Impact of Modified Urban Surfaces on Enhancing the Microclimate of Residential Landscape Areas in Hot Arid Environments – Case Study of Jumeirah Village Circle Community, Dubai

تأثير السطوح الحضرية المعدلة على تعزيز المناخ المحيط للمناطق السكنية ذات المساحات الخضراء في البيئات الحرارية القاحلة - دراسة على مجتمع قرية جميرا الدائرية, دبي

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ABSTRACT

The existing structure of the urban form with negligible greenery has created the urban heat islands (UHI) in many areas of the world. This can to an extent be reduced through thoughtful landscape design, which in turn influences the sustainability of urban fabric.

The microclimate can be modified by the urban environment through certain techniques. The geographical situation and the arrangement of the metropolitan such as geometrical formation, morphology local climatology, human activities, vegetation, building and surface materials and water, contribute essential impacts on the urban microclimate.

The aim of this study was to redesign the landscape surfaces of Dubai residential neighborhood based on bioclimatic interventions in order to achieve lower Mean Radiant and Ambient Air temperatures in hot arid climates.

This paper, comprehensively investigated the effects of selected bioclimatic factors on the air temperature in order to improve residential outdoor spaces in Dubai. The Jumeirah Village Circle neighborhood was selected for the current study as an ideal spot due to its huge untreated spaces, building proximity, climatic factors, high demands and newly developed. The current situation of the site consists of absence of proper and adequate vegetation coverage, absence of water features or water bodies throughout the whole plot, presence of traditional asphalt roads and existence of many untreated spots covered with sandy soil.

Primarily, in addition to the existing condition of the site four scenarios were proposed and examined to select the most useful ones in terms of passive cooling. The

longest summer day -21st of June- was the target of the variables including cool pavement, vegetation and water bodies. The five scenarios had a half day simulation consisting the part of the day when the sun appears between 6.00 AM and 6.00 PM to accomplish stability between the temperature behaviors during daytime and nighttime. The experimental outcomes of the simulations performed, displayed the behaviors of Ambient Air Temperature and Mean Radiant Temperature phenomena which were extracted from ENVI-met and justified.

The results of the five scenarios compared to each other revealed that the integration of the bioclimatic criteria recommended, enhanced the Ambient Air Temperature by 0.44 K. In a logical sequence, the enhanced vegetation scenario recorded the second best performance after the combined scenario. Therefore, the vegetation demonstrated to be the most temperature reduction parameter followed by the cool pavement material and waterbodies respectively. This highlights the capability of the bio-climatically enhanced scenario to generate the lowest temperature values in the current investigation as predicted. Moreover, the findings confirmed that vegetation, water bodies and cool pavements are highly recommended as actual means for the enhancement of microclimatic conditions in outdoors in hot dry regions.

الملخص

بغض النظر عن المساحات الخضراء المتواجدة, فإن الهياكل المتواجدة للشكل الحضري قد خلقت الجزر الحضرية الحرارية في عدة مناطق حول العالم. خلق الجزر الحضرية الحرارية أدى إلى محاولة تقليل المشكلة المختلقة عن طريق إيجاد أفكار بناءة للتصميم المساحي, و التي من خلالها ستعود بالنفع لإستمرار النسيج الحضري.

و من خلال تقنيات محددة, بالإمكان تعديل المناخ المحيط عن طريق البيئة الحضرية. الحالة الجغرافية و التوزيعات العمرانية كالتكوين الهندسي و دراسة المناخ المحلي و الممارسات البشرية و الحياة النباتية و البناء و المواد السطحية و استخدام المياه. كل هذه الأمثلة لها تأثير مهم على المناخ في المناطق الحضرية.

