found that thicker soil substrate increase roof insulation level, reducing the impact of radiation on roof. According to Dubai Green Building Regulations (2010) green roofs or roofs with a Solar Reflective Index (SRI) of greater or equal to 29 can mitigate heat islands. However a detailed account assessing the SRI value of roof materials, foliage and soil type is not part of the scope of this study.

Table 6: Mean Radiant Temperature (MRT) results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
		MySim 13:00:00 21.06.2011 ***Mean Radiant Temperature*** 🟩 below 34.80 C 🟩 34.80 to 36.91 C 🟩 36.91 to 39.03 C ⬜ 39.03 to 41.15 C 🟨 41.15 to 43.27 C 🟨 43.27 to 45.38 C 🟧 45.38 to 47.50 C 🟧 47.50 to 49.62 C 🟥 49.62 to 51.73 C 🟥 above 51.73 C	21-06-2012
		MySim 13:00:00 21.12.2011 ***Mean Radiant Temperature*** 🟩 below 34.80 C 🟩 34.80 to 36.91 C 🟩 36.91 to 39.03 C ⬜ 39.03 to 41.15 C 🟨 41.15 to 43.27 C 🟨 43.27 to 45.38 C 🟧 45.38 to 47.50 C 🟧 47.50 to 49.62 C 🟥 49.62 to 51.73 C 🟥 above 51.73 C	21-12-2012

A Relative Humidity (RH) study was conducted using ENVI-met to measure the difference in levels during the summer period for the base and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived; it was taken to the Leonardo program to define the results. The legend in table 7 depicts the findings of the ENVI-met model. Relative humidity (RH) model (parameter 4) (See table 7) is recorded in the range of 83.44% to 86.87% as measured in the summer time base case and green roof scenario. Relative humidity is above 108.05% during the winter time, slightly higher when compared to the winter base case conventional roof scenario. The average RH is recorded at 85% in the dense urban context at 13:00 hours.

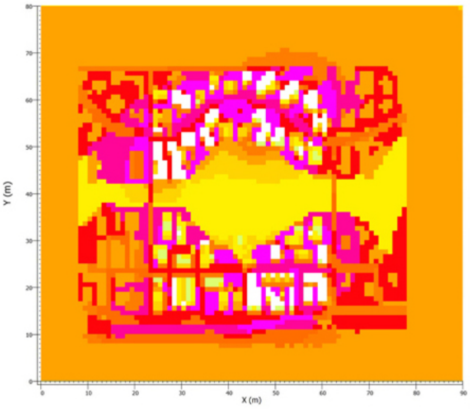
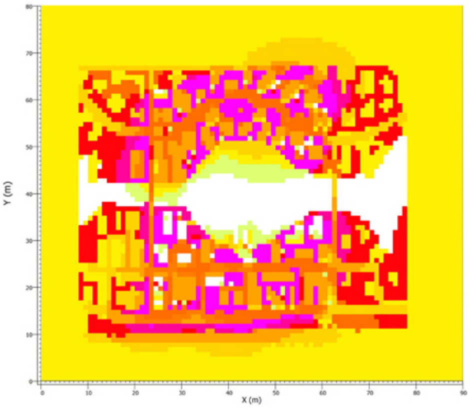
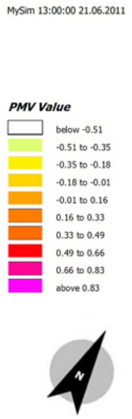
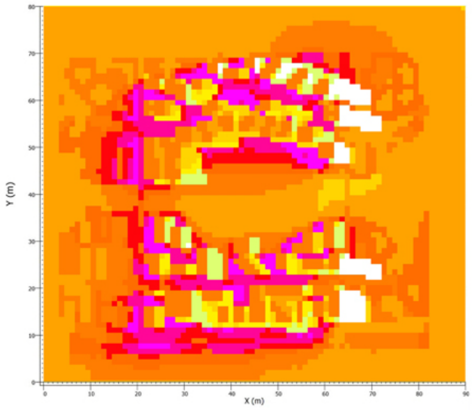
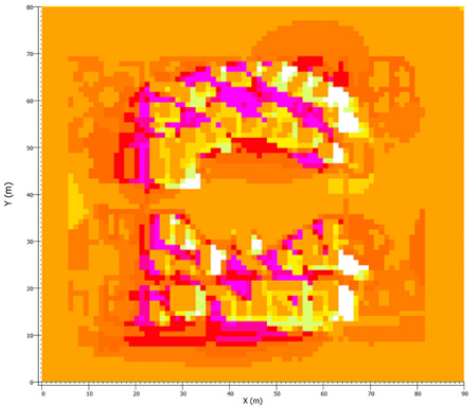
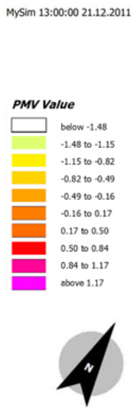
Table 7: Relative Humidity (RH) results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
			21-06-2012
			21-12-2012

From evidence of RH studied through literature review in chapter 2, very little change in RH occurs with green roof installation. Relative Humidity (RH) levels studied by Wong et al. (2003) in Singapore and Kakon and Nobou, (2009) in Bangladesh, showed that wind and building heights largely influenced RH where as vegetated canopies can decrease RH levels. However the research concluded that RH on hard surfaces and vegetated surface did not change. Since there is no change yielded in RH over between base roof and green roof in both seasons during the ENVI-met experiment and it is recommended that further research be conducted on soil and substrate depth and its influence on RH as studied by Williams et al. (2010) on Australian cities and Theodosiou (2003) on Mediterranean climates. Theodosiou (2003) found that plant density can influence RH.

Possible implications of using plant and soil typology have not been studied in depth; however a detailed discussion in chapter 2 with precedence and recommendations as above is noted.

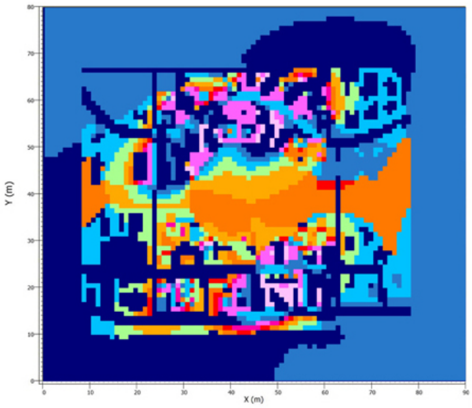
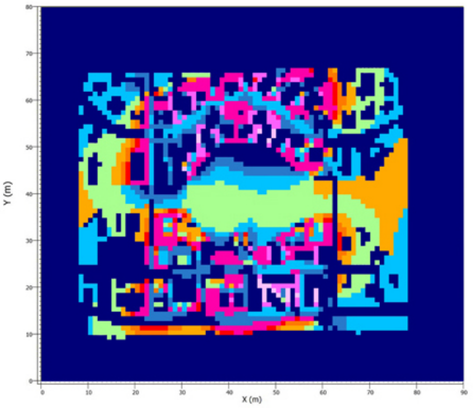
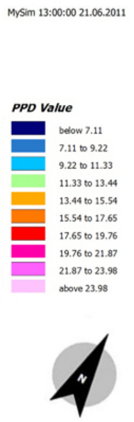
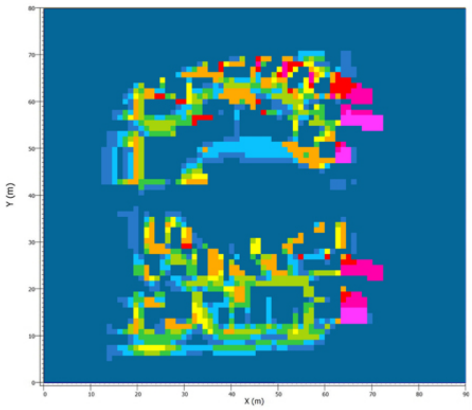
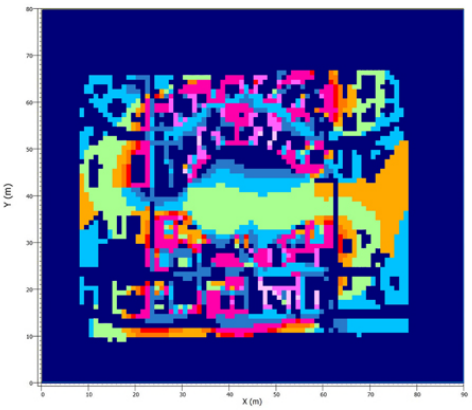
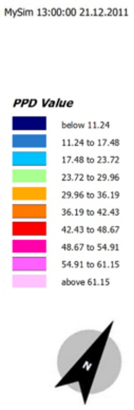
Table 8: Predicted Mean Vote (PMV) results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
			21-06-2012
			21-12-2012

A Predicted Mean Vote (PMV) study was conducted using ENVI-met to measure the difference in levels during the summer period for the base roof and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived, it was taken to the Leonardo program to define the results. The legend in table 8 depicts the findings of the ENVI-met model. The Predicted Mean Vote (PMV) (parameter 5) simulated by ENVI-met depicts a slight change in PMV numbers from the summer time base case and green roof scenario (See table 8). This slight change is represented from -0.51 to -0.35 in the base case scenario to -0.01 to 0.33 in the green roof scenario. As this satisfies the ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) of human thermal comfort range - 0.5 to +0.5 (neutral) the level of thermal sensations experienced by an individual is minor when measured on a small section of the Dubai Marina (Refer to Chapter 4, Figure 30) but the nature of plants and large scale application when tested may suggest different results. Consequently, the ENVI-met green roof model December 21st 2011 measured PMV at -1.15 to -0.16 which resulted in a slight change in PMV numbers from the base case winter time roof scenario measured at -1.48 to -0.82. Compared to the summer time green roof number which is measured at -0.01 to 0.33, the winter time PMV range is cooler. PMV is found cooler in winter due to the UAE warm/cool winter months and north-westerly shamal winds. When testing these results the thermal comfort level was not expected to increase significantly in a small section of the Dubai Marina. The surrounding vegetated environment will provide adequate cooling for the development. Further study is recommended on cooling based on factors such as, plant height, shading, building height, sky view factor and any other possible means of deflection of solar radiation which was not tested by the ENVI-met program.

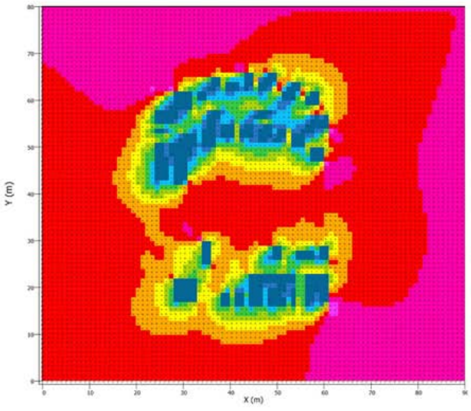
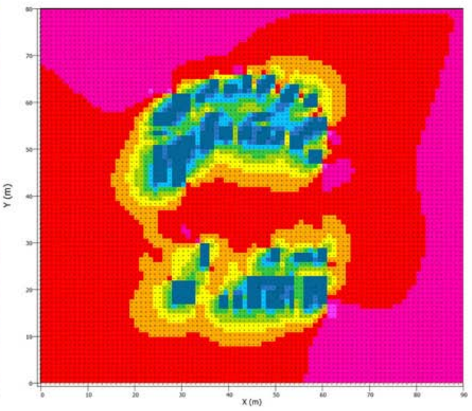
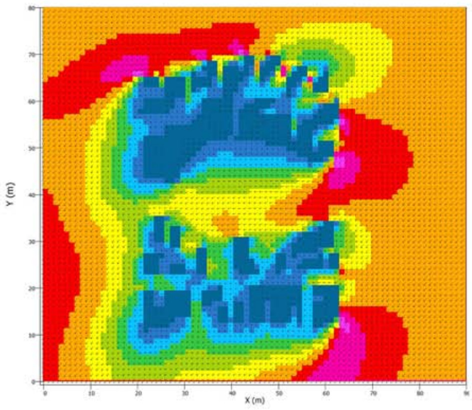
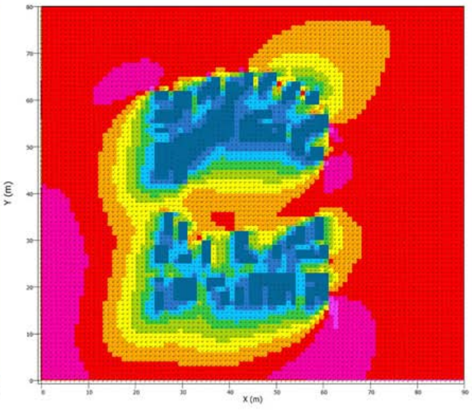
A Percentage of People Dissatisfied (PPD) study was conducted using ENVI-met to measure the difference in levels during the summer period for the base and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived; it was taken to the Leonardo program to define the results. The legend in table 9 represents the findings of the ENVI-met model. The Percentage of People Dissatisfied (PPD) (parameter 6) simulated by ENVI-met represents a temperature range variation (See table 9 on previous page). In summer the base roof PPD was documented at 7% to 23% where as by using green roofs the PPD value decreased ranging from 0% to 11.33%. Not much change was represented in winter between the base roof and green roof scenario, also measured from 0% to 11.24%. In all scenarios an increase in satisfaction of human thermal sensations was found in using green roof when compared to those found in base roof. All summer and winter scenarios showed that green roofs represented a increase in satisfaction of human thermal sensations in compliance with ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) of human thermal comfort. Additional recommendations for further research included finding out how elements such as plant shading or building canopy shading which is not currently studied in the ENVI-met model can positively contribute to the overall human thermal comfort level.

Table 9: Percentage of People Dissatisfied (PPD) results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
			21-06-2012
			21-12-2012

A Wind Speed study was conducted using ENVI-met to measure the difference in levels during the summer period for the base and green roof scenario. In doing so the ENVI-met simulation was run for all four models and once the edi. file was derived; it was taken to the Leonardo program to define the results. The legend in table 10 depicts the findings of the ENVI-met model. Wind speed (parameter 7) (See table 10) does not change with summer and winter time green roofs inputted in the ENVI-met model and therefore still remains at a range of 0.47 m/s to 1.68 m/s. A low wind speed of 0.5% to 2% is considered acceptable, open space and plants (trees) can influence wind speed in the Dubai Marina development. Variation in building height is also indicative of possible regulation of wind sped patterns. In chapter 2, literature review, findings suggest that building height, building width and vegetated canopies greatly influence wind as documented by Air-Toudert and Mayer (2006). They suggested further study on understanding airflow patterns were an important factor in understanding thermal comfort.

Table 10: Wind Speed results of base and green roof compared.

Base Case Scenario	Green Roof Scenario	Legend	
		MySim 13:00:00 21.06.2011 **Wind Speed** 🟦 below 0.47 m/s 🟦 0.47 to 0.87 m/s 🟦 0.87 to 1.28 m/s 🟩 1.28 to 1.68 m/s 🟩 1.68 to 2.09 m/s 🟨 2.09 to 2.49 m/s 🟧 2.49 to 2.90 m/s 🟥 2.90 to 3.30 m/s 🟪 3.30 to 3.70 m/s 🟪 above 3.70 m/s	21-06-2012
		MySim 13:00:00 21.12.2011 **Wind Speed** 🟦 below 1.23 m/s 🟦 1.23 to 2.43 m/s 🟦 2.43 to 3.62 m/s 🟩 3.62 to 4.82 m/s 🟩 4.82 to 6.02 m/s 🟨 6.02 to 7.22 m/s 🟧 7.22 to 8.42 m/s 🟥 8.42 to 9.62 m/s 🟪 9.62 to 10.82 m/s 🟪 above 10.82 m/s	21-12-2012

In conclusion, ENVI-met software limitations does not allow for a detailed assessment of plant and substrate details to influence all parameters discussed above. However ENVI-met does provide a general analysis through conceptual model the potential impacts of using green roofs and potential of benefits of that application. The outcome of the results provided through the numeric ENVI-met model showed that there is evidence to suggest that green roof applications can effectively increase surface albedo and improve outdoor thermal comfort as studied through PMV and PPD. Climatic conditions and urban planning practices studied in ENVI-met support the development of green roof in the hot humid micro-climate however possible monitoring of large scale sites, developments with different densities and available technical solutions for green roof systems such and layers, materials, plants, and soil thickness can be observed. In order to deduce quantitative results the parameters will have be standardized to suit previous research findings and can be recommended for further research to determine the similarities and differences of possible outcomes. Furthermore, a more specific technical objective can then be suggested based on the quality of green roof performance and the involved components of the system. This can then be developed as a successful dialogue to address design and planning of green roofs for sustainable development and construction. In the next section a dialogue on the potential impacts of vegetation on green roof thermal performance.

5.7 Urban Thermal Considerations and Simulations

Site orientation and urban environment conditions play an important role in green roof thermal performance and therefore factors that can possibly affect the parameters measured through ENVI-met are building heights, sky view factor and shading. The main highway Sheikh Zayed road is oriented in the North-South with parallel internal streets and perpendicular East-West streets running through the Dubai Marina. The direction encourages unobstructed air flow passage in key areas, thereby increasing thermal comfort levels while enhancing energy conservation of buildings in the Dubai Marina. A look in urban environmental conditions affecting the thermal performance levels at present.