يذكر أن الهدف من هذه الدراسة هو إعادة تصميم السطوح المساحية في الأحياء السكنية في دبي على أساس التتدخلات المناخية الحيوية من أجل الحصول على أدنى درجات حرارة الأشعة المتوسطة و حرارة الهواء المحيط.هذه الرسالة العلمية تهدف إلى تحقيق شامل لدراسة آثار العوامل المناخية الحيوية المعينة على درجة حرارة الهواء من أجل تحسين المساحات السكنية في الهواء الطلق في دبي. و قد تم اختيار مجتمع قرية جميرا الدائرية للدراسة الحالية كموقع مثالي بسبب تواجد مساحات ضخمة غير معالجة و قرب البنيان و عوامل المناخ و ارتفاع نسبة الطلبات للبنيان المطور حديثا. و يتألف الموقع في الوقت الحالي من غياب المساحات النباتية المناسبة و الكافية و غياب خصائص المياه أو غياب المسطحات المائية على مدار المنطقة كاملة و وجود الشوراع الإسفلتية التقليدية و العديد من البقع الغير معالجة المغطاة بالتربة الرملية.

بالإضافة للمشهد الحالي للموقع, تم إقتراح و إختبار أربع سيناريوهات مختلفة لإختيار أنسب سيناريو و أكثرهم فائدة من ناحية التبريد السلبي. و أختير أطول يوم في الصيف (21 يونيو) كهدف للمتغيرات كالأرضيات المرصوفة المبردة و الحياة النباتية و المسطحات المائية. و تم إجراء محاكاة الكمبيوتر للسيناريوهات الخمسة على مدار النهار من الساعة السادسة صباحا إلى السادسة مساءا لبلوغ درجة الإستقرار ما بين سلوكيات درجة الحرارة في النهار و في الليل. بعد الحصول على أداء نتائج إختبارات المحاكاة, تم إظهار سلوكيات درجات حرارة الأشعة المتوسطة و حرارة الهواء المحيط التي تم إشتقاقها من برنامج Envi-metلتبرير صحة النتائج.

مقارنة النتائج للسيناريوهات الخمسة أظهرت بأن دمج معايير المناخ الحيوي الموصى بها عززت درجة حرارة الهواء الطلق بنسبة 0.44 K. و في تسلسل منطقي, فإن سيناريو الحياة النباتية المطورة سجل كثاني أفضل سيناريو فعال خلف السيناريو المشترك (السيناريو الخامس). و بناءا على ذلك, فقد أظهر سيناريو الحياة النبتاتية أقصى نسبة خفض لدرجات الحرارة في العوامل المتغيرة يليها سيناريو إضافة المواد المرصوفة المبردة و سيناريو المسطحات المائية. هذه النتائج تسلط الضوء على قدرة سيناريو المناخ الحيوي المطور لإنتاج أخفض درجة حرارة كقيمة في البحث الحالي كما هو متوقع. علاوة على ذلك, أكدت النتائج بأن الحياة النباتية و المسطحات المائية و الأرصفة الباردة يوصى بها بشدة كوسائل فعالة لتطوير المناخ الخارجي في المناطق الحارة و الجافة.

DEDICATION

I dedicate this work to my better half Abdulrahman, whom have always supported me and strengthened my will, which has enabled me to complete this research. I owe my every achievement to him. I am grateful to my family for bearing with me through stressful moments and providing me with love and support. I thank the Almighty for providing me the strength to endure this journey to completion.

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Chapter 1 – INTRODUCTION

1.1. Sustainability

The continuous raise in population growth propelling to more resource demands and products is an apparent universal issue being observed in our time. There is no surprise that human beings pay no attention to negative side effects of their behavior for continuous survival. Effects of contemporary lifestyles, bad habits and lack of awareness of the negative effects are damaging our environment resulting in neglecting the depletion of natural resources joint with the inexhaustible demand for energy use. Global warming, carbon footprints and emission enhancements, desertification, urban heat island effects, deforestation, and so onward are only some examples of the shocking negative effects being occurred. These are just few common factors that are desired to be overcome; so as to decrease the failures being experienced. Sustainability is the answer to such concerns. Declared by the Royal institute of chartered surveyors (2007), the most conventional definition of sustainable development is a development which meets the needs of the present without compromising the ability of future generations to meet their own needs.

Many countries worldwide confront similar problems, although the majority of developed countries have explored, suggested solutions and applied several sustainable strategies to attempt and defeat the negative upcoming setbacks. On the other hand, developing countries are still adjusting and trying to go behind their tracks. In the Middle East, the topic of sustainability has appeared in the previous years while renewable energy integration and conservation has also turned out to be a significant topic of argument and research. Many causes and issues lead to the demand for worldwide solutions at decreasing the negative effects that have evoked harming further generations to come.

The UAE has been succeeding to surpass at decreasing the negative impacts of climate change. It has launched different bids to pay its share to the international program for the mitigation of the results on climate change. A significant step towards the road of improving the existing situation made by Abu Dhabi government is the establishment of the Estidama System, which is an innovation that aspires for sustainable expansion. The construction industry is one of the most energy consuming sectors in the UAE. It was manifested that the construction sector uses 40% of the total electricity consumption in the country, consequently making this a main issue as experts are searching for alternatives to reduce energy consumption (Abu Dhabi Urban Planning Council, 2010).

Therefore, a compromise between the use of natural resources and the consumption required for the world's progress needs to be managed properly within a sustainable development plan. To limit our footprints on this world we need to build, evolve and sprawl in a sustainable manner (Wright and Boorse, 2011).Thus, applying sustainable practices is mandatory in all aspects of social, economical and mainly environmental.

1.2. Sustainable Urban Environment

Urban environments consume 75% of the worldwide resources per year while they occupy only 2% of the earth's land surface. Human beings make huge demands on soil and water resources for food and on forestry for wood and paper (Pearce, 2006). Urban environments are rapidly developing environments which have an important impact on resource use and ecological sustainability. Urbanization is increasing around the world and this highlights the responsibility that cities should take in solving the serious universal problems. The active urban structure of any city today is dependent on the manners of its citizens with the passage of time, thus design considerations should be comprehensively incorporated at all stages and disciplines (Jabareen, 2006).

Urbanization results into change in the scheme of the environment with augmented buildings, infrastructure and less open spaces. This amplifies the urban temperatures in contrast with the countryside areas. The impacts of urbanization as well affect the economic sides of any nation. With increased density, the infrastructure and the resource must be preserved for these nations. Therefore, the interest in applying sustainable development ideologies to landscape design has been increased in the recent years (Campbell & Ogden 1999). Unfortunately, the existing composition of the urban form with negligible greenery has created the urban heat islands (UHI) in many areas of the world. This can to an extent be diminished through considerate landscape design which in turn influences the sustainability of urban fabric. Growing urban trees and using high-albedo surfaces mitigates the ambient temperature throughout summer season hence improves the urban environment (Santamouris, 2007).

Building construction plays an enormous ingredient in the impressions shaping imminent exhaustion of our ecosystem. Many countries around the world face similar issues; however, The United Arab Emirates has become one of top countries with the greatest carbon footprint levels. When the economic recession occurred in 2008, UAE has observed the worldwide environmental disaster produced by its fast expansion lacking a cognizant deliberation of the natural resources. Consequently, it has pursued a creative manner to understand and direct the Ecological Footprint by finding various initiatives and organizations such as Masdar and Estidama in Abu Dhabi. In some parts of the world the initiatives towards zero carbon cities are believed to be the start for attaining a sustainable future.