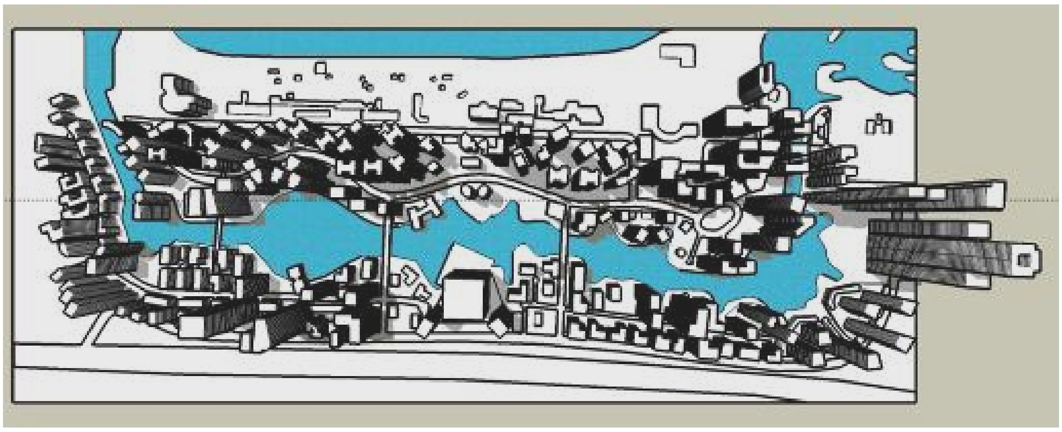


Figure 59: Shading on June 21st 2011 @ 13:00 hrs by Google Sketchup

The variation in building heights encourages easy air flow reducing the level of wind turbulence within the urban block. The height variation is not limited by the sky view factor in the development, but ensures that adequate shading is provided even when measured during the summer period of June 21st, 2011 (See figure 59).

Figure 60: Shading on June 21st 2011 @ 08:00 hrs by Google Sketchup

Figure 61: Shading on June 21st 2011 @ 17:00 hrs by Google Sketchup

At 13:00 hrs the level of outdoor thermal comfort in the Dubai Marina is challenging endeavour however, aided by green roofs the thermal levels have shown marked improvement as discussed in section 5.2- 5.4. The Dubai Marina is adequately shaded during the 08:00 hrs and 17:00 hrs and hence concern of high levels of solar radiation emission is reduced (See figures 60 & 61).

During the winter months the Dubai Marina provides adequate shading at 13:00 hrs as shown in figure 62 below, since the sun is at a lower angle. This can further improve thermal comfort levels on the test green roof scenario when compare to those readings during the summer months.

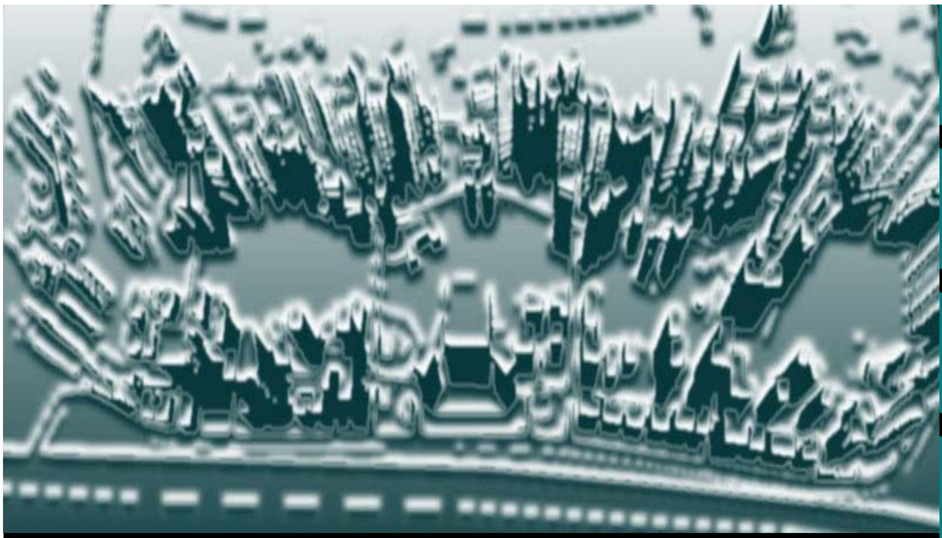
Figure 62: Shading on December 21st 2011 @ 13:00 hrs by Google Sketchup

Figure 63: Shading on December 21st 2011 @ 08:00 hrs by Google Sketchup

Figure 64: Shading on December 21st 2011 @ 17:00 hrs by Google Sketchup

As mentioned before, the Dubai Marina is adequately shaded during the 08:00 hrs and 17:00 hrs (See figure 63 and 64), more so when compared to shading documented during the summer months. Again this is because of the sun's altitude the winter months. Consequently resulting in temperature changes as documented in the ENVI-met simulations.

Results of the green roof experiment in chapter 5 highlight the impact of vegetation in summer and winter. It offers a comparative assessment of using conventional roofs when compared to using green roofs. In chapter 6, a look at the conclusions reached from the investigated results will be discussed a long with recommendations for further research.



Chapter 6

Conclusions and Recommendations

6.1 Introduction

In the study of thermal performance of green roofs, the direct and indirect implications of using green roofs were evaluated. The process of investigating green roof research included an in-depth literature review, an analysis of the research methodology through simulation, a discussion on the simulation set up, results and discussion of the simulated scenario along with possible reasons for the results. As the last chapter 5 closed with the results of a simulation conducted in the Dubai Marina development in the UAE, this chapter focuses on the conclusions draw from the simulated experiment and recommendations for further research.

6.2 Conclusions

Thermal implications of using green roofs in the built environment as the main aim of this study was met through the objectives laid out in chapter 1. The first objective aimed at researching green roofs as a means to mitigate heat islands through literature review and simulation study. The second objective involved testing the introduction of vegetation in the hot humid climate through ENVI-met simulation. The ENVI-met study undertaken observed the impact of green roofs in the hot humid micro-climate of the Dubai Marina development and in doing so, fulfilling the fourth objective of the dissertation study. The third objective of the dissertation documenting the potential environmental savings in the rating will be discussed in section 6.4 of this chapter. The outdoor thermal implications of this study are essential for developers, architects and engineers to progress toward innovative strategies for heat island mitigation. The quantitative data obtained through the numeric simulation investigation of the Dubai Marina development fulfilling the fifth and sixth objective is as follows:

Experimentation by Taha (1997) and Sailor (2008) concluded that vegetation can result in higher albedos. ENVI-met research on the Dubai Marina simulation in chapter 5 showed an increase in surface albedo when compared to that of a conventional roof. In the hot humid Dubai climate adding vegetation to roofs has shown to raise surface albedo. The surface albedo rise is considerable but still not considered a significant increase. The increase in surface albedo means that long wave radiation is reduced in the green roof environment. Further increase in surface albedo can be accomplished depending on the type of vegetation selected. Vegetation that meets the minimal water requirement and is climate specific is ideal for any green roof scenario.

A study on heat flux by Takebayashi et al. (2007) used sensors to determine changes in heat flux and found that further studies on evaporative efficiency were necessary to determine the analysis. The exchange coefficient of heat studied using ENVI-met in chapter 5 depicted heat transfer between plant surface and air when compared to the conventional roof did not change. Although green roofs can induce thermal flux, the plant type or vegetation inputted in this study is purely conceptual and further studies on evaporative efficiency, plant height information and variation can give an accurate assessment of the heat transfer.

Wong et al. (2003) and Katon et al. (2009) found that when measuring mean radiant temperature (MRT) on vegetated roofs resulted in reduced long wave radiation when compared to conventional roofs. The ENVI-met simulation on the Dubai Marina in chapter 5 confirmed changes in MRT in the winter months when compared to summer months consequently due to the lower sun angle in the winter than compared to summer.

Relative Humidity (RH) levels studied by Wong et al. (2003) and Katon et al. (2009) showed that wind and building heights largely influenced RH, however vegetated canopies also decreased RH levels. However the research concluded that RH on hard surfaces and vegetated surface did not change much. RH levels in the ENVI-met simulation study in chapter 5 on the Dubai Marina found decreased RH levels in the summer when compared to that depicted in winter. The change could be the result of higher wind temperature during winter months. However, RH on green roofs changed very little from those levels found on the conventional roof in both winter and summer scenarios similar to the results found in the literature review.

According to ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) of human thermal comfort for Predicted Mean Vote (PMV) ranges between - 0.5 to +0.5 (neutral). Consequently, the ENVI-met green roof model December 21st 2011 measured PMV at -1.15 to -0.16 which resulted in a slight change in PMV numbers from the base case winter time roof scenario measured at -1.48 to -0.82. Compared to the summer time green roof number which is measured at -0.01 to 0.33, the winter time PMV range is cooler.

The Percentage of People Dissatisfied (PPD) simulated by ENVI-met in the Dubai Marina development chapter 5 represents a temperature range variation in the summer when compared to winter. In the summer time PPD value decreased by using vegetated roofs compared to conventional roofs. Not much change was represented in the winter time base roof and green roof scenario. When measured with ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994) of human thermal comfort, all scenarios depicted an increase in satisfaction of human thermal sensations by using green roof compared to using base roof.

Air Toudert and Mayer (2006) concluded that building height, building width and vegetated canopies greatly influenced wind. They suggested further study on understanding airflow patterns were an important factor in understanding thermal comfort. Wind Speed studied in the ENVI-met simulation of the Dubai Marina development in chapter 5 showed no change with inclusion of green roofs during summer and winter.

Climatic factors such as Mean Radiant Temperature (MRT), Relative Humidity (RH) and Wind Speed is found consistent in both simulation scenarios, however this is because the green roof inputs were simply normalized ENVI-met input and variation in plant selection or foliage density could result in a change of either of the above parameters. Green roofs also provide protection to the roof membrane from incoming solar radiation and so although the Mean Radiant Temperature (MRT) value does not change, green roofs can moderate the long wave radiation emitted and heat transfer coefficient. By protecting the roof membrane from long wave radiation, green roofs provide an effective insulation barrier which can reduce indoor cooling loads and regulate energy consumption. The Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PPD) represented an improvement in the thermal comfort level of green roofs compared to that of the base roof, these changes were not significant and were still considered in the neutral range satisfying the ANSI/ASHRAE Standard 55 (2004) and ISO 7730 (1994). However, it gives evidence that planted roofs could effectively mitigate the UHI effect in urban environment.

Developers, architects and engineers can assess the value of green roofs in a development by studying the thermal performance criteria around the buildings. With the help of ENVI-met engineers can calculate the surface albedo, exchange coefficient of heat, mean radiant temperature, relative humidity, predicted mean vote, percentage of people dissatisfied and wind speed. By assessing these parameters, architects and designers can then modify their designs to create suitable level of thermal comfort as requested by the clients. Developers can then use this thermal comfort assessment when applying for prestigious local and international sustainable development ratings.

Although there is great potential for the use of ENVI-met simulation, the software is time consuming and limitations do exist which would otherwise make the green roof experiment highly accurate. These limits include a variety of plants in database, foliage intensity setting and type of vegetated roof intensity (extensive, semi-intensive and intensive). Foliage density can dictate how much soil surface is protected for incoming solar radiation, at present ENVI-met only caters to a normalize foliage density equation. Vegetated roof intensity can dictate the materials for soil substrate, at present ENVI-met has a normalized equation for soil based on root density. Adding this flexibility to the software would result in a more accurate reading for the ENVI-met model. In terms of software use, the software interface is not very user friendly and several time consuming simulation runs had to be conducted in order to achieve accurate and consistent results.

6.3 Summary of Research Contributions

As mentioned in the previous section the implications of using green roofs can reap potential benefits especially when it comes to mitigating heat islands. The major contributions in the assessment of thermal performance in using green roofs in the hot humid micro-climate is essentially studying the Dubai Marina development as case study for future developments considering green roofs as a means to improve outdoor thermal comfort.

Key research contributions of using the dense urban Dubai Marina development context is that in a dense area with a variation in building heights, green roofs have little impact in improved thermal performance as measure by ENVI-met during summer but show better rate of improvement in winter. However, depending on the type of vegetation used green roofs can regulate long wave radiation. Experiments conducted by Wong et al. (2003) and Katon et al. (2009) depicted reduced long wave radiation on vegetated roofs when compared to conventional roofs. Also, studies by Taha (1997) and Sailor (2008) found that vegetation can result in higher albedos, depending on the planting method and materials. Further investigation deduced that surface temperature in green roofs can vary depending on the type of plants used.

6.4 Government Policies and Regulatory Frameworks

Green roofs are not yet common in the UAE. The Dubai Municipality is striving to make this a mandatory requirement; however opposition from developments and architects have been raised due to heavy costs and concerns over water use. The Dubai Green Building Regulations issued by Dubai Municipality includes regulatory policy in place for vegetation roofs, i.e. regulation 304.2 which states that all new buildings can have Part 1 of Regulation 304.1 (Urban Heat Island Effect stating that all roofs to have a minimum Solar Reflective Index value) waived, if the roof of the building is provided with a vegetated roof (green roof) for at least thirty percent (30%) of the total roof area (DM, 2010). No government incentives have been issued for green roofs and the only form of reward for use is through the prestigious rating systems LEED and Estidama. A number of points are awarded for the utilization of green roofs in the urban environment as mitigating heat island and storm water drainage is of concern in planning and building management systems. Only a small section of the Dubai Marina is tested on a micro-scale urban model and the potential reduction in temperature from a city wide application can be recommended for further research.

6.5 Recommendations for Further Research

Understanding the thermal implications of using green roofs and government policies is detrimental to accomplishing city wide energy and carbon savings. Recommendations for further research involve areas not targeted during the ENVI-met analysis and these include:

- Plant variation/ height can influence surface temperature. An example would be through the use of vegetated canopies that can provide shading through foliage thus protecting the roof from solar radiation. This was not conducted during the ENVI-met analysis as it was beyond scope of research. Alternatively besides ENVI-met, other software packages such as, ECOTECT and IES can be used.

- The impact of green roofs on indoor thermal comfort can be conducted to reduce overall cooling loads with in the building in which case some of the parameters studied in this thesis may apply. This was not part of research scope covered in the study of outdoor micro-climate. However the impact of green roofs on indoor micro-climate can be an interesting next step.

- Leaf Area Index (LAI) of plants used on the green roofs to test if foliage density can further reduced surface temperature and MRT. Leaf density is a feature of the ENVI-met simulation software package. However, a detailed analysis is not part of the scope. Also, at the scale the model tested, a detailed LAI analysis will need to be conducted to produce a more accurate assessment. This can be done using software packages such as ENVI-met, IES and ECOTECT.

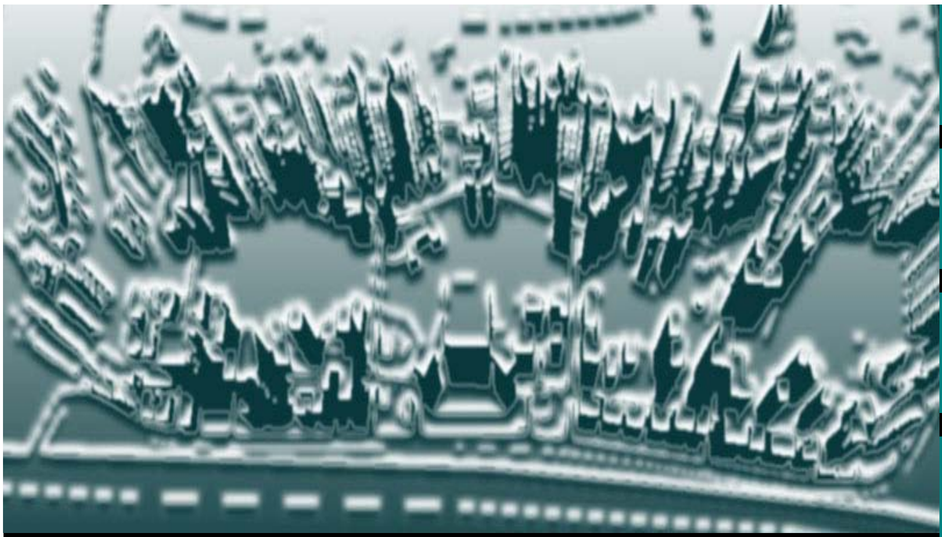
- The thermal performance of green roofs materials in the Dubai Marina compared to other cool roof materials, such as the white roof. The scope of research only covered green roofs and the conventional roof. A study on using various roofing materials or the white roof can produced interesting results and can be evaluated using ENVI-met.

- A comparative analysis of other case studies such as other areas in Dubai when compared to the Dubai Marina. Perhaps an alternative would be another urban district in Dubai city not surrounded by water or a low density development compared to the high density development of the Dubai Marina. At time, this research is not part of the scope of works and can be studied further using the same ENVI-met software package.

- A comparative analysis of another region in the middle when compared to Dubai, such as Oman or Saudi Arabia. Other cities with similar climate conditions can proof to be a valuable resource to support the current research findings. This research was not conducted at this time as it is not part of the scope of works. ENVI-met can be used to validate similar findings.

- Water management systems for green roofs. A detailed analysis of how green roof systems manage water consumption, grey water and storm water. At present this is not part of the scope of work, however in this region with the limited water resources and pressure induced to consume water, this could be a very effective and much needed research for further development. A software package called TerMus-GR is recommended.