The development of urban design during the decades has shown that no particular morphology is suitable to be applied in all places. The features of an urban environment must be set in a way to supply to this particular place. The balance formed linking solids and voids in an urban development, is enormously important and responsible for the spirit of the public area. Open spaces have to come together with buildings, whereas buildings should emphasize and highlight open spaces. The interface among the building and the space, the solid and the void, the indoor and the outdoor has been an essential matter for the urban practitioners all the time. The fact which requires huge consideration is to bear in mind how impressive a space can alter its surroundings. The lifestyle civilizations owned years ago was assumed from the way their towns where created and structured. It accentuated their magnitude, awareness and the level of social communication of such people. Throughout our existing urban developments and the way they are created, upcoming generations are to anticipate these theories such as the need for individual territory, decayed social affairs and non-conservative use of materials.

In Dubai, the urban structure of the neighborhoods has not completely considered the sustainability ideologies. In recent years, ‘Estidama’ meaning sustainability in Arabic under the Urban Planning Council of Abu Dhabi initiatives, certifies through a rating system that built fabrics and neighborhoods integrate sustainability practices into their plans. The municipality of Dubai has also incorporated requirements in the policies to direct the sustainability principles in the construction market. In general, for irrigation of public areas Treated sewage effluent (TSE) system and potable water for private gardens are used in Dubai. Supplying water is through an energy intensive procedure of sea water desalination. Thus, water is a valuable resource in this country.

1.3. Sustainable Landscape

"Sustainable Landscaping" has no single definition in the existing literature, although in general the theory comprises all the environmental, social and economic elements. According to Welker and Green (2003), the term "Sustainable Landscaping" has appeared to indicate to landscape design, mechanism and management functions that reduce negative ecological impacts, preserve resources and increase environmental function while achieving practical and aesthetic targets. Pitman (2007) defines sustainable landscape as a healthy and strong landscape that is in harmony with native environmental settings containing climate, water, soil and topography. Smith (2005) identifies one of the key indicators for sustainable design as whether a development creates an external environment that is both a visual amenity and offers environmental benefits such as summer shading from trees, and evaporative cooling from water features. In simpler terms, a successful outdoor design is one which looks good to people and one they want to spend time in because they are comfortable.

In a study by Musacchio (2009), a conceptual framework about the six Es of sustainable landscape design –economic, environment, aesthetics, equity, ethics and experience- was introduced. He discussed the opportunities, limitations and interrelatedness of the proposed conceptual framework with regards to biodiversity, ecosystem services, resource management and human health/ security. He concluded a sustainable landscape does not rely on a certain condition that is unmoving in time and geographic space or something probably attained by exercising a recipe book of practices. Finally, it provides an active condition of the system with several directions and results and offers ecosystems services represents multi-functionality and is flexible and adaptive.

Grant et al. (1996), introduce a systematic view and planning framework for protecting landscapes and ecosystems. They suggest that sustainable communities should acknowledge the following principles: reduce settlement impacts on ecosystems, preserve and renovate landscape practices and functions, protect natural resources and resource lands, maximize individuals' involvement in promoting sustainability, minimize waste outputs for residential communities and encourage healthy social environments.

A common framework that concerns ecological knowledge in landscape planning, applicable to all physical planning activities was argued by Leitao and Ahern (2002). They proposed a dual sustainable landscape planning metrics; integrating horizontal and vertical perspective, which are understood as the most useful and relevant for landscape planning. The horizontal perspective defines the principle factors as human and ecological, space and time including issues like water resources, biodiversity and human comfort. Whereas the vertical perspective is more solution-providing, technically oriented and results oriented approach.

Sustainable landscape design in arid climates should think about natural resources. This involves together equilibrated water supervision and the use of design interventions, and particularly to the selection of the correct plants that must be matched with the local plant district as much as feasible. The shortage of water which is the restrictive parameter of all plants in the desert caused dealing of wastewater for irrigation use an obligation. An individual makes sufficient wastewater for irrigation of six trees.

Sustainable landscaping is efficiently involved with creating healthy neighborhoods with the ability to contribute in designing, building and running healthy urban settings. Moreover, social benefits of sustainable landscaping are numerous including: safety, privacy and tranquility, health benefits, increasing the community appeal, noise reduction, aesthetic aspects, etc. Therefore, urban landscapes can significantly improve urban ecological footprint with proper design, careful energy use and plant and material selections.