In conclusion, green roofs have numerous benefits in the hot humid climate. The thermal performance of green roof studied proved that urban heat islands can be mitigated but on a smaller scale. Not all parameters tested suggested that the theory measured is a recommended option. However for various development considerations green roofs can be an approved means chosen for various design reasons discussed in the literature review and ENVI-met results. The recommended research for further development of the premise may have different repercussions for this climate but as many cities are looking to green roofs for heat island mitigation, energy reduction, aesthetics, food security and green urban humanization, the UAE in 20 years will not be far behind.



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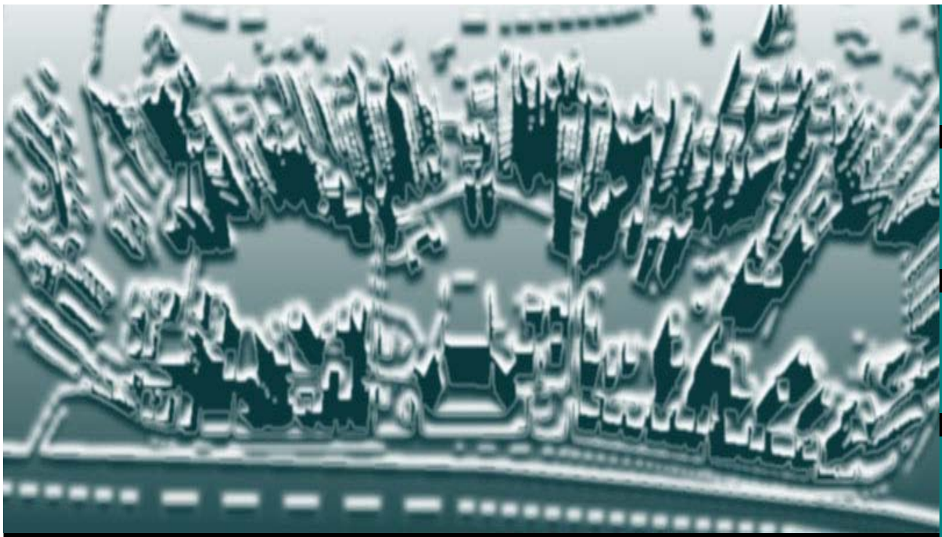

Appendices

Appendix A-G

Appendix A: Weather Data

Statistics for ARE_Abu.Dhabi.412170_IWEC
Location -- ABU DHABI - ARE
{N 24° 25'} {E 54° 39'} {GMT +4.0 Hours}
Elevation -- 27m above sea level
Standard Pressure at Elevation -- 101001Pa
Data Source -- IWEC Data

WMO Station 412170

- Using Design Conditions from "Climate Design Data 2009 ASHRAE Handbook"

- If the design condition source is ASHRAE, the design conditions are carefully generated

- from a period of record (typically 30 years) to be representative of that location and
- be suitable for use in heating/cooling load calculations. If the source is not ASHRAE,
- please consult the referenced source for the reasoning behind the data.

Design Stat	ColdestMonth	DB996	DB990	DP996	HR_DP996	DB_DP996	DP990	HR_DP990	DB_DP990	WS004c	DB_WS004c	WS010c	DB_WS010c	WS_DB996	WD_DB996
Units	{}	{°C}	{°C}	{°C}	{}	{°C}	{°C}	{}	{°C}	{m/s}	{°C}	{m/s}	{°C}	{m/s}	{deg}
Heating	1	11.5	12.9	0.1	3.8	30.6	2.7	4.6	29.6	9.9	20.5	9	21.9	2.1	110

Design Stat	HottestMonth	DBR	DB004	WB_DB004	DB010	WB_DB010	DB020	WB_DB020	WB004	DB_WB004	WB010	DB_WB010	WB020	DB_WB020	WS_DB004	WD_DB004	DP004	HR_DP004	DB_DP004	DP010	HR_DP010	DB_DP010	DP020	HR_DP020	DB_DP020	EN004	DB_EN004	EN010	DB_EN010	EN020	DB_EN020	#Hrs_8-4_&_DB-12.8/20.6
Units	{}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{m/s}	{deg}	{°C}	{}	{°C}	{°C}	{}	{°C}	{°C}	{}	{°C}	{kJ/kg}	{°C}	{kJ/kg}	{°C}	{kJ/kg}	{°C}	{}
Cooling	8	12.5	44.9	23.2	43.3	23.5	42.1	23.7	30.6	35.3	30	34.8	29.4	34.4	4.3	320	29.4	26.4	33.5	29	25.6	33.2	28.2	24.4	32.9	103.7	35	100.5	34.8	97.9	34.4	309

Design Stat	WS010	WS025	WS050	WBmax	DBmin_mean	DBmax_mean	DBmin_stddev	DBmax_stddev	DBmin05years	DBmax05years	DBmin10years	DBmax10years	DBmin20years	DBmax20years	DBmin50years	DBmax50years
Units	{m/s}	{m/s}	{m/s}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}	{°C}
Extremes	9.4	8.4	7.5	33.8	8.3	47.2	2.3	0.9	6.6	47.8	5.3	48.4	3.9	48.9	2.2	49.5

- Monthly Statistics for Dry Bulb temperatures °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	28.0	33.8	39.0	41.0	45.6	44.0	47.0	46.1	42.6	39.0	35.0	29.7
Day:Hour	17:17	28:16	24:15	12:14	31:13	3:12	23:15	10:13	14:13	7:15	3:14	23:13
Minimum	9.7	5.0	10.5	17.5	20.0	23.0	25.9	25.1	24.0	18.7	15.8	9.1
Day:Hour	20:07	2:08	10:07	3:07	12:05	7:05	1:06	23:07	13:06	29:07	24:07	10:07
Daily Avg	18.0	19.9	22.2	26.5	30.8	32.8	34.4	34.8	32.6	28.6	24.4	20.1

- Maximum Dry Bulb temperature of 47.0°C on Jul 23
- Minimum Dry Bulb temperature of 5.0°C on Feb 2

- Average Hourly Statistics for Dry Bulb temperatures °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:01- 1:00	15.7	16.9	19.8	23.3	26.5	29.0	30.8	31.6	29.5	25.5	21.9	17.7
1:01- 2:00	15.2	16.3	19.4	22.8	26.1	28.2	30.3	31.2	28.9	25.0	21.2	17.2
2:01- 3:00	14.8	15.9	19.0	22.5	25.7	27.8	29.7	30.3	28.5	24.3	20.7	16.7
3:01- 4:00	14.2	15.7	18.8	22.0	25.1	27.3	29.3	29.8	27.9	23.7	20.1	16.6
4:01- 5:00	13.8	15.0	18.5	21.8	24.9	27.1	29.3	29.6	27.6	23.3	19.6	16.1
5:01- 6:00	13.7	14.5	18.1	21.3	24.7	26.8	28.9	29.1	27.3	22.9	19.4	15.8
6:01- 7:00	13.3	14.3	17.9	21.7	25.5	28.0	29.3	29.2	27.5	23.1	19.1	15.5
7:01- 8:00	14.1	15.4	19.2	24.2	29.1	30.9	31.9	31.7	29.7	25.6	20.9	16.2
8:01- 9:00	16.2	17.8	21.1	26.8	32.5	33.7	34.4	34.7	31.9	28.8	23.0	18.2
9:01-10:00	18.3	20.3	23.1	29.0	34.6	35.8	36.8	36.8	33.8	30.8	25.9	20.7
10:01-11:00	20.6	22.8	25.1	30.8	36.5	37.9	38.8	39.1	36.5	33.2	27.9	23.1
11:01-12:00	21.8	24.5	26.4	31.8	37.5	38.8	40.2	40.6	38.2	34.7	29.0	24.6
12:01-13:00	22.6	25.8	27.0	32.7	37.3	39.2	40.7	40.9	38.8	34.7	29.8	25.0
13:01-14:00	22.9	26.2	27.1	32.0	37.1	39.1	40.9	41.4	39.2	34.8	29.9	25.2
14:01-15:00	23.1	26.0	26.9	31.5	36.4	39.0	40.7	40.8	38.6	34.3	29.5	25.1
15:01-16:00	22.7	25.7	26.6	30.9	35.9	37.9	39.6	39.9	37.6	33.2	29.1	24.7
16:01-17:00	22.1	24.6	25.9	29.6	35.0	37.0	38.2	38.6	36.0	32.1	27.9	23.9
17:01-18:00	20.8	23.3	24.8	28.6	33.6	35.6	37.0	37.3	34.5	30.8	26.7	22.6
18:01-19:00	19.5	22.0	23.4	27.3	31.7	33.9	35.8	36.1	33.5	29.5	25.5	21.4
19:01-20:00	18.8	20.9	22.4	26.5	30.4	32.4	34.5	34.9	32.5	28.4	24.8	20.5
20:01-21:00	18.0	19.9	22.0	25.7	29.6	31.6	33.5	33.9	31.8	27.8	23.8	19.9
21:01-22:00	17.4	19.0	21.1	25.3	28.7	30.8	32.7	33.3	31.0	27.1	23.5	19.2
22:01-23:00	16.7	18.1	20.4	24.6	27.9	30.0	32.1	32.5	30.4	26.4	22.8	18.5
23:01-24:00	16.1	17.7	20.1	24.0	27.2	29.5	31.4	32.0	29.9	25.8	22.4	17.9
Max Hour	15	14	14	13	12	13	14	14	14	14	14	14
Min Hour	7	7	7	6	6	6	6	6	6	6	7	7

- Monthly Statistics for Extreme temperatures °C

#Days	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max >= 32		2	7	16	31	30	31	31	30	31	8	
Max <= 0												
Min <= 0												
Min <=-18												

- Monthly Statistics for Dew Point temperatures °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	18.0	18.0	24.0	22.0	27.0	27.5	30.0	30.2	29.0	26.3	22.4	21.0
Day:Hour	14:17	19:18	25:17	14:01	30:20	22:01	17:24	12:01	11:03	3:22	11:19	24:18
Minimum	0.0	-6.0	0.0	0.0	-2.0	1.0	-2.0	6.0	1.0	5.0	8.0	0.0
Day:Hour	21:05	18:12	20:15	21:15	31:12	15:09	11:11	21:15	13:14	14:05	19:13	10:17
Daily Avg	11.9	11.9	15.5	15.2	17.5	20.3	22.3	22.1	23.0	18.8	18.1	13.0

- Maximum Dew Point temperature of 30.2°C on Aug 12
- Minimum Dew Point temperature of -6.0°C on Feb 18

- Monthly Statistics for Relative Humidity %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	100	100	100	95	100	100	100	100	100	100	100	96
Day:Hour	12:24	2:02	16:05	5:07	13:07	22:06	4:06	2:03	22:08	22:05	25:24	3:04
Minimum	23	9	14	9	6	8	7	10	9	18	24	20
Day:Hour	5:12	18:12	23:13	20:13	31:12	15:12	11:11	10:12	13:14	11:13	19:13	10:17
Daily Avg	70	65	69	55	50	53	55	53	62	59	71	66

- Average Hourly Relative Humidity %

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:01- 1:00	81	79	78	69	66	69	71	68	80	73	83	76
1:01- 2:00	82	80	80	69	66	71	71	67	82	75	85	78
2:01- 3:00	82	81	80	71	66	70	73	70	83	75	85	79
3:01- 4:00	83	80	81	73	68	71	73	70	85	77	86	78
4:01- 5:00	84	81	82	72	67	69	72	68	83	76	87	78
5:01- 6:00	84	82	83	72	68	68	72	68	82	75	86	79
6:01- 7:00	85	82	83	72	65	64	71	68	81	74	85	80
7:01- 8:00	83	76	79	61	52	55	63	59	69	64	79	76
8:01- 9:00	77	70	71	52	41	47	51	46	57	54	72	69
9:01-10:00	71	62	65	45	32	41	42	39	49	48	63	61
10:01-11:00	61	52	56	35	27	32	35	32	38	38	57	53
11:01-12:00	55	44	52	32	25	30	32	28	33	32	51	48
12:01-13:00	51	41	51	31	26	28	31	28	31	34	48	47
13:01-14:00	48	38	51	33	29	29	30	29	31	36	48	46
14:01-15:00	47	41	51	35	30	31	31	33	35	39	49	47
15:01-16:00	50	43	53	39	32	35	35	36	40	43	50	49
16:01-17:00	54	47	55	43	35	37	41	41	47	48	55	52
17:01-18:00	61	53	61	47	41	44	46	48	56	56	64	60
18:01-19:00	69	61	68	52	51	51	52	52	61	62	72	65
19:01-20:00	73	65	72	57	58	58	59	59	67	67	74	69
20:01-21:00	76	70	73	61	60	62	63	63	70	68	78	71
21:01-22:00	78	74	75	64	64	64	66	65	74	71	79	72
22:01-23:00	78	76	78	66	64	67	68	68	76	71	81	74
23:01-24:00	80	77	78	68	65	68	70	68	78	72	83	76
Max Hour	7	6	7	4	6	2	3	3	4	4	5	7
Min Hour	15	14	15	13	12	13	14	12	13	12	14	14

- Monthly Indicators for Precipitation/Moisture (kPa)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.3	1.3	1.8	1.5	1.8	2.1	2.3	2.4	2.4	2.1	2.0	1.5

- Monthly Statistics for Wind Chill/Heat Index temperatures °C **

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum WC	8	8									6	
Day:Hour	20:07	26:07										10:07
Average WC	8	8									6	
Avg Del WC	2	2									3	

# Hours WC	1	1									1	
Maximum H	27	29	42	40	45	49	53	55	53	45	34	30
Day:Hour	17:16	19:17	25:17	26:14	31:18	12:15	18:15	4:15	11:08	3:14	1:13	23:13
Average HI	27	28	31	29	33	36	40	41	38	33	29	28
Avg Del HI	0	0	2	1	2	5	8	8	7	3	1	0
# Hours HI	3	9	87	121	274	438	481	460	510	316	195	26

- **WindChill/HeatIndex Temps -- statistics...only those different from Air Temps

- Monthly Wind Direction % {N=0 or 360,E=90,S=180,W=270}

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North	13	16	21	23	21	14	17	19	21	22	16	12
NorthEast	4	5	7	6	5	5	5	9	12	12	4	7
East	9	17	13	14	8	6	7	10	19	24	12	16
SouthEast	13	8	11	8	6	7	10	9	8	11	9	7
South	15	16	11	8	7	9	16	17	17	10	14	16
SouthWest	14	5	6	5	16	10	10	7	3	5	6	3
West	8	6	5	6	5	11	6	5	3	1	4	8
NorthWest	24	28	26	30	32	37	30	23	17	16	35	31

- Monthly Statistics for Wind Speed m/s

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	24.2	11.3	17.0	15.9	12.9	15.4	15.4	19.0	13.4	9.3	8.8	13.9
Day:Hour	21:18	10:10	20:04	27:07	12:24	11:19	24:18	8:04	24:12	10:15	6:14	5:13
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Day:Hour	2:21	1:23	9:22	3:06	13:10	1:01	4:22	2:03	11:03	3:23	3:14	1:01
Daily Avg	3.0	3.5	3.9	3.8	4.2	4.2	3.6	3.7	3.7	3.5	3.0	3.7

- Maximum Wind Speed of 24.2 m/s on Jan 21
- Minimum Wind Speed of 0.0 m/s on Jan 2

- Monthly Statistics for Solar Radiation (Direct Normal, Diffuse, Global Horizontal) Wh/m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Direct Avg	5459	6647	5201	5781	7293	7458	6545	6744	6712	6556	5918	5191
Direct Max	7481	8106	8182	8166	7974	7721	7284	7222	7077	7070	6950	7052
Day	29	9	21	28	4	4	26	8	4	8	30	10
Diffuse Avg	1275	1334	2020	2169	1916	1828	2128	1884	1596	1345	1186	1239
Global Avg 4221	5323	5546	6507	7635	7772	7404	7216	6624	5707	4557	3940	

- Maximum Direct Normal Solar of 8182 Wh/m² on Mar 21

- Average Hourly Statistics for Direct Normal Solar Radiation Wh/m²

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:01- 1:00	0	0	0	0	0	0	0	0	0	0	0	0
1:01- 2:00	0	0	0	0	0	0	0	0	0	0	0	0
2:01- 3:00	0	0	0	0	0	0	0	0	0	0	0	0
3:01- 4:00	0	0	0	0	0	0	0	0	0	0	0	0
4:01- 5:00	0	0	0	0	0	0	0	0	0	0	0	0
5:01- 6:00	0	0	0	0	0	0	0	0	0	0	0	0
6:01- 7:00	0	0	0	20	71	66	23	0	0	0	0	0
7:01- 8:00	96	141	182	277	332	324	238	223	188	197	211	103
8:01- 9:00	235	417	371	476	573	577	471	477	508	542	485	368
9:01-10:00	544	640	502	597	688	703	611	651	687	728	680	582
10:01-11:00	659	727	552	629	771	794	710	749	794	820	754	658
11:01-12:00	675	790	578	662	814	855	781	817	857	848	752	671
12:01-13:00	722	821	586	649	837	860	795	830	868	834	736	660
13:01-14:00	709	809	581	648	834	855	791	826	844	815	736	661
14:01-15:00	669	765	584	608	802	816	736	778	779	761	694	618
15:01-16:00	605	700	562	547	715	729	645	686	669	635	562	531
16:01-17:00	443	583	470	452	575	582	509	506	418	366	308	341
17:01-18:00	102	254	234	218	282	288	233	201	102	11	0	0
18:01-19:00	0	0	0	0	0	11	3	0	0	0	0	0
19:01-20:00	0	0	0	0	0	0	0	0	0	0	0	0
20:01-21:00	0	0	0	0	0	0	0	0	0	0	0	0
21:01-22:00	0	0	0	0	0	0	0	0	0	0	0	0

```
 22:01-23:00        0      0      0      0      0      0      0      0      0      0      0      0
 23:01-24:00        0      0      0      0      0      0      0      0      0      0      0      0
Max Hour*          13     13     13     12     13     13     13     13     13     12    11*     12
Min Hour            1      1      1      1      1      1      1      1      1      1      1      1

 - Monthly Calculated "undisturbed" Ground Temperatures** °C
                  Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct    Nov    Dec
          0.5 m  22.8   20.2   19.5   20.1   23.6   27.5   31.2   33.9   34.7   33.4   30.4   26.6
          2.0 m  25.1   22.7   21.5   21.5   23.3   26.0   28.9   31.4   32.7   32.4   30.7   28.1
          4.0 m  26.7   24.8   23.6   23.3   23.9   25.5   27.4   29.3   30.6   30.9   30.2   28.7

  - **These ground temperatures should NOT BE USED in the GroundTemperatures object to compute building floor losses.
  -   The temperatures for 0.5 m depth can be used for GroundTemperatures:Surface.
  -   The temperatures for 4.0 m depth can be used for GroundTemperatures:Deep.
  -   Calculations use a standard soil diffusivity of 2.3225760E-03 {m**2/day}

 - Monthly Heating/Cooling Degree Days/Hours
                  Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct    Nov    Dec
 HDD base 10C       0      0      0      0      0      0      0      0      0      0      0      0
 HDD base 18C      18      4      2      0      0      0      0      0      0      0      0      0

 CDD base 10C     248    278    380    496    645    684    758    769    677    576    431    313
 CDD base 18C      18     59    133    256    397    444    510    521    437    328    191     65

 CDH base 20C     618   1336   2378   4740   8045   9226  10749  11012   9037   6380   3300   1236
 CDH base 23C     120    572   1197   2937   5845   7066   8518   8780   6877   4261   1730    429
 CDH base 27C       2    164    391   1289   3329   4278   5550   5814   4069   2032    473     44

   - 6254 annual cooling degree-days (10°C baseline)
   -    0 annual heating degree-days (10°C baseline)

   - 3358 annual cooling degree-days (18°C baseline)
   -   24 annual heating degree-days (18°C baseline)

 - Climate type "BWh" (Köppen classification)**
 - Subtropical hot desert (lat. 15-25°N)
 - **Note that the Köppen classification shown here is derived algorithmically from the source weather data.
 -   It may not be indicative of the long term climate for this location.

 - Climate type "1B" (ASHRAE Standards 90.1-2004 and 90.2-2004 Climate Zone)**
 - Very Hot - Dry, Probable Köppen classification=Bw, Arid Tropical Dry
 - **Note that the ASHRAE classification shown here is derived algorithmically from the source weather data.
 -   It may not be indicative of the long term climate for this location.

 - Typical/Extreme Period Determination

 - Summer is Jun:Aug
    Extreme Summer Week (nearest maximum temperature for summer)
    Extreme Hot Week Period selected: Jul 20:Jul 26, Maximum Temp=  47.00°C, Deviation=|10.626|°C
    Typical Summer Week (nearest average temperature for summer)
    Typical Week Period selected: Aug 17:Aug 23, Average Temp=  34.03°C, Deviation=| 0.065|°C
 - Winter is Dec:Feb
    Extreme Winter Week (nearest minimum temperature for winter)
    Extreme Cold Week Period selected: Jan 27:Feb  2, Minimum Temp=   5.00°C, Deviation=|12.024|°C
    Typical Winter Week (nearest average temperature for winter)
    Typical Week Period selected: Feb 10:Feb 16, Average Temp=  19.33°C, Deviation=| 0.027|°C
 - Autumn is Sep:Nov
    Typical Autumn Week (nearest average temperature for autumn)
    Typical Week Period selected: Oct 13:Oct 19, Average Temp=  28.49°C, Deviation=| 0.064|°C
 - Spring is Mar:May
    Typical Spring Week (nearest average temperature for spring)
    Typical Week Period selected: Apr 26:May  2, Average Temp=  26.53°C, Deviation=| 0.287|°C
```

Appendix B – Wind Design for Vegetated Roofs

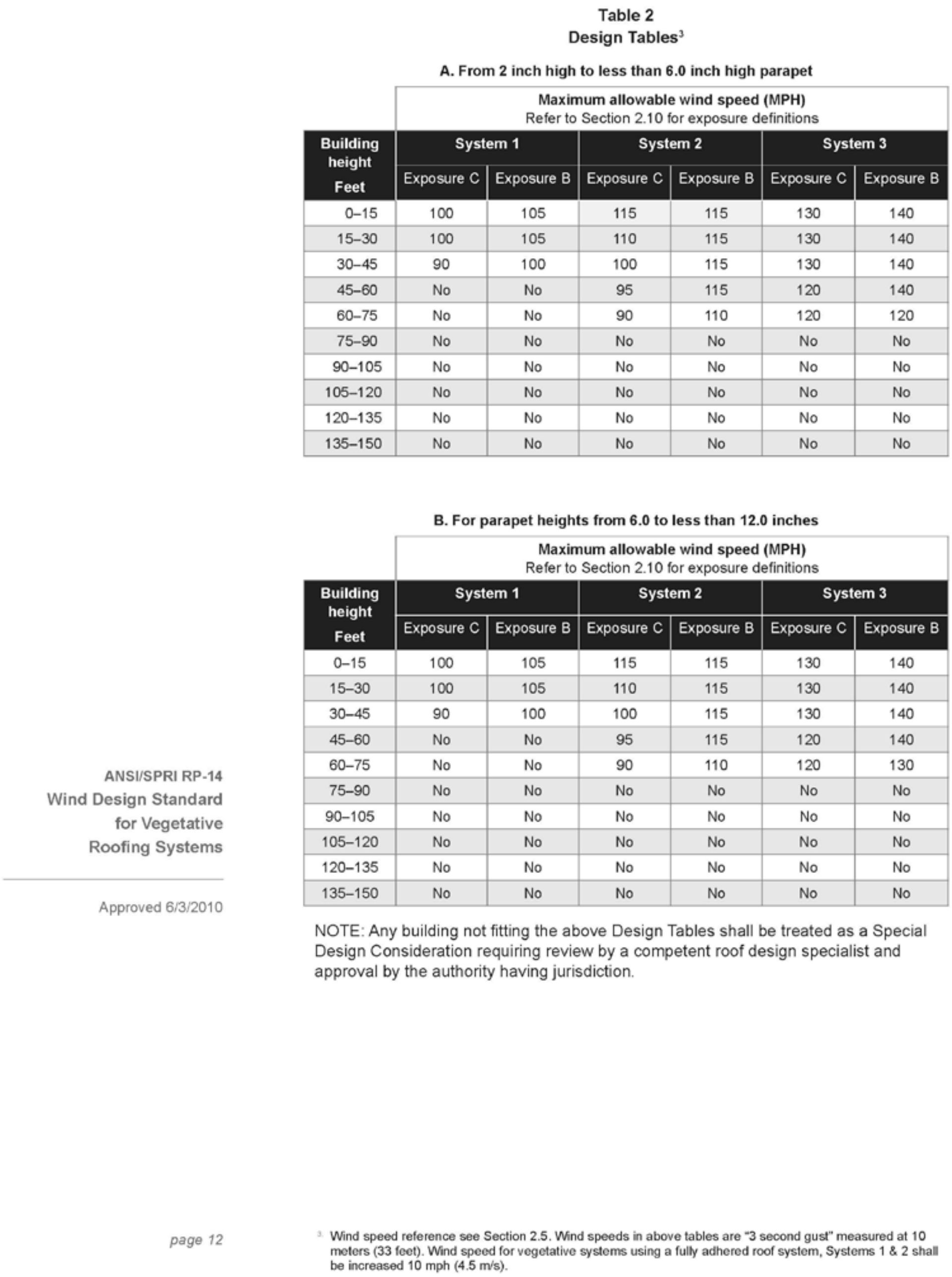

Table 2
Design Tables[3]

A. From 2 inch high to less than 6.0 inch high parapet

	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
Building height Feet	**System 1**		**System 2**		**System 3**	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	100	105	115	115	130	140
15–30	100	105	110	115	130	140
30–45	90	100	100	115	130	140
45–60	No	No	95	115	120	140
60–75	No	No	90	110	120	120
75–90	No	No	No	No	No	No
90–105	No	No	No	No	No	No
105–120	No	No	No	No	No	No
120–135	No	No	No	No	No	No
135–150	No	No	No	No	No	No

B. For parapet heights from 6.0 to less than 12.0 inches

	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
Building height Feet	**System 1**		**System 2**		**System 3**	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	100	105	115	115	130	140
15–30	100	105	110	115	130	140
30–45	90	100	100	115	130	140
45–60	No	No	95	115	120	140
60–75	No	No	90	110	120	130
75–90	No	No	No	No	No	No
90–105	No	No	No	No	No	No
105–120	No	No	No	No	No	No
120–135	No	No	No	No	No	No
135–150	No	No	No	No	No	No

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

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[3] Wind speed reference see Section 2.5. Wind speeds in above tables are "3 second gust" measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables[4]

C. For parapet heights from 12.0 to less than 18.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		**System 2**		**System 3**	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	100	105	115	115	140	140
15–30	100	105	110	115	140	140
30–45	90	105	105	115	140	140
45–60	No	90	95	115	130	140
60–75	No	90	90	110	120	130
75–90	No	No	90	110	110	120
90–105	No	No	90	100	110	110
105–120	No	No	85	100	100	110
120–135	No	No	No	100	100	110
135–150	No	No	No	95	100	110

D. For parapet heights from 18.0 to less than 24.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		**System 2**		**System 3**	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	110	120	140	140
30–45	95	110	110	120	140	140
45–60	85	110	95	120	140	140
60–75	No	90	90	110	140	140
75–90	No	90	90	110	120	130
90–105	No	No	90	100	110	120
105–120	No	No	90	100	110	110
120–135	No	No	90	100	110	110
135–150	No	No	No	100	100	110

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

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[4] Wind speed reference see Section 2.5. Wind speeds in above tables are "3 second gust" measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables[5]

E. For parapet heights from 24.0 to less than 36.0 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	120	120	140	140
30–45	95	110	110	120	140	140
45–60	85	110	100	120	140	140
60–75	No	90	90	120	130	140
75–90	No	90	90	110	130	140
90–105	No	No	90	100	120	140
105–120	No	No	90	100	120	140
120–135	No	No	90	100	120	140
135–150	No	No	90	100	110	140

F. For parapet heights from 36.0 to less than 72 inches

Building height Feet	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	120	120	140	140
30–45	100	110	120	120	140	140
45–60	95	110	105	120	140	140
60–75	90	100	100	120	140	140
75–90	90	100	100	120	140	140
90–105	90	90	100	110	130	140
105–120	85	90	100	110	130	140
120–135	85	90	100	110	130	140
135–150	No	85	100	110	130	140

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

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[5] Wind speed reference see Section 2.5. Wind speeds in above tables are "3 second gust" measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables[6]

G. For parapet heights from 72 inches and above

	Maximum allowable wind speed (MPH) Refer to Section 2.10 for exposure definitions					
Building height Feet	**System 1**		**System 2**		**System 3**	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–15	110	110	120	120	140	140
15–30	110	110	120	120	140	140
30–45	110	110	120	120	140	140
45–60	100	110	120	120	140	140
60–75	95	110	115	120	140	140
75–90	90	100	110	120	140	140
90–105	90	100	110	120	140	140
105–120	90	100	110	120	130	140
120–135	90	100	110	120	130	140
135–150	85	100	110	110	130	140

Design Tables—Metric

A. From 50 mm height to less than 150 mm parapet height

	Maximum allowable wind speed (m/s)					
Building height Feet	**System 1**		**System 2**		**System 3**	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	45	47	51	51	58	63
5–9	45	47	49	51	58	63
9–14	40	45	45	51	58	63
14–18	No	No	47	51	54	63
18–23	No	No	40	49	54	63
23–27	No	No	No	No	No	54
27–32	No	No	No	No	No	No
32–37	No	No	No	No	No	No
37–41	No	No	No	No	No	No
41–46	No	No	No	No	No	No

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

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[6] Wind speed reference see Section 2.5. Wind speeds in above tables are "3 second gust" measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables—Metric[7]

B. For parapet heights from 150 mm to less than 300 mm

	Maximum allowable wind speed (m/s)					
Building height	**System 1**		**System 2**		**System 3**	
Feet	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	45	47	51	51	58	63
5–9	45	47	49	51	58	63
9–14	40	45	45	51	58	63
14–18	No	No	47	51	54	63
18–23	No	No	40	49	54	58
23–27	No	No	No	No	No	58
27–32	No	No	No	No	No	No
32–37	No	No	No	No	No	No
37–41	No	No	No	No	No	No
41–46	No	No	No	No	No	No

C. For parapet heights from 0.3 m to less than 0.45 m

	Maximum allowable wind speed (m/s)					
Building height	**System 1**		**System 2**		**System 3**	
Feet	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	45	47	51	51	63	63
5–9	45	47	49	51	63	63
9–14	40	47	47	51	63	63
14–18	No	No	42	51	58	63
18–23	No	No	40	49	54	58
23–27	No	No	40	49	49	54
27–32	No	No	40	45	49	49
32–37	No	No	38	45	45	49
37–41	No	No	No	45	45	49
41–46	No	No	No	42	45	49

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

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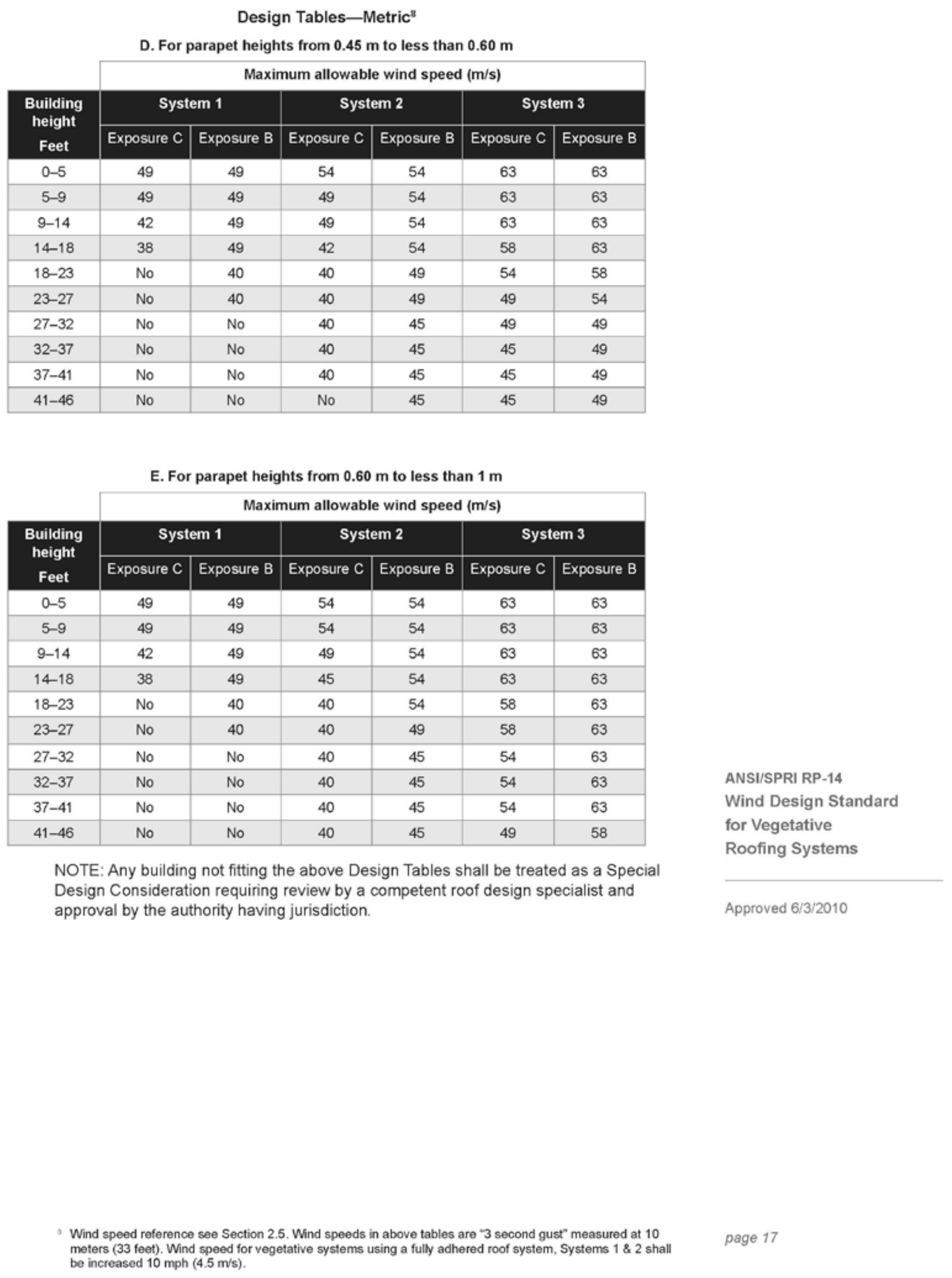
[7] Wind speed reference see Section 2.5. Wind speeds in above tables are “3 second gust” measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).