Like in urban planning for energy conservation, the concept is to minimize the effects of heat and corresponding use of energy consuming climate control systems by improving the microclimate conditions. These require solutions in vegetation, site planning and landscape and building designs. Advocated practices include selecting sites to maximize wildlife habitat preservation, managing storm water on site, minimizing soil disturbance during site construction, preserving and restoring native plant communities, utilizing recycled materials, and promoting human well-being through creation of livable outdoor spaces (SSI, 2009).

1.4. Landscape in Dubai

There has been humble yet growing stress put on landscape design in gulf region. In the Gulf, attempts to battle desertification were in accordance with the causes that formed landscape design in hot arid environments: 1) the economic development of Gulf countries which motivated the need for proper landscape design and conservation of heritage; 2) growing historical investigation on landscapes in arid regions and 3) global and local green movements. Improved oil incomes in the 1970s inspired mega scale landscape production in Qatar, Kuwait, Saudi Arabia and the United Arab Emirates. Landscape Architects in these countries confronted deep problems that continue till date: plant reproduction and conservation, increasing requirement for greenery, irrigation water supplies and technologies and unknown cultural, social, and aesthetic purposes (Miller 1978).

Environmental scientists were more helpful in challenging contemporary development implements. They have combated to enhance using native and adaptable plant species, decrease irrigation and move to grey water for landscape irrigation and water treatment. Their comments have been interpreted into innovative design solutions (Hester, 1990).

Although sustainable landscape design concepts appear to be shifting as new migrant to arid environments to discovered beauties in xeriscaping, previous mentality of dry land and water increase fade and the relations between landscape design, landscape heritage and environmental guidelines in arid regions stay incapable. Theses monographs about arid region landscape have not got the interest they merit (Joma, 1991). Therefore, landscape design practices that seek the forms of sustainability in arid regions ensure greater consideration.

Dealing with open spaces in Dubai is however another area of concern mainly to be covered in this study. Outdoor spaces in Dubai can be assumed to go throughout a phase of life and death during the year. A phase where the attractive open spaces around the town are seriously in use is when the weather conditions are in accordance with the normal comfort levels. All through summer season the outdoor places are completely uninhabited. By the decrease of the outside air temperatures and increasing the thermal comfort levels, the usage of the outdoor life can be expanded. Bioclimatic approach can be applied to revive the outdoor spaces in Dubai during the year through achieving comfort.

The urban strategy of creating smaller urban neighborhoods within the same city can be assumed as a helpful practice to urban variety. However the practice of smaller cities needs an essential combining of sub-services that smoothly intersects to the major network, but if attained correctly would be useful. Dubai has various urban compositions that are not essentially in harmony with abandoning its residents with a sense of not belonging to the place.

Between December and March the serviceability of the open spaces in Dubai is great due to the fair climatic situation. Expanding the functional period of the open spaces can be attained by increasing the comfort zone span. Proposing the strategies that can enhance the thermal conditions of such spaces will avail the sustainable growth of the UAE. Although, not only new ideas are to integrate these strategies but existing spaces should be reviewed and possible methods should be taken to reduce their ecological footprint of Dubai.

The landscape in Dubai, inspired by the worldwide landscape practices and desiring to imitate such places, has led to a widespread requirement on the depleting resources of water. Therefore, Dubai urban landscapes keep on being resource-demanding requiring huge amounts of water, energy, nutrients, materials and products while a lot of our choices of plants and approaches are inappropriate to the hot arid environments. The consequence is usually craving landscapes that exhaust the soil, use non-sustainable materials, let offensive plants to escape, lead to stream infection and deliver restricted habitat for local wildlife.

1.5. Aim and Significance of the Study

The following research questions need to be answered in order to achieve the purpose of the study:

- What principles should be considered when designing for a bioclimatic landscape in hot arid regions?
- How can the application of vegetation, cool pavement and water features enhance the mean radiant and ambient air temperatures of urban outdoor spaces?
- To what level the treatment of landscape surfaces can reduce the mean radiant temperature in hot arid environments?
- Which proposed scenario has the most influence on reducing the mean radiant and ambient air temperatures of the current case study?
- Does the implication of treated landscape surfaces make a significant contribution to lowering the ambient air temperature of the community?
- To what extent are the landscape surfaces of Dubai's residential neighborhoods bioclimatic?

The aim of the study is to redesign the landscape surfaces of Dubai residential neighborhood based on bioclimatic interventions in order to achieve lower surface and air temperature in hot arid contexts. Therefore, the research objectives are:

- Determining the influence of bioclimatic factors on outdoor thermal performance in hot arid environments.
- Presenting an optimum scenario for the landscape of the selected case study based on bioclimatic parameters to carry out a comparative study that will assist in:

i. Analyzing the amount of progress in reducing the surface and air temperature accomplished by each and all parameters.

ii. Recognizing the performance of the parameters examined.

- Demonstrating a successful proposal to promote appropriate landscape land use design including pavement materials, greenery application and water features of a typical gated urban community in Dubai.
- Assessing the advantages of bioclimatic landscaping against the paradox of the region's contextual climate.
- Establishing a series of recommendations and innovations embracing benefits of bioclimatic landscape design for the professionals in the region.

1.6. Research Potentials and Limitations

A successful landscape entices the inhabitants to revitalize the place thus affecting its surrounding. It is obvious that the majority of the city‘s landscape design missed the human factor throughout the primary design phases. For landscapes to be successful there has to be a set of design strategies to follow in order to accomplish the inhabitants comfort both psychologically and physiologically. The design of landscape areas in Dubai needs an electrical shock to be revitalized which is the ecological aspect.

It should also be considered that Dubai's climate is incredibly challenging for landscape designers and urban planners. With a hot arid climate, it is so difficult to use outdoor spaces through half of the year. Therefore, it is quite difficult to present solutions mainly for the outdoor environment. However, hot arid climate has the benefit that we do not have to give solutions for severe climate conditions. An environment with hot arid climate needs solutions in summer rather than looking for solutions in winter where the thermal conditions in such cities as Dubai is currently within the comfort zone of human being. The sustainable design of outdoor places depends on a number of factors which require being preferred upon other factors.

Like in any other field, sustainability is still supposed to be a new topic in the industry. The restrictions landscape architects confront when designing according to bioclimatic values are massive compared with the required objectives to accomplish. Equipment differs from tools that estimate current measures, software simulations, experiments and social surveys. The major privilege of software simulations is their appropriateness for studies with limited financial resources and restricted time similar to the current paper. Software modeling copies the actual scenario which permits the scholar to control the situation to reach their targets. The idea of adjusting the parameters of a study is to approve them before the creation stage, making sure the final product has the required conditions. In this context, the existing software is considered to be restricted in terms of realizing some of the outdoor environment variables.

Due to unmanageable reasons that might influence correctness of the overall result, outdoor environments are much more demanding than indoor environments. The more precise the simulation procedure compared to the actual environment, the more reliable the results. In the current paper, Envi-MET is selected as the simulation software to calculate variations in the thermal parameters based on the applied design proposals and strategies. The most important benefit of this particular software is that it can recognize the majority of the outdoor environment variables and their assembled performance (Dooley, 2002). An assessment matrix will be given according to the existing collection of parameters in outdoor environments and the idea of ecological design.