Design Tables—Metric[8]

D. For parapet heights from 0.45 m to less than 0.60 m

Building height	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
Feet	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	49	54	63	63
9–14	42	49	49	54	63	63
14–18	38	49	42	54	58	63
18–23	No	40	40	49	54	58
23–27	No	40	40	49	49	54
27–32	No	No	40	45	49	49
32–37	No	No	40	45	45	49
37–41	No	No	40	45	45	49
41–46	No	No	No	45	45	49

E. For parapet heights from 0.60 m to less than 1 m

Building height	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
Feet	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	54	54	63	63
9–14	42	49	49	54	63	63
14–18	38	49	45	54	63	63
18–23	No	40	40	54	58	63
23–27	No	40	40	49	58	63
27–32	No	No	40	45	54	63
32–37	No	No	40	45	54	63
37–41	No	No	40	45	54	63
41–46	No	No	40	45	49	58

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

Approved 6/3/2010

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[8] Wind speed reference see Section 2.5. Wind speeds in above tables are "3 second gust" measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

Design Tables—Metric[9]

F. For parapet heights from 1 m to less than 2 m

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	54	54	63	63
9–14	45	49	54	54	63	63
14–18	42	49	47	54	63	63
18–23	40	45	45	54	63	63
23–27	40	45	45	54	63	63
27–32	40	40	45	49	58	63
32–37	38	40	45	49	58	63
37–41	38	40	45	49	58	63
41–46	No	38	45	49	58	63

G. For parapet heights from 2 m and above

Building height Feet	Maximum allowable wind speed (m/s)					
	System 1		System 2		System 3	
	Exposure C	Exposure B	Exposure C	Exposure B	Exposure C	Exposure B
0–5	49	49	54	54	63	63
5–9	49	49	54	54	63	63
9–14	49	49	54	54	63	63
14–18	45	49	54	54	63	63
18–23	42	49	51	54	63	63
23–27	40	45	49	54	63	63
27–32	40	45	49	54	63	63
32–37	40	45	49	54	58	63
37–41	40	45	49	54	58	63
41–46	38	45	49	49	58	63

NOTE: Any building not fitting the above Design Tables shall be treated as a Special Design Consideration requiring review by a competent roof design specialist and approval by the authority having jurisdiction.

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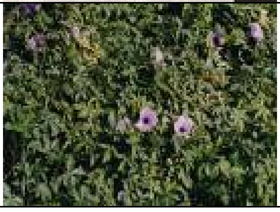
[9] Wind speed reference see Section 2.5. Wind speeds in above tables are "3 second gust" measured at 10 meters (33 feet). Wind speed for vegetative systems using a fully adhered roof system, Systems 1 & 2 shall be increased 10 mph (4.5 m/s).

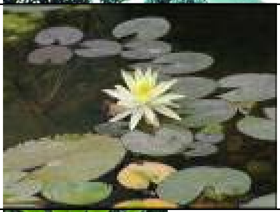
Appendix C – Plant Data from Dubai Municipality

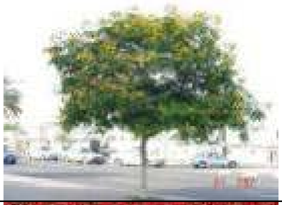
No.	DM Plant List	Type	Plant Height
1	Agave americana	Semi-Intensive	
2	Antigonon leptopus	Semi-Intensive	
3	Antirrhinum Hybrid Dwarf	Extensive	
4	Azadirachta indica	Intensive	
5	Bauhinia varigata	Intensive	
6	Beacarnea recurvata	Intensive	
7	Bismarckia nobilis	Intensive	

8	Caesalpinia pulcherrima	Semi-Intensive	
9	Callistemon lanceolatus	Intensive	
10	Carica papaya	Intensive	
11	Caryota mitis	Intensive	
12	Cassia fistula	Intensive	
13	Chamaerops humilis	Intensive	
14	Citrus aurantifolia	Intensive	
15	Cocos nucifera	Intensive	

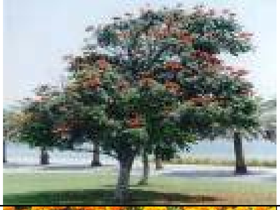
16	Conocarpus erectus sericeus	Intensive	
17	Cryptostagia randiflora	Semi-Intensive	
18	Cycas media Citrus sinensis	Intensive	
19	Cycas revoluta	Intensive	
20	Cyperus papyrus	Intensive	
21	Delonix regia	Intensive	
22	Euphorbia canariensis	Semi-Intensive	

23	Ficus benjamina	Intensive	
24	Ficus carica	Intensive	
25	ficus nitida	Intensive	
26	Ficus rubiginosa	Intensive	
27	Furcraea foetida	Semi-Intensive	
28	Gliricidia sepium	Intensive	
29	Hibiscus Spp.	Semi-Intensive	
30	Ipomoea palmata	Semi-Intensive	

31	Ixora spp.	Semi-Intensive	
32	Jacaranda imosifolia	Intensive	
33	Jacquemontia pentantha	Semi-Intensive	
34	Jasminum grandiflorum	Semi-Intensive	
35	Lantana Camara	Extensive	
36	Mangifera indica	Intensive	
37	Nymphaea spp.	Intensive	
38	Pachypodium lamerei	Intensive	

39	Pandanus utilis	Intensive	
40	Paspalium Vagiratum	Extensive	
41	Pedilanthus ithimaloides	Semi-Intensive	
42	Pelargonium Grandiflora	Extensive	
43	Peltophorum inerme	Intensive	
44	Petunia Spp.	Extensive	
45	Phoenix dactylifera	Intensive	
46	Phoenix roebelenii	Intensive	

47	Plumeria spp	Semi-Intensive	
48	Portulaca Grandiflora	Extensive	
49	Portulacaria afra	Semi-Intensive	
50	Pritchardia pacifica	Intensive	
51	Psidium guaiva	Intensive	
52	Ravenala adagascariensis	Intensive	
53	Rhoeo Spathacea	Extensive	
54	Roystonea regia	Intensive	

55	Ruellia Macrantha	Extensive	
56	Sansavieria slendrica	Semi-Intensive	
57	Sesevium Portulacastrum	Extensive	
58	Setcreasea Purpurea	Extensive	
59	Spathodea campanulata	Intensive	
60	Tagets Erecta	Extensive	
61	Tecoma smithi	Semi-Intensive	
62	Tecoma stans	Intensive	

63	Tecomella undulata	Intensive	
64	Tristellateia australasiae	Semi-Intensive	
65	Typha latifolia	Intensive	
66	Vinca Rosa	Extensive	
67	Washingtonia filifera	Intensive	
68	Yucca aloifolia	Intensive	
69	Yucca filamentosa	Intensive	
70	Zoysia Sp.	Extensive	