1.7. Dissertation Outline

The current paper is divided into the following sections where each involves the step towards creating a sustainable landscape design for residential neighborhoods:

Chapter 1 provides an introduction and general idea about the concept of sustainability and understanding its importance. The chapter also introduces the topic of sustainable urban development and sustainable landscape and highlights the condition of landscape in Dubai. Moreover, the research potentials and limitations are pointed in this chapter. Chapter 2 is a thorough review of scientific papers debating the definition and principles of sustainable landscape design and investigating their findings with regards to the microclimatic advantages of implementing bioclimatic practice into landscape. This process is essential for any study since it enables the researcher to attain broad knowledge about the findings of the previous research works done in a specific area. Besides, aims and significance of the study will be dedicated at the end of this section.

Chapter 3 evaluates the research methodologies that were used by existing literature to conduct similar studies. Different research methodologies will be considered based on their advantages and disadvantages, therefore the most appropriate methodology for conducting this study will be selected. In addition, selection of the most applicable software, tools and sources for conducting this study will be within the same chapter. Chapter 4 contains site selection and data collection and establishes further information about the case study and discusses the data analysis. General knowledge on the microclimatic conditions of Dubai city will be provided also.

Moreover, chapter 5 presents the results and findings of the proposed scenario acquired through the study based on the methodology chosen before. In chapter 6, findings from the previous chapter will go through systematic analysis and interpretations based on the pre-established criteria in literature review will be made to discuss and provide justification to validate the significance of strategies in each scenario. It also presents a comparison between the qualification of existing and proposed scenarios and recognizes the advantages and disadvantages of each. Finally, chapter 7 establishes a conclusion according to the results obtained in the previous chapter. It also wraps up the various features discussed in the whole paper. Design guidelines and future recommendations proving the objectives targeted will be included here. Therefore, when reaching this stage a holistic vision of the research will be accomplished.

Chapter 2 – LITERATURE REVIEW

2.1. Introduction

In this section, a detailed review of the literature involved in similar area of study will be presented. Several key words have been searched such as: environmental aspects of sustainable landscape design, urban microclimate in hot arid regions, bioclimatic design, landscape design for urban residential neighborhoods, landscape metrics, urban ecological networks, bioclimatic urban areas development, cooling effects of vegetation and impacts of cool pavements on the microclimate. Concentration on all factors of the issue will be submitted evidently recognizing the potentials and limitations of parallel articles. A full perception of the related efforts done previously by researchers based on the topic's main issues was relied only on online scientific resources.

In order to select the most relevant articles for a better review those which focused more on psychological parameters than physiological ones were assigned less priority in the skeleton of the research. Also, studies with shortage in their methodology or results were prevented. On the other hand, when searching for papers dealing with ecological impacts of vegetation in landscapes, the application of green roofs and green were neglected. In addition, articles investigating surface materials of urban infrastructure were only limited to outdoor pavement surfaces and not roof surfaces. Papers with recommendations and guidelines were prioritized particularly those studying the impact of meteorological factors on enhancing the microclimate of outdoor environment in hot arid areas. The papers incorporated were then reviewed carefully, evaluated and categorized according to their objectives and area of concentration. The review of the literature that was done argues the factors to be utilized for investigating the meteorological parameters submitted in the upcoming chapter.

2.2. Urban Heat Island Effect

In urban areas the ambient temperature is generally several degrees larger than that of the surrounding rural areas and outlying. The occurrence is known as the Heat Island Effect and symbolizes an important variation in the urban microclimate. Modern urban spaces have usually less vegetation and darker surfaces than the suburban areas. These diversities influence climate, habitability of the metropolis and energy consumption. Cooperatively, decreased vegetation and dark surfaces warm the air above urban areas contributing to the formation of Urban Heat Islands (Akbari et al. 2001).

Similarly, Gui et al. (2007) declares that an important reason of higher air temperature in urban neighborhoods compared to that in rural districts is the surface area and material combination which creates urban developments. However, rural areas are usually occupied with dense vegetation, cities mainly contain of two key engineered materials: asphalt concrete and Portland cement. These materials with comparatively high volumetric heat capacity and decreased evapotranspiration due to their impermeability produce higher heat levels in contrast to their local vegetation complements in rural regions. This increases the nearby air temperature throughout the day and night. This happening is extensively recognized as the Urban Heat Island (UHI) effect.