Appendix D – ENVI-met Output - Conventional Roof on June 21st 2011

```
ENVI-met V3.1 BETA 4 © 1997-2010 by Michael Bruse and Team  Build 3.0.99.5
A Microscale Urban Climate Model
This version: 100 x 100 x 35 Grids maximum
www.envi-met.com

Computer name for ENVI-met cluster: ENVI node_HP-PAVILLION

Checking folder structure...
$$  Reading Soils sys.base data\SOILS.DAT...
$$ ********************** Soils-Database ********************
          "00" :Default Soil (Loam) Type:natural soil
          "SD" :Sand Type:natural soil
          "LS" :Loamy Sand Type:natural soil
          "SL" :Sandy Loam Type:natural soil
          "SL" :Silt Loam Type:natural soil
          "LE" :Loam Type:natural soil
          "TS" :Sandy Clay Loam Type:natural soil
          "TL" :Silty Clay Loam Type:natural soil
          "LT" :Clay Loam Type:natural soil
          "ST" :Sandy Clay Type:natural soil
          "TS" :Silty Clay Type:natural soil
          "TO" :Clay Type:natural soil
          "TF" :Peat Type:natural soil
          "ZB" :Cement Concrete Type:artificial soil
          "MB" :Mineral Concrete Type:artificial soil
          "AK" :Asphalt (with Gravel Type:artificial soil
          "AB" :Asphalt (with Basalt Type:artificial soil
          "GR" :Granite Type:artificial soil
          "BA" :Basalt Type:artificial soil
          "WW" :Water Type:water body
          "ZZ" :Brick Type:artificial soil
$$ ******************** Total: 21 Soils out of 50 **********************

$$  Reading global Source Database SOURCES.DAT...
          "XX" :Test_Pointsource 10m,10µg/s Type=Line (µg)
          "SS" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
          "YY" :Test_Pointsource 10m,10mg/s Type=Line (mg)
          "R1" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
          "SP" :Test_Spray 2m cm 10mg/s Type=Area (µg)
$$ ********************   Total:  5 Sources(s) out of 150 ******************

Source Model Settings : --------------------------------
Identified Source Type: PM  (Particulate Matter)
Given Name: PM10
Type of source: Particle
    Particle Diameter (µm)       :10.00
    Particle Density (g/cm³)     :1.00
    Settling Velocity (cm/h)     :1107.50
    Diffusion Coefficient (cm²/s):0.0000
    Schmitt-Number               :4054944.25
    Transfer resistance soils    :0.00
    Mesophyll transfer resistance:0.00
```

```
$$  Reading Global Plant Database sys.basedata\plants.dat...
$$ ********************** Plant-Database V3 ********************
          "XX" : (C3) Grass 50 cm aver. dense
          "SO" : (C3) soja 90. soja 63cm
          "LG" : (C3) luzerne 18cm
          "MO" : (C3) Tree 20m aver. dense., no distinct crown layer
          "DO" : (C3) Tree 20 m dense., no distinct crown layer
          "DM" : (C3) Tree 20 m dense., distinct crown layer
      --->"DM" : ** ID already loaded. Plant skipped **
          "DS" : (C3) Tree 10 m dense.,distinct crown layer
          "SM" : (C3) Tree 20 m very dense, distinct crown layer
          "SK" : (C3) Tree 15 m very dense, distinct crown layer
          "H2" : (C3) Hedge dense, 2m
          "T1" : (C3) Tree 10 m very dense, leafless base
          " G" : (C3) Grass 50 cm aver. dense
          "BS" : (C3) Tree 20 m dense.,distinct crown layer
          "SC" : (C3) Tree 20 m very dense, free stem crown layer
          " W" : (C3) Forst 20 m dense., no distinct crown layer
          "L1" : (C3) Tree, light 15 m
          "L2" : (C3) Tree, light 20 m
          " H" : (C3) Hedge dense, 2m
          " M" : (C4) Maize, 1.5 m
          " C" : (C3) Corn, 1.5 m
          "GB" : (C3) Grass 50 cm aver. dense
          "GZ" : (C3) Grass 50 cm aver. dense
          "T2" : (C3) Tree 15 m very dense, leafless base
          "TB" : (C3) Tree 15 m very dense
          "EE" : (C3) Tree 20m aver. dense., no distinct crown layer
          "TH" : (C3) Tree 15m dense, distinct crown layer, Christer
$$ ******************** Total : 26 Plant(s)  out of 150 ******************
```

```
$$  Setting up model grid...
$$  Loading Area Input file...
  >> This input file has no overhanging shelters !
  >> This file has detailed soil information for each grid
```

```
$$ Grid Information:
$$    dxy(Main)=10.00 m  Nesting:0 grids. dxy(Nest) m
$$    dz=10.00 (equidistant)
$$ Top of 3D Model is at 195.00 m height
$$ Highest object in model area is 4.00 m high
```

```
$$ DEM Terrain Model Information:     No DEM used.
```

```
$$ PROFILS.DAT format is V3, cool! We are up to date.
$$ Getting soil profile definitions from C:\ENVImet31\sys.basedata\PROFILS.DAT ...
       " 0" :Default Useald Soil (** do not change **
       " S" :Asphalt Road
       " P" :Pavement (Concrete)
       " L" :Loamy Soil
       "SD" :Sandy Soil
       " W" :Deep Water
       "KK" :Brick road (red stones)
       "KG" :Brick road (yellow stones)
       "GG" :Dark Granit Pavement
       "GS" :Granit Pavement (single stones)
       "G2" :Granit shining
$$ ******************* Total: 11 Profiles out of 150 *********************
$$ Linking SOILS.DAT <-> PROFILS.DAT <-> "C:\ENVImetprojects\Models\Dubai
Marina4.in"
```

```
$$ All links in between PROFIL.DAT and SOILS.DAT are valid. :-)
** Checking profiles used but not defined in PROFILES.DAT...
$$ Setting Datalinks, z0- length, Emissivity and Albedo...
$$ Average z0 over nesting area:0.015

$$  Gridding Plants and other Shelters...
$$ Checking Grid Structure...
$$ Selected Stomata Resistance Model: A-Gs Approach (Jacobs)(=2)
$$ CO2 Background concentration: 350.00 ppm
$$ CO2 subsystem enabled
$$ Additional CO2 sources present: No

$$ This is how the present constellation looks like :
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          "#" Building, "=" Overhanging Building, "~" Plant "*" Plant on Roof "R" Receptor
Calculating max radiation at noon...
Calculating SOR coefficients...
$$  Asymptotic relaxation parameter was calculated to 1.9333
$$  Geostrophic wind is u=-6.53 v=-6.53

$$  Model Initialisation (Initial Guess on 1D BL)

[+00:02:04] $$ Starting ENVI-met Initialisation on 21/05/2011@04:41:57
$$ ENVI-met mode: Normal turbulence

$$ 3D Initialisation: Flow Diastrophy
     100% [150 st] remaining div: 0.00000 (OK)
      50% [301 st] remaining div: 0.00005 (Stopped)
       0% [301 st] remaining div: 0.00008 (Stopped)
$$ 3D Initialisation: Complete Modell
 Turbulence Adjustment:428 Steps, dt=0.526 (max. 0.8 s) Relax: 1.00
Initial Flow Adjustment. Total time to calculate: 10.000 sec
                         Maximum allowed change: 0.0924 m/s
[+00:05:33] $$ Setting up wind field completed
 Turbulence Adjustment:152 Steps, dt=0.592 (max. 0.8 s) Relax: 1.00
[04:46:14] $$ Time needed for Initialisation: 00:06:20

$$ ***********************************************************
$$ ******** ENVI-met (c) Michael Bruse 1997-2006 ************
$$ *********    A microscale climatology model    ************
$$ ***********************************************************
$$    Start: 22.06.2011 06:00:00 End: 23.06.2011 06:00:00 = 86400.0 sec
$$    Dynamical time steps enabled:
$$    Sun height <40.00Â° : dt=10.00 s
$$         40.00-50.00Â° : dt=5.00 s
$$               >50.00Â° : dt=2.00 s

$$ Passive Particle/Gas Concentration:
       Not used

$$ Other moduls:
$$ Moduls for Biometeorology:
$$     PMV-Value: ok

$$ Turbulence Closure 3D Main model: Prognostic. Fine.

$$ Starting ENVI-met Mainmodule on 21/05/2011@04:46:14
$$ Writing Output file MySim_AT_06.00.00 22.06.2011 and others
 Model start up phase. Main time step is set to class 2 (dt=2 sec)
[+00:09:43] New flow: 1 Steps [65 SOR Steps] du:0.028 dv:0.029 dw:0.009 after 10.95 s
total
Maximum divergence in flow field= 0.01202 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+00:18:27] New flow: 1 Steps [301 SOR Steps] du:0.017 dv:0.019 dw:0.007 after 11.90
```

```
s total
Maximum divergence in flow field= 0.01200 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
Dynamical time step adjustment. Set dt=10 sec. (Class 0)
[+00:21:14] New flow: 1 Steps [301 SOR Steps] du:0.016 dv:0.016 dw:0.006 after 12.85
s total
Maximum divergence in flow field= 0.01197 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+00:24:28] New flow: 1 Steps [301 SOR Steps] du:0.015 dv:0.014 dw:0.006 after 13.81
s total
Maximum divergence in flow field= 0.01192 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_07.00.00 22.06.2011 and others
```

```
[05:11:50]   ENVI-met at 22.06.2011 [07:00:00] Sun: h=18.16° a=162.10°  T0ref=293.253
q0ref=14.402
[+00:25:36]  Time executed in prognostic flow equation: 13.81 s
```

```
[+00:30:05] New flow: 1 Steps [102 SOR Steps] du:0.016 dv:0.016 dw:0.006 after 14.77
s total
Maximum divergence in flow field= 0.01186 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+00:35:03] New flow: 1 Steps [301 SOR Steps] du:0.029 dv:0.031 dw:0.018 after 15.73
s total
Maximum divergence in flow field= 0.01178 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+00:39:58] New flow: 1 Steps [301 SOR Steps] du:0.038 dv:0.042 dw:0.022 after 16.70
s total
Maximum divergence in flow field= 0.01169 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+00:44:54] New flow: 1 Steps [238 SOR Steps] du:0.044 dv:0.048 dw:0.019 after 17.67
s total
Maximum divergence in flow field= 0.01162 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_08.00.00 22.06.2011 and others
```

```
[05:32:16]   ENVI-met at 22.06.2011 [08:00:00] Sun: h=31.23° a=166.85°  T0ref=296.026
q0ref=16.989
[+00:46:02]  Time executed in prognostic flow equation: 17.67 s
```

```
[+00:50:54] New flow: 1 Steps [301 SOR Steps] du:0.056 dv:0.057 dw:0.015 after 18.64
s total
Maximum divergence in flow field= 0.01158 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+00:55:51] New flow: 1 Steps [301 SOR Steps] du:0.060 dv:0.061 dw:0.016 after 19.60
s total
Maximum divergence in flow field= 0.01158 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
Dynamical time step adjustment. Set dt=5 sec. (Class 1)
[+01:01:12] New flow: 1 Steps [301 SOR Steps] du:0.056 dv:0.055 dw:0.016 after 20.56
s total
Maximum divergence in flow field= 0.01162 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+01:07:26] New flow: 1 Steps [301 SOR Steps] du:0.050 dv:0.050 dw:0.015 after 21.51
```

```
s total
Maximum divergence in flow field= 0.01167 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_09.00.00 22.06.2011 and others
```

```
[05:54:47]   ENVI-met at 22.06.2011 [09:00:00] Sun: h=44.54° a=171.26°  T0ref=298.613
q0ref=19.724
[+01:08:32]  Time executed in prognostic flow equation: 21.51 s
```

```
[+01:14:43] New flow: 1 Steps [301 SOR Steps] du:0.044 dv:0.045 dw:0.014 after 22.46
s total
Maximum divergence in flow field= 0.01173 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+01:20:57] New flow: 1 Steps [301 SOR Steps] du:0.041 dv:0.041 dw:0.013 after 23.40
s total
Maximum divergence in flow field= 0.01181 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
Dynamical time step adjustment. Set dt=2 sec. (Class 2)
[+01:30:58] New flow: 1 Steps [301 SOR Steps] du:0.038 dv:0.037 dw:0.012 after 24.34
s total
Maximum divergence in flow field= 0.01188 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+01:41:01] New flow: 1 Steps [301 SOR Steps] du:0.035 dv:0.036 dw:0.012 after 25.27
s total
Maximum divergence in flow field= 0.01195 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_10.00.00 22.06.2011 and others
```

```
[06:28:20]   ENVI-met at 22.06.2011 [10:00:00] Sun: h=58.02° a=175.77°  T0ref=301.272
q0ref=22.924
[+01:42:06]  Time executed in prognostic flow equation: 25.27 s
```

```
[+01:52:04] New flow: 1 Steps [301 SOR Steps] du:0.032 dv:0.035 dw:0.011 after 26.20
s total
Maximum divergence in flow field= 0.01202 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+02:01:28] New flow: 1 Steps [301 SOR Steps] du:0.030 dv:0.033 dw:0.011 after 27.12
s total
Maximum divergence in flow field= 0.01211 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+02:10:35] New flow: 1 Steps [301 SOR Steps] du:0.030 dv:0.032 dw:0.010 after 28.03
s total
Maximum divergence in flow field= 0.01219 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+02:19:23] New flow: 1 Steps [301 SOR Steps] du:0.029 dv:0.031 dw:0.010 after 28.93
s total
Maximum divergence in flow field= 0.01227 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_11.00.00 22.06.2011 and others
```

```
[07:06:42]   ENVI-met at 22.06.2011 [11:00:00] Sun: h=71.57° a=181.52°  T0ref=302.980
q0ref=25.033
[+02:20:28]  Time executed in prognostic flow equation: 28.93 s
```

```
[+02:29:06] New flow: 1 Steps [301 SOR Steps] du:0.027 dv:0.030 dw:0.010 after 29.83
s total
Maximum divergence in flow field= 0.01236 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+02:37:44] New flow: 1 Steps [301 SOR Steps] du:0.027 dv:0.029 dw:0.010 after 30.72
s total
Maximum divergence in flow field= 0.01245 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+02:46:13] New flow: 1 Steps [301 SOR Steps] du:0.027 dv:0.028 dw:0.009 after 31.59
s total
Maximum divergence in flow field= 0.01254 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+02:54:44] New flow: 1 Steps [301 SOR Steps] du:0.026 dv:0.028 dw:0.009 after 32.47
s total
Maximum divergence in flow field= 0.01263 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_12.00.00 22.06.2011 and others
```

```
[07:42:03]   ENVI-met at 22.06.2011 [12:00:00] Sun: h=84.96° a=200.49°  T0ref=304.032
q0ref=26.224
[+02:55:48]  Time executed in prognostic flow equation: 32.47 s
```

```
[+03:04:16] New flow: 1 Steps [301 SOR Steps] du:0.026 dv:0.027 dw:0.009 after 33.33
s total
Maximum divergence in flow field= 0.01272 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+03:12:48] New flow: 1 Steps [301 SOR Steps] du:0.025 dv:0.027 dw:0.009 after 34.19
s total
Maximum divergence in flow field= 0.01281 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+03:21:17] New flow: 1 Steps [301 SOR Steps] du:0.025 dv:0.027 dw:0.009 after 35.04
s total
Maximum divergence in flow field= 0.01290 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+03:29:48] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.009 after 35.88
s total
Maximum divergence in flow field= 0.01300 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_13.00.00 22.06.2011 and others
```

```
[08:17:07]   ENVI-met at 22.06.2011 [13:00:00] Sun: h=80.83° a=350.41°  T0ref=304.548
q0ref=26.639
[+03:30:53]  Time executed in prognostic flow equation: 35.88 s
```

```
[+03:39:25] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.009 after 36.72
s total
Maximum divergence in flow field= 0.01309 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+03:47:59] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.009 after 37.55
s total
Maximum divergence in flow field= 0.01319 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+03:56:30] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.009 after 38.38
```

```
s total
Maximum divergence in flow field= 0.01329 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+04:05:02] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 39.20
s total
Maximum divergence in flow field= 0.01339 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_14.00.00 22.06.2011 and others
```

```
[08:52:22]   ENVI-met at 22.06.2011 [14:00:00] Sun: h=67.31° a=0.58°  T0ref=304.509
q0ref=26.348
[+04:06:07]  Time executed in prognostic flow equation: 39.20 s
```

```
[+04:14:42] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 40.01
s total
Maximum divergence in flow field= 0.01350 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+04:23:28] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 40.82
s total
Maximum divergence in flow field= 0.01360 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+04:32:20] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 41.62
s total
Maximum divergence in flow field= 0.01371 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+04:41:14] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 42.42
s total
Maximum divergence in flow field= 0.01382 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_15.00.00 22.06.2011 and others
```

```
[09:28:37]   ENVI-met at 22.06.2011 [15:00:00] Sun: h=53.77° a=5.69°  T0ref=303.874
q0ref=25.453
[+04:42:23]  Time executed in prognostic flow equation: 42.42 s
```

```
[+04:51:30] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 43.22
s total
Maximum divergence in flow field= 0.01393 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
Dynamical time step adjustment. Set dt=5 sec. (Class 1)
[+04:57:41] New flow: 1 Steps [301 SOR Steps] du:0.024 dv:0.026 dw:0.008 after 44.00
s total
Maximum divergence in flow field= 0.01404 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:03:00] New flow: 1 Steps [301 SOR Steps] du:0.023 dv:0.025 dw:0.008 after 44.79
s total
Maximum divergence in flow field= 0.01415 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:07:48] New flow: 1 Steps [301 SOR Steps] du:0.023 dv:0.025 dw:0.008 after 45.57
s total
Maximum divergence in flow field= 0.01426 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_16.00.00 22.06.2011 and others
```

```
[09:55:10]   ENVI-met at 22.06.2011 [16:00:00] Sun: h=40.34° a=10.11°  T0ref=302.624
q0ref=24.051
[+05:08:56]  Time executed in prognostic flow equation: 45.57 s

Dynamical time step adjustment. Set dt=10 sec. (Class 0)
[+05:13:39] New flow: 1 Steps [301 SOR Steps] du:0.023 dv:0.025 dw:0.008 after 46.34
s total
Maximum divergence in flow field= 0.01436 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:17:08] New flow: 1 Steps [301 SOR Steps] du:0.022 dv:0.025 dw:0.008 after 47.11
s total
Maximum divergence in flow field= 0.01447 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:21:32] New flow: 1 Steps [301 SOR Steps] du:0.022 dv:0.025 dw:0.008 after 47.88
s total
Maximum divergence in flow field= 0.01458 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:25:52] New flow: 1 Steps [301 SOR Steps] du:0.022 dv:0.024 dw:0.008 after 48.65
s total
Maximum divergence in flow field= 0.01468 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_17.00.00 22.06.2011 and others

[10:13:23]   ENVI-met at 22.06.2011 [17:00:00] Sun: h=27.09° a=14.59°  T0ref=300.887
q0ref=22.309
[+05:27:08]  Time executed in prognostic flow equation: 48.65 s

[+05:32:09] New flow: 1 Steps [301 SOR Steps] du:0.022 dv:0.024 dw:0.007 after 49.41
s total
Maximum divergence in flow field= 0.01478 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:36:32] New flow: 1 Steps [301 SOR Steps] du:0.021 dv:0.024 dw:0.007 after 50.17
s total
Maximum divergence in flow field= 0.01488 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:40:57] New flow: 1 Steps [301 SOR Steps] du:0.021 dv:0.024 dw:0.007 after 50.93
s total
Maximum divergence in flow field= 0.01497 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+05:45:14] New flow: 1 Steps [301 SOR Steps] du:0.021 dv:0.023 dw:0.007 after 51.68
s total
Maximum divergence in flow field= 0.01507 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_18.00.00 22.06.2011 and others

[10:32:38]   ENVI-met at 22.06.2011 [18:00:00] Sun: h=14.12° a=19.52°  T0ref=298.785
q0ref=20.229
[+05:46:24]  Time executed in prognostic flow equation: 51.68 s

[+05:50:53] New flow: 1 Steps [301 SOR Steps] du:0.021 dv:0.023 dw:0.007 after 52.43
s total
Maximum divergence in flow field= 0.01516 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
```

```
[+05:55:23] New flow: 1 Steps [301 SOR Steps] du:0.021 dv:0.023 dw:0.007 after 53.19 s total
Maximum divergence in flow field= 0.01524 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+05:59:02] New flow: 1 Steps [301 SOR Steps] du:0.021 dv:0.023 dw:0.006 after 53.94 s total
Maximum divergence in flow field= 0.01532 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:01:49] New flow: 1 Steps [301 SOR Steps] du:0.020 dv:0.023 dw:0.006 after 54.68 s total
Maximum divergence in flow field= 0.01539 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Output file MySim_AT_19.00.00 22.06.2011 and others

[10:49:15]   ENVI-met at 22.06.2011 [19:00:00] Sun: h=1.58° a=25.23°  T0ref=297.345 q0ref=18.736
[+06:03:00]  Time executed in prognostic flow equation: 54.68 s

[+06:05:14] New flow: 1 Steps [301 SOR Steps] du:0.020 dv:0.023 dw:0.006 after 55.43 s total
Maximum divergence in flow field= 0.01546 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:07:38] New flow: 1 Steps [301 SOR Steps] du:0.020 dv:0.023 dw:0.006 after 56.18 s total
Maximum divergence in flow field= 0.01552 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:09:58] New flow: 1 Steps [301 SOR Steps] du:0.020 dv:0.022 dw:0.006 after 56.93 s total
Maximum divergence in flow field= 0.01558 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:12:18] New flow: 1 Steps [301 SOR Steps] du:0.020 dv:0.022 dw:0.005 after 57.67 s total
Maximum divergence in flow field= 0.01563 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Output file MySim_AT_20.00.00 22.06.2011 and others

[10:59:42]   ENVI-met at 22.06.2011 [20:00:00] Sun: h=-10.33° a=32.16°  T0ref=297.104 q0ref=18.419
[+06:13:28]  Time executed in prognostic flow equation: 57.67 s

[+06:15:41] New flow: 1 Steps [301 SOR Steps] du:0.019 dv:0.022 dw:0.005 after 58.42 s total
Maximum divergence in flow field= 0.01568 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:17:55] New flow: 1 Steps [301 SOR Steps] du:0.019 dv:0.021 dw:0.005 after 59.16 s total
Maximum divergence in flow field= 0.01573 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:20:10] New flow: 1 Steps [301 SOR Steps] du:0.019 dv:0.021 dw:0.005 after 59.90 s total
Maximum divergence in flow field= 0.01578 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+06:22:25] New flow: 1 Steps [301 SOR Steps] du:0.018 dv:0.020 dw:0.004 after 60.64 s total
```

```
Maximum divergence in flow field= 0.01582 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Output file MySim_AT_21.00.00 22.06.2011 and others
```

```
[11:09:48]   ENVI-met at 22.06.2011 [21:00:00] Sun: h=-21.25° a=40.88°  T0ref=296.934 q0ref=18.193
[+06:23:33]  Time executed in prognostic flow equation: 60.64 s
```

```
[+06:45:48] New flow: 1 Steps [301 SOR Steps] du:0.018 dv:0.020 dw:0.004 after 61.38 s total
Maximum divergence in flow field= 0.01587 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+07:23:31] New flow: 1 Steps [301 SOR Steps] du:0.018 dv:0.019 dw:0.004 after 62.12 s total
Maximum divergence in flow field= 0.01591 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+07:25:43] New flow: 1 Steps [301 SOR Steps] du:0.017 dv:0.019 dw:0.004 after 62.85 s total
Maximum divergence in flow field= 0.01595 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+07:27:53] New flow: 1 Steps [301 SOR Steps] du:0.017 dv:0.019 dw:0.004 after 63.58 s total
Maximum divergence in flow field= 0.01599 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Output file MySim_AT_22.00.00 22.06.2011 and others
```

```
[12:15:16]   ENVI-met at 22.06.2011 [22:00:00] Sun: h=-30.61° a=52.11°  T0ref=296.794 q0ref=18.011
[+07:29:01]  Time executed in prognostic flow equation: 63.58 s
```

```
[+07:31:07] New flow: 1 Steps [301 SOR Steps] du:0.016 dv:0.018 dw:0.003 after 64.31 s total
Maximum divergence in flow field= 0.01602 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+07:33:15] New flow: 1 Steps [301 SOR Steps] du:0.016 dv:0.017 dw:0.003 after 65.04 s total
Maximum divergence in flow field= 0.01606 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+07:35:23] New flow: 1 Steps [301 SOR Steps] du:0.016 dv:0.017 dw:0.003 after 65.76 s total
Maximum divergence in flow field= 0.01609 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+07:37:32] New flow: 1 Steps [301 SOR Steps] du:0.015 dv:0.016 dw:0.003 after 66.49 s total
Maximum divergence in flow field= 0.01612 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Outputfile MySim_AT_23.00.00 22.06.2011 and others
```

```
[12:24:55]   ENVI-met at 22.06.2011 [23:00:00] Sun: h=-37.58° a=66.47°  T0ref=296.675 q0ref=17.857
[+07:38:40]  Time executed in prognostic flow equation: 66.49 s
```

```
[+07:40:43] New flow: 1 Steps [301 SOR Steps] du:0.015 dv:0.016 dw:0.003 after 67.21
```

```
s total
Maximum divergence in flow field= 0.01614 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+07:42:50] New flow: 1 Steps [301 SOR Steps] du:0.014 dv:0.015 dw:0.003 after 67.93
s total
Maximum divergence in flow field= 0.01617 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+07:44:55] New flow: 1 Steps [301 SOR Steps] du:0.014 dv:0.015 dw:0.003 after 68.65
s total
Maximum divergence in flow field= 0.01619 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+07:47:00] New flow: 1 Steps [301 SOR Steps] du:0.014 dv:0.014 dw:0.003 after 69.37
s total
Maximum divergence in flow field= 0.01621 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_00.00.00 23.06.2011 and others

[12:34:23]   ENVI-met at 23.06.2011 [00:00:00] Sun: h=-41.10° a=96.30°  T0ref=296.571
q0ref=17.724
[+07:48:09]  Time executed in prognostic flow equation: 69.37 s

[+07:50:10] New flow: 1 Steps [301 SOR Steps] du:0.013 dv:0.014 dw:0.003 after 70.09
s total
Maximum divergence in flow field= 0.01623 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+07:52:15] New flow: 1 Steps [301 SOR Steps] du:0.013 dv:0.013 dw:0.003 after 70.81
s total
Maximum divergence in flow field= 0.01624 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+07:54:19] New flow: 1 Steps [301 SOR Steps] du:0.013 dv:0.013 dw:0.003 after 71.53
s total
Maximum divergence in flow field= 0.01626 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+07:56:22] New flow: 1 Steps [301 SOR Steps] du:0.012 dv:0.012 dw:0.003 after 72.24
s total
Maximum divergence in flow field= 0.01627 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_01.00.00 23.06.2011 and others

[12:43:45]   ENVI-met at 23.06.2011 [01:00:00] Sun: h=-40.43° a=101.88°
T0ref=296.473  q0ref=17.615
[+07:57:30]  Time executed in prognostic flow equation: 72.24 s

[+07:59:29] New flow: 1 Steps [301 SOR Steps] du:0.012 dv:0.012 dw:0.003 after 72.96
s total
Maximum divergence in flow field= 0.01628 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:01:31] New flow: 1 Steps [301 SOR Steps] du:0.012 dv:0.012 dw:0.003 after 73.67
s total
Maximum divergence in flow field= 0.01629 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:03:33] New flow: 1 Steps [301 SOR Steps] du:0.011 dv:0.011 dw:0.003 after 74.39
s total
Maximum divergence in flow field= 0.01629 @ 53,15,6 (absolute)/53,15,6 (without
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nesting grids)
[+08:05:36] New flow: 1 Steps [301 SOR Steps] du:0.011 dv:0.011 dw:0.003 after 75.10
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_02.00.00 23.06.2011 and others

[12:52:59]   ENVI-met at 23.06.2011 [02:00:00] Sun: h=-35.73° a=118.34°
T0ref=296.383  q0ref=17.518
[+08:06:44]  Time executed in prognostic flow equation: 75.10 s

[+08:08:41] New flow: 1 Steps [301 SOR Steps] du:0.011 dv:0.010 dw:0.003 after 75.82
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:10:42] New flow: 1 Steps [301 SOR Steps] du:0.010 dv:0.010 dw:0.003 after 76.53
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:12:42] New flow: 1 Steps [301 SOR Steps] du:0.010 dv:0.009 dw:0.003 after 77.25
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:14:42] New flow: 1 Steps [301 SOR Steps] du:0.010 dv:0.009 dw:0.003 after 77.96
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_03.00.00 23.06.2011 and others

[13:02:04]   ENVI-met at 23.06.2011 [03:00:00] Sun: h=-27.91° a=131.70°
T0ref=296.303  q0ref=17.433
[+08:15:49]  Time executed in prognostic flow equation: 77.96 s

[+08:17:45] New flow: 1 Steps [301 SOR Steps] du:0.009 dv:0.009 dw:0.003 after 78.67
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:19:44] New flow: 1 Steps [301 SOR Steps] du:0.009 dv:0.008 dw:0.003 after 79.39
s total
Maximum divergence in flow field= 0.01630 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:21:43] New flow: 1 Steps [301 SOR Steps] du:0.009 dv:0.008 dw:0.002 after 80.10
s total
Maximum divergence in flow field= 0.01629 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
[+08:23:33] New flow: 1 Steps [1 SOR Steps] du:0.009 dv:0.008 dw:0.002 after 80.81 s
total
Maximum divergence in flow field= 0.01629 @ 53,15,6 (absolute)/53,15,6 (without
nesting grids)
$$ Writing Output file MySim_AT_04.00.00 23.06.2011 and others

[13:10:56]   ENVI-met at 23.06.2011 [04:00:00] Sun: h=-17.99° a=142.07°
T0ref=296.231  q0ref=17.357
```