Studies have shown that increased temperatures in urban heat islands can have negative impacts on the microclimate of a community and therefore the quality of life consisting of increased air pollution, greenhouse gas emissions, enhanced energy demands, reduced water quality and human health impacts (Akbari, 1995). A study by Jung et al. (2004) concentrated on the effects of various artificial pavement materials in Hungary. They found that artificial surfaces alter the urban microclimate of desert areas especially during summer period which plays a huge role in increasing urban heat island effects.

In this regard, Akbari et al. (2001) found that on a clear summer afternoon in a typical American city, the air temperature is as much as 2.5 °C higher than in the nearby suburban areas. They realized that peak urban electric requirement increases by 2-4% for each 1 °C increase in daily maximum temperature over a 15 to 20 °C threshold. Therefore, the extra AC utilization caused by the air temperature rise is responsible for 5-10% of urban electric demand at a number of billion dollars cost per year.

2.3. Thermal Comfort in Outdoor Space

ASHRAE defines human thermal comfort as the state of mind which declares satisfaction with the nearby environment (ANSI/ASHRAE Standard 55). Human thermal comfort is merely the zone where a person acquires a comfortable thermal sensation due to many parameters defined by previous researchers. The air velocity, the ambient air temperature, the mean radiant temperature and the relative humidity are the physical factors that attain the thermal comfort sensation. There are psychological factors that also influence the thermal comfort levels of human which is the clothing type and activity levels. Researchers found that a combination of physiological in addition to psychological parameters compliment to obtain the ideal comfort zone. The psychometric chart is a graphical image of these factors which can obviously show the comfort range based on the climatic zone. Instruments that measure the thermal comfort levels are according to the input of the psychometric chart as a guideline to evaluate with.

Any parameter that influences thermal sensation of an individual within an environment depends upon the kind of their activity, clothing, expectation of the climate condition before their exposure and many other psychological parameters. In fact, the way of life of an individual directly influences their comfort sensation also. In UAE, almost all activities depend on the availability of air conditioning which makes its residents to expect higher thermal comfort levels (Nikolopoulou et al. 2001). Therefore, there has to be a balance between all factors to achieve the best results for thermal comfort levels. The concern of the current study is to reduce the ambient air temperature in through the application of sustainable landscape principles that contribute to the improvement of the outdoor thermal sensation.

Healthy and comfortable urban microclimate qualities are essential for all environments. Human beings are exposed to different kinds of stress in outdoor spaces. The most important one is the microclimatic qualities which differ considerably from suburban areas. The causes are the modification of the surface infrastructure in terms of vegetation, the geometry and orientation of the buildings and proportion of the built up area. These factors influence climatic phenomena including UHI and the deviation in the radiation fluxes.

Latest research illustrated outdoor thermal condition parameters such as wind speed, air temperature, solar radiation and relative humidity influence estimation of satisfaction, thermal perception and thermal comfort (Hassan and Mahmoud, 2011).

Human beings are often in contact with the weather during activities and recreation in outdoor areas. Therefore, a convenient outdoor environment is really important to the satisfaction of similar places. Several studies showed that users' thermal evaluations of a place may comprehensively affect their utilization of the place (Thorsson et al. 2004 and Kenz and Thorsson, 2008). There are proofs that thermal comfort in outside places and satisfactory thermal range differ from the one in closed spaces due to behavioural and psychological parameters (Spagnolo and de Dear, 2003 and Nikolopoulou et al. 2001).

2.4. Bioclimatic Design Principles for Landscapes in Hot Arid Environments

Landscaping can have an important impact on regulating the outdoor temperature. If applied to a large scale it can even have a considerable impact in tempering the Urban Heat Island effect (Akbari et al. 2001).

A bioclimatic practice depends upon