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[+08:24:41]  Time executed in prognostic flow equation: 80.81 s
```

```
[+08:26:27] New flow: 1 Steps [1 SOR Steps] du:0.008 dv:0.007 dw:0.002 after 81.53 s total
Maximum divergence in flow field= 0.01629 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+08:28:16] New flow: 1 Steps [1 SOR Steps] du:0.008 dv:0.007 dw:0.002 after 82.24 s total
Maximum divergence in flow field= 0.01628 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+08:30:05] New flow: 1 Steps [1 SOR Steps] du:0.008 dv:0.006 dw:0.002 after 82.96 s total
Maximum divergence in flow field= 0.01628 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+08:31:56] New flow: 1 Steps [1 SOR Steps] du:0.007 dv:0.006 dw:0.002 after 83.67 s total
Maximum divergence in flow field= 0.01627 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Output file MySim_AT_05.00.00 23.06.2011 and others
```

```
[13:19:19]   ENVI-met at 23.06.2011 [05:00:00] Sun: h=-6.72° a=150.16°  T0ref=296.167 q0ref=17.290
[+08:33:04]  Time executed in prognostic flow equation: 83.67 s
```

```
[+08:34:48] New flow: 1 Steps [1 SOR Steps] du:0.007 dv:0.006 dw:0.002 after 84.38 s total
Maximum divergence in flow field= 0.01627 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+08:36:37] New flow: 1 Steps [1 SOR Steps] du:0.007 dv:0.006 dw:0.002 after 85.10 s total
Maximum divergence in flow field= 0.01626 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+08:38:27] New flow: 1 Steps [1 SOR Steps] du:0.007 dv:0.006 dw:0.002 after 85.81 s total
Maximum divergence in flow field= 0.01625 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
[+08:40:19] New flow: 1 Steps [1 SOR Steps] du:0.007 dv:0.006 dw:0.002 after 86.53 s total
Maximum divergence in flow field= 0.01624 @ 53,15,6 (absolute)/53,15,6 (without nesting grids)
$$ Writing Output file MySim_AT_06.00.00 23.06.2011 and others
```

```
[13:27:44]   ENVI-met at 23.06.2011 [06:00:00] Sun: h=5.42° a=156.66°  T0ref=296.109 q0ref=17.229
[+08:41:29]  Time executed in prognostic flow equation: 86.53 s
```

```
$$ Writing Output file MySim_AT_06.00.00 23.06.2011 and others
[13:28:49] *
$$ I am finished !!
```

Appendix E – ENVI-met Outputs - Green Roof on June 21st 2011

```
ENVI-met V3.1 BETA 4 © 1997-2010 by Michael Bruse and Team  Build 3.0.99.5
A Microscale Urban Climate Model
This version: 100 x 100 x 35 Grids maximum
www.envi-met.com

Computer name for ENVI-met cluster: ENVI node_HP-PAVILLION

Checking folder structure...
$$  Reading Soils sys.basedata\SOILS.DAT...
$$ ********************** Soils-Database ********************
        "00" :Default Soil (Loam) Type:natural soil
        "SD" :Sand Type:natural soil
        "LS" :Loamy Sand Type:natural soil
        "SL" :Sandy Loam Type:natural soil
        "SL" :Silt Loam Type:natural soil
        "LE" :Loam Type:natural soil
        "TS" :Sandy Clay Loam Type:natural soil
        "TL" :Silty Clay Loam Type:natural soil
        "LT" :Clay Loam Type:natural soil
        "ST" :Sandy Clay Type:natural soil
        "TS" :Silty Clay Type:natural soil
        "TO" :Clay Type:natural soil
        "TF" :Peat Type:natural soil
        "ZB" :Cement Concrete Type:artificial soil
        "MB" :Mineral Concrete Type:artificial soil
        "AK" :Asphalt (with Gravel Type:artificial soil
        "AB" :Asphalt (with Basalt Type:artificial soil
        "GR" :Granite Type:artificial soil
        "BA" :Basalt Type:artificial soil
        "WW" :Water Type:water body
        "ZZ" :Brick Type:artificial soil
$$ ******************** Total: 21 Soils out of 50 **********************

$$  Reading global Source Database SOURCES.DAT...
        "XX" :Test_Pointsource 10m,10µg/s Type=Line (µg)
        "SS" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
        "YY" :Test_Pointsource 10m,10mg/s Type=Line (mg)
        "R1" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
        "SP" :Test_Spray 2m cm 10mg/s Type=Area (µg)
$$ ********************   Total:  5 Sources(s) out of 150 ******************

Source Modell Settings : --------------------------------
Identified Source Type: PM  (Particulate Matter)
Given Name: PM10
Type of source: Particle
     Particle Diameter (µm)       :10.00
     Particle Density (g/cm³)     :1.00
     Settling Velocity (cm/h)     :1107.50
     Diffusion Coefficient (cm²/s):0.0000
     Schmitt-Number               :4054944.25
     Transfer resistance soils    :0.00
     Mesophyll transfer resistance:0.00
```

```
$$  Reading Global Plant Database sys.basedata\plants.dat...
$$ ********************** Plant-Database V3 ********************
         "XX" : (C3) Grass 50 cm aver. dense
         "SO" : (C3) soja 90. soja 63cm
         "LG" : (C3) luzerne 18cm
         "MO" : (C3) Tree 20m aver. dense., no distinct crown layer
         "DO" : (C3) Tree 20 m dense., no distinct crown layer
         "DM" : (C3) Tree 20 m dense., distinct crown layer
      --->"DM" : ** ID already loaded. Plant skipped **
         "DS" : (C3) Tree 10 m dense.,distinct crown layer
         "SM" : (C3) Tree 20 m very dense, distinct crown layer
         "SK" : (C3) Tree 15 m very dense, distinct crown layer
         "H2" : (C3) Hedge dense, 2m
         "T1" : (C3) Tree 10 m very dense, leafless base
         " G" : (C3) Grass 50 cm aver. dense
         "BS" : (C3) Tree 20 m dense.,distinct crown layer
         "SC" : (C3) Tree 20 m very dense, free stem crown layer
         " W" : (C3) Forst 20 m dense., no distinct crown layer
         "L1" : (C3) Tree, light 15 m
         "L2" : (C3) Tree, light 20 m
         " H" : (C3) Hedge dense, 2m
         " M" : (C4) Maize, 1.5 m
         " C" : (C3) Corn, 1.5 m
         "GB" : (C3) Grass 50 cm aver. dense
         "GZ" : (C3) Grass 50 cm aver. dense
         "T2" : (C3) Tree 15 m very dense, leafless base
         "TB" : (C3) Tree 15 m very dense
         "EE" : (C3) Tree 20m aver. dense., no distinct crown layer
         "TH" : (C3) Tree 15m dense, distinct crown layer, Christer
$$ ******************** Total : 26 Plant(s)  out of 150 ******************

$$  Setting up model grid...
$$  Loading Area Input file...
  >> This input file has no overhanging shelters !
  >> This file has detailed soil information for each grid

$$ Grid Information:
$$    dxy(Main)=5.00 m  Nesting:0 grids. dxy(Nest) m
$$    dz=5.00 (non-equidistant with telecoping factor= 20%)
$$ Top of 3D Model is at 853.57 m height
$$ Highest object in model area is 20.00 m high

$$ DEM Terrain Model Information:     No DEM used.

$$ PROFILS.DAT format is V3, cool! We are up to date.
$$ Getting soil profile definitions from C:\ENVImet31\sys.basedata\PROFILS.DAT ...
       " 0" :Default Useald Soil (** do not change **
       " S" :Asphalt Road
       " P" :Pavement (Concrete)
       " L" :Loamy Soil
       "SD" :Sandy Soil
       " W" :Deep Water
       "KK" :Brick road (red stones)
       "KG" :Brick road (yellow stones)
       "GG" :Dark Granit Pavement
       "GS" :Granit Pavement (single stones)
       "G2" :Granit shining
$$ ******************* Total: 11 Profiles out of 150 *********************
$$ Linking SOILS.DAT <-> PROFILS.DAT <-> "C:\ENVImetprojects\Models\Dubai
```

```
Marina70.in"
$$ All links in between PROFIL.DAT and SOILS.DAT are valid. :-)
** Checking profils used but not defined in PROFILES.DAT...
$$ All profiles used in "C:\ENVImetprojects\Models\Dubai Marina70.in"  are ok.
$$ Setting Datalinks, z0- length, Emissivity and Albedo...
$$ Average z0 over nesting area:0.015
```

```
$$  Gridding Plants and other Shelters...
$$ Checking Grid Structure...
$$ Selected Stomata Resistance Model: A-Gs Approach (Jacobs)(=2)
$$ CO2 Background concentration: 350.00 ppm
$$ CO2 subsystem enabled
$$ Additional CO2 sources present: No
```

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$$ This is how the present constellation looks like :
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__________________________________________________________________________________
 "#" Building, "=" Overhanging Building, "~" Plant "*" Plant on Roof "R" Receptor
Calculating max radiation at noon...
Calculating SOR coefficients...
$$  Asymptotic relaxation parameter was calculated to 1.9488
$$  Geostrophic wind is u=-6.53 v=-6.53
__________________________________________________________________________________
                                        __________
$$  Modell Initialisation (Initial Guess on 1D BL)
__________________________________________________________________________________
                                        __________
[+00:03:11] $$ Starting ENVI-met Initialisation on 11/06/2011@13:33:22
$$ ENVI-met mode: Normal turbulence
__________________________________________________________________________________
                                        __________
$$ 3D Initialisation: Flow Diastrophy
   100% [301 st] remaining div: 0.00000 (Stopped)
    50% [301 st] remaining div: 0.00004 (Stopped)
     0% [301 st] remaining div: 0.00001 (Stopped)
$$ 3D Initialisation: Complete Model
 Turbulence Adjustment:529 Steps, dt=0.290 (max. 0.8 s) Relax: 1.00
Initial Flow Adjustment. Total time to calculate: 10.000 sec
                   Maximum allowed change: 0.0924 m/s
[+00:12:09] $$ Setting up wind field completed
 Turbulence Adjustment:401 Steps, dt=0.290 (max. 0.8 s) Relax: 1.00
[13:45:15] $$ Time needed for Initialisation: 00:15:04
__________________________________________________________________________________
                                        __________
$$ ***********************************************************
$$ ******** ENVI-met (c) Michael Bruse 1997-2006 ************
$$ *********    A microscale climatology model    ************
$$ ***********************************************************
$$    Start: 21.06.2011 13:00:00 End: 21.06.2011 14:00:00 = 3600.0 sec
$$    Dynamical time steps enabled:
$$    Sun height <40.00Â° : dt=10.00 s
$$         40.00-50.00Â° : dt=5.00 s
$$              >50.00Â° : dt=2.00 s
__________________________________________________________________________________
                                        __________
```

```
$$ Passive Particle/Gas Concentration:
      Not used
```

```
$$ Other moduls:
$$ Moduls for Biometeorology:
$$     PMV-Value: ok
```

```
$$ Turbulence Closure 3D Main model: Prognostic. Fine.
```

```
$$ Starting ENVI-met Main module on 11/06/2011@13:45:15
$$ Writing Output file MySim_AT_13.00.00 21.06.2011 and others
 Model start up phase. Main time step is set to class 2 (dt=2 sec)
[+00:22:38] New flow: 2 Steps [301 SOR Steps] du:0.088 dv:0.089 dw:0.045 after 10.93
s total
Maximum divergence in flow field= 0.28508 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
[+00:43:33] New flow: 1 Steps [301 SOR Steps] du:0.079 dv:0.073 dw:0.068 after 11.39
s total
Maximum divergence in flow field= 0.27788 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
[+01:04:16] New flow: 1 Steps [301 SOR Steps] du:0.077 dv:0.084 dw:0.064 after 11.86
s total
Maximum divergence in flow field= 0.27546 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
[+01:25:03] New flow: 1 Steps [301 SOR Steps] du:0.070 dv:0.076 dw:0.050 after 12.33
s total
Maximum divergence in flow field= 0.27488 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
$$ Writing Output file MySim_AT_14.00.00 21.06.2011 and others
```

```
[15:11:57]   ENVI-met at 21.06.2011 [14:00:00] Sun: h=67.26° a=0.61°  T0ref=301.942
q0ref=23.111
[+01:26:41]  Time executed in prognostic flow equation: 12.33 s
```

```
$$ Writing Output file MySim_AT_14.00.00 21.06.2011 and others
[15:13:31] *
$$ I am finished !!
```

Appendix F – ENVI-met Outputs – Conventional Roof on December 21st 2011

ENVI-met V3.1 BETA 4 © 1997-2010 by Michael Bruse and Team
Build 3.0.99.5
A Microscale Urban Climate Model
This version: 100 x 100 x 35 Grids maximum
www.envi-met.com

```
Computer name for ENVI-met cluster: ENVInode_HP-PAVILLION
```

```
Checking folder structure...
$$  Reading Soils sys.basedata\SOILS.DAT...
$$ ********************* Soils-Database *******************
          "00" :Default Soil (Loam) Type:natural soil
          "SD" :Sand Type:natural soil
          "LS" :Loamy Sand Type:natural soil
          "SL" :Sandy Loam Type:natural soil
          "SL" :Silt Loam Type:natural soil
          "LE" :Loam Type:natural soil
          "TS" :Sandy Clay Loam Type:natural soil
          "TL" :Silty Clay Loam Type:natural soil
          "LT" :Clay Loam Type:natural soil
          "ST" :Sandy Clay Type:natural soil
          "TS" :Silty Clay Type:natural soil
          "TO" :Clay Type:natural soil
          "TF" :Peat Type:natural soil
          "ZB" :Cement Concrete Type:artificial soil
          "MB" :Mineral Concrete Type:artificial soil
          "AK" :Asphalt (with Gravel Type:artificial soil
          "AB" :Asphalt (with Basalt Type:artificial soil
          "GR" :Granite Type:artificial soil
          "BA" :Basalt Type:artificial soil
          "WW" :Water Type:water body
          "ZZ" :Brick Type:artificial soil
$$ ******************* Total: 21 Soils out of 50 *********************
```

```
$$  Reading global Source Database SOURCES.DAT...
          "XX" :Test_Pointsource 10m,10µg/s Type=Line (µg)
          "SS" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
          "YY" :Test_Pointsource 10m,10mg/s Type=Line (mg)
          "R1" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
          "SP" :Test_Spray 2m cm 10mg/s Type=Area (µg)
$$ *******************   Total:  5 Sources(s) out of 150 *****************
```

```
Source Modell Settings : --------------------------------
Identified Source Type: PM  (Particulate Matter)
Given Name: PM10
Type of source: Particle
    Particle Diameter (µm)       :10.00
    Particle Density (g/cm³)     :1.00
    Settling Velocity (cm/h)     :1107.50
    Diffusion Coefficient (cm²/s):0.0000
    Schmitt-Number               :4054944.25
    Transfer resistance soils    :0.00
    Mesophyll transfer resistance:0.00
```

```
$$  Reading Global Plant Database sys.basedata\plants.dat...
$$ ********************** Plant-Database V3 ********************
          "XX" : (C3) Grass 50 cm aver. dense
          "SO" : (C3) soja 90. soja 63cm
          "LG" : (C3) luzerne 18cm
          "MO" : (C3) Tree 20m aver. dense., no distinct crown layer
          "DO" : (C3) Tree 20 m dense., no distinct crown layer
          "DM" : (C3) Tree 20 m dense., distinct crown layer
      --->"DM" : ** ID already loaded. Plant skipped **
          "DS" : (C3) Tree 10 m dense.,distinct crown layer
          "SM" : (C3) Tree 20 m very dense, distinct crown layer
          "SK" : (C3) Tree 15 m very dense, distinct crown layer
          "H2" : (C3) Hedge dense, 2m
          "T1" : (C3) Tree 10 m very dense, leafless base
          " G" : (C3) Grass 50 cm aver. dense
          "BS" : (C3) Tree 20 m dense.,distinct crown layer
          "SC" : (C3) Tree 20 m very dense, free stem crown layer
          " W" : (C3) Forst 20 m dense., no distinct crown layer
          "L1" : (C3) Tree, light 15 m
          "L2" : (C3) Tree, light 20 m
          " H" : (C3) Hedge dense, 2m
          " M" : (C4) Maize, 1.5 m
          " C" : (C3) Corn, 1.5 m
          "GB" : (C3) Grass 50 cm aver. dense
          "GZ" : (C3) Grass 50 cm aver. dense
          "T2" : (C3) Tree 15 m very dense, leafless base
          "TB" : (C3) Tree 15 m very dense
          "EE" : (C3) Tree 20m aver. dense., no distinct crown layer
          "TH" : (C3) Tree 15m dense, distinct crown layer, Christer
$$ ******************** Total : 26 Plant(s)  out of 150 ******************
```

```
$$  Setting up model grid...
$$  Loading Area Input file...
  >> This input file has no overhanging shelters !
  >> This file has detailed soil information for each grid
```

```
$$ Grid Information:
$$    dxy(Main)=5.00 m  Nesting:0 grids. dxy(Nest) m
$$    dz=5.00 (non-equidistant with telecoping factor= 20%)
$$ Top of 3D Model is at 853.57 m height
$$ Highest object in model area is 40.00 m high
```

```
$$ DEM Terrain Model Information:     No DEM used.
```

```
$$ PROFILS.DAT format is V3, cool! We are up to date.
$$ Getting soil profil definitions from C:\ENVImet31\sys.basedata\PROFILS.DAT ...
       " 0" :Default Useald Soil (** do not change **
       " S" :Asphalt Road
       " P" :Pavement (Concrete)
       " L" :Loamy Soil
       "SD" :Sandy Soil
       " W" :Deep Water
       "KK" :Brick road (red stones)
       "KG" :Brick road (yellow stones)
       "GG" :Dark Granit Pavement
       "GS" :Granit Pavement (single stones)
       "G2" :Granit shining
$$ ******************* Total: 11 Profils out of 150 *********************
```

```
$$ Linking SOILS.DAT <-> PROFILS.DAT <-> "C:\ENVImetprojects\Models\Dubai Marina50.in"
$$ All links inbetween PROFIL.DAT and SOILS.DAT are valid. :-)
** Checking profils used but not defined in PROFILES.DAT...
$$ All profils used in "C:\ENVImetprojects\Models\Dubai Marina50.in"  are ok.
$$ Setting Datalinks, z0- length, Emissivity and Albedo...
$$ Average z0 over nesting area:0.015
```

```
$$  Gridding Plants and other Shelters...
$$ Checking Grid Structure...
$$ Selected Stomata Resistance Model: A-Gs Approach (Jacobs)(=2)
$$ CO2 Background concentration: 350.00 ppm
$$ CO2 subsystem enabled
$$ Additional CO2 sources present: No
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```
$$ This is how the present constellation looks like :
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 "#" Building, "=" Overhanging Building, "~" Plant "*" Plant on Roof "R" Receptor
Calculating max radiation at noon...
Calculating SOR coefficients...
$$  Asymptotic relaxation parameter was calculated to 1.9421
$$  Geostrophic wind is u=-18.66 v=-18.66
________________________________________________________________________

$$  Modell Initialisation (Initial Guess on 1D BL)
________________________________________________________________________

$$ ENVI-met mode: Normal turbulence
________________________________________________________________________

$$ 3D Initialisation: Flow Diastrophy
    100% [133 st] remaining div: 0.00000 (OK)
     50% [301 st] remaining div: 0.00022 (Stopped)
      0% [301 st] remaining div: 0.00010 (Stopped)
$$ 3D Initialisation: Complete Model
 Turbulence Adjustment:996 Steps, dt=0.090 (max. 0.8 s) Relax: 1.00
Initial Flow Adjustment. Total time to calculate: 10.000 sec
                         Maximum allowed change: 0.2639 m/s
[+00:16:07] $$ Setting up wind field completed
 Turbulence Adjustment:866 Steps, dt=0.102 (max. 0.8 s) Relax: 1.00
[02:54:00] $$ Time needed for Initialisation: 00:20:31
________________________________________________________________________

$$ ********************************************************
$$ ******** ENVI-met (c) Michael Bruse 1997-2006 ************
$$ *********    A microscale climatology model   ************
$$ ********************************************************
$$    Start: 21.12.2011 13:00:00 End: 21.12.2011 14:00:00 = 3600.0 sec
$$    Dynamical time steps enabled:
$$    Sun height <40.00Â° : dt=10.00 s
$$         40.00-50.00Â° : dt=5.00 s
$$              >50.00Â° : dt=2.00 s
________________________________________________________________________

$$ Passive Particle/Gas Concentration:
      Not used
________________________________________________________________________

$$ Other moduls:
$$ Moduls for Biometeorology:
$$     PMV-Value: ok
________________________________________________________________________

$$ Turbulence Closure 3D Main model: Prognostic. Fine.
________________________________________________________________________

$$ Writing Output file MySim_AT_13.00.00 21.12.2011 and others
 Model start up phase. Main time step is set to class 2 (dt=2 sec)
[+00:33:22] New flow: 1 Steps [301 SOR Steps] du:0.094 dv:0.118 dw:0.063 after 10.16
s total
```

```
Maximum divergence in flow field= 0.99828 @ 51,57,4 (absolute)/51,57,4 (without
nesting grids)
[+01:05:26] New flow: 1 Steps [301 SOR Steps] du:0.104 dv:0.124 dw:0.066 after 10.32
s total
Maximum divergence in flow field= 0.99599 @ 51,57,4 (absolute)/51,57,4 (without
nesting grids)
Dynamical time step adjustment. Set dt=10 sec. (Class 0)
[+01:18:55] New flow: 1 Steps [301 SOR Steps] du:0.098 dv:0.126 dw:0.076 after 10.49
s total
Maximum divergence in flow field= 0.99746 @ 51,57,4 (absolute)/51,57,4 (without
nesting grids)
[+01:29:26] New flow: 1 Steps [301 SOR Steps] du:0.085 dv:0.112 dw:0.066 after 10.65
s total
Maximum divergence in flow field= 0.99957 @ 51,57,4 (absolute)/51,57,4 (without
nesting grids)
$$ Writing Output file MySim_AT_14.00.00 21.12.2011 and others
```

```
[04:25:20]   ENVI-met at 21.12.2011 [14:00:00] Sun: h=35.30° a=299.32°  T0ref=296.519
q0ref=17.507
[+01:31:19]  Time executed in prognostic flow equation: 10.65 s
```

```
$$ Writing Output file MySim_AT_14.00.00 21.12.2011 and others
[04:26:40] *
$$ I am finished !!
```

Appendix G – ENVI-met Outputs – Green Roof on December 21st 2011

ENVI-met V3.1 BETA 4 © 1997-2010 by Michael Bruse and Team Build 3.0.99.5
A Microscale Urban Climate Model
This version: 100 x 100 x 35 Grids maximum
www.envi-met.com

```
Computer name for ENVI-met cluster: ENVInode_HP-PAVILLION
```

```
Checking folder structure...
$$  Reading Soils sys.basedata\SOILS.DAT...
$$ ********************** Soils-Database ********************
          "00" :Default Soil (Loam) Type:natural soil
          "SD" :Sand Type:natural soil
          "LS" :Loamy Sand Type:natural soil
          "SL" :Sandy Loam Type:natural soil
          "SL" :Silt Loam Type:natural soil
          "LE" :Loam Type:natural soil
          "TS" :Sandy Clay Loam Type:natural soil
          "TL" :Silty Clay Loam Type:natural soil
          "LT" :Clay Loam Type:natural soil
          "ST" :Sandy Clay Type:natural soil
          "TS" :Silty Clay Type:natural soil
          "TO" :Clay Type:natural soil
          "TF" :Peat Type:natural soil
          "ZB" :Cement Concrete Type:artificial soil
          "MB" :Mineral Concrete Type:artificial soil
          "AK" :Asphalt (with Gravel Type:artificial soil
          "AB" :Asphalt (with Basalt Type:artificial soil
          "GR" :Granite Type:artificial soil
          "BA" :Basalt Type:artificial soil
          "WW" :Water Type:water body
          "ZZ" :Brick Type:artificial soil
$$ ******************** Total: 21 Soils out of 50 **********************
```

```
$$  Reading global Source Database SOURCES.DAT...
          "XX" :Test_Pointsource 10m,10µg/s Type=Line (µg)
          "SS" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
          "YY" :Test_Pointsource 10m,10mg/s Type=Line (mg)
          "R1" :Test_Linesource 30 cm 10µg/s Type=Line (µg)
          "SP" :Test_Spray 2m cm 10mg/s Type=Area (µg)
$$ ********************   Total:  5 Sources(s) out of 150 *****************
```

```
Source Modell Settings : --------------------------------
Identified Source Type: PM  (Particulate Matter)
Given Name: PM10
Type of source: Particle
```

```
   Particle Diameter (µm)       :10.00
   Particle Density (g/cm³)     :1.00
   Settling Velocity (cm/h)     :1107.50
   Diffusion Coefficient (cm²/s):0.0000
   Schmitt-Number               :4054944.25
   Transfer resistance soils    :0.00
   Mesophyll transfer resistance:0.00
```

```
$$  Reading Global Plant Database sys.basedata\plants.dat...
$$ ********************** Plant-Database V3 ********************
          "XX" : (C3) Grass 50 cm aver. dense
          "SO" : (C3) soja 90. soja 63cm
          "LG" : (C3) luzerne 18cm
          "MO" : (C3) Tree 20m aver. dense., no distinct crown layer
          "DO" : (C3) Tree 20 m dense., no distinct crown layer
          "DM" : (C3) Tree 20 m dense., distinct crown layer
       --->"DM" : ** ID already loaded. Plant skipped **
          "DS" : (C3) Tree 10 m dense.,distinct crown layer
          "SM" : (C3) Tree 20 m very dense, distinct crown layer
          "SK" : (C3) Tree 15 m very dense, distinct crown layer
          "H2" : (C3) Hedge dense, 2m
          "T1" : (C3) Tree 10 m very dense, leafless base
          " G" : (C3) Grass 50 cm aver. dense
          "BS" : (C3) Tree 20 m dense.,distinct crown layer
          "SC" : (C3) Tree 20 m very dense, free stem crown layer
          " W" : (C3) Forst 20 m dense., no distinct crown layer
          "L1" : (C3) Tree, light 15 m
          "L2" : (C3) Tree, light 20 m
          " H" : (C3) Hedge dense, 2m
          " M" : (C4) Maize, 1.5 m
          " C" : (C3) Corn, 1.5 m
          "GB" : (C3) Grass 50 cm aver. dense
          "GZ" : (C3) Grass 50 cm aver. dense
          "T2" : (C3) Tree 15 m very dense, leafless base
          "TB" : (C3) Tree 15 m very dense
          "EE" : (C3) Tree 20m aver. dense., no distinct crown layer
          "TH" : (C3) Tree 15m dense, distinct crown layer, Christer
$$ ******************** Total : 26 Plant(s)  out of 150 ******************
```

```
$$  Setting up model grid...
$$  Loading Area Input file...
  >> This input file has no overhanging shelters !
  >> This file has detailed soil information for each grid
```

```
$$ Grid Information:
$$    dxy(Main)=5.00 m  Nesting:0 grids. dxy(Nest) m
$$    dz=5.00 (non-equidistant with telecoping factor= 20%)
$$ Top of 3D Model is at 853.57 m height
$$ Highest object in model area is 20.00 m high
```

```
$$ DEM Terrain Model Information:     No DEM used.

$$ PROFILS.DAT format is V3, cool! We are up to date.
$$ Getting soil profil definitions from C:\ENVImet31\sys.basedata\PROFILS.DAT ...
        " 0" :Default Useald Soil (** do not change **
        " S" :Asphalt Road
        " P" :Pavement (Concrete)
        " L" :Loamy Soil
        "SD" :Sandy Soil
        " W" :Deep Water
        "KK" :Brick road (red stones)
        "KG" :Brick road (yellow stones)
        "GG" :Dark Granit Pavement
        "GS" :Granit Pavement (single stones)
        "G2" :Granit shining
$$ ******************** Total: 11 Profils out of 150 *********************
$$ Linking SOILS.DAT <-> PROFILS.DAT <-> "C:\ENVImetprojects\Models\Dubai
Marina70.in"
$$ All links inbetween PROFIL.DAT and SOILS.DAT are valid. :-)
** Checking profils used but not defined in PROFILES.DAT...
$$ All profils used in "C:\ENVImetprojects\Models\Dubai Marina70.in"  are ok.
$$ Setting Datalinks, z0- length, Emissivity and Albedo...
$$ Average z0 over nesting area:0.015

$$  Gridding Plants and other Shelters...
$$ Checking Grid Structure...
$$ Selected Stomata Resistance Model: A-Gs Approach (Jacobs)(=2)
$$ CO2 Background concentration: 350.00 ppm
$$ CO2 subsystem enabled
$$ Additional CO2 sources present: No

$$ This is how the present constellation looks like :

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               "#" Building, "=" Overhanging Building, "~" Plant "*" Plant on Roof "R" Receptor
Calculating max radiation at noon...
Calculating SOR coefficients...
$$  Asymptotic relaxation parameter was calculated to 1.9488
$$  Geostrophic wind is u=-18.66 v=-18.66


$$  Modell Initialisation (Initial Guess on 1D BL)


$$ ENVI-met mode: Normal turbulence


$$ 3D Initialisation: Flow Diastrophy
     100% [301 st] remaining div: 0.00001 (Stopped)
      50% [301 st] remaining div: 0.00012 (Stopped)
       0% [301 st] remaining div: 0.00004 (Stopped)
$$ 3D Initialisation: Complete Modell
 Turbulence Adjustment:743 Steps, dt=0.102 (max. 0.8 s) Relax: 1.00
Initial Flow Adjustment. Total time to calculate: 10.000 sec
                         Maximum allowed change: 0.2639 m/s
[+00:18:56] $$ Setting up wind field completed
 Turbulence Adjustment:932 Steps, dt=0.102 (max. 0.8 s) Relax: 1.00
[07:24:19] $$ Time needed for Initialisation: 00:24:58


$$ *********************************************************
$$ ******** ENVI-met (c) Michael Bruse 1997-2006 ************
$$ *********    A microscale climatology model   ************
$$ *********************************************************
$$    Start: 21.12.2011 13:00:00 End: 21.12.2011 14:00:00 = 3600.0 sec
$$    Dynamical time steps enabled:
$$    Sun height <40.00Â° : dt=10.00 s
$$         40.00-50.00Â° : dt=5.00 s
$$               >50.00Â° : dt=2.00 s


$$ Passive Particle/Gas Concentration:
       Not used


$$ Other moduls:
$$ Moduls for Biometeorology:
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$$     PMV-Value: ok
```

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$$ Turbulence Closure 3D Mainmodel: Prognostic. Fine.
```

```
$$ Writing Outputfile MySim_AT_13.00.00 21.12.2011 and others
 Model start up phase. Main time step is set to class 2 (dt=2 sec)
[+00:42:47] New flow: 1 Steps [301 SOR Steps] du:0.115 dv:0.108 dw:0.053 after 10.16
s total
Maximum divergence in flow field= 0.77516 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
[+01:24:15] New flow: 1 Steps [301 SOR Steps] du:0.090 dv:0.102 dw:0.066 after 10.32
s total
Maximum divergence in flow field= 0.77277 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
Dynamical time step adjustment. Set dt=10 sec. (Class 0)
[+01:35:01] New flow: 1 Steps [301 SOR Steps] du:0.083 dv:0.102 dw:0.072 after 10.49
s total
Maximum divergence in flow field= 0.77352 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
[+01:48:04] New flow: 1 Steps [301 SOR Steps] du:0.072 dv:0.086 dw:0.062 after 10.65
s total
Maximum divergence in flow field= 0.77497 @ 56,62,2 (absolute)/56,62,2 (without
nesting grids)
$$ Writing Outputfile MySim_AT_14.00.00 21.12.2011 and others
```

```
[09:14:17]   ENVI-met at 21.12.2011 [14:00:00] Sun: h=35.30° a=299.32°  T0ref=296.509
q0ref=17.499
[+01:49:58]  Time executed in prognostic flow equation: 10.65 s
```

```
$$ Writing Outputfile MySim_AT_14.00.00 21.12.2011 and others
[09:15:50] *
$$ I am finished !!
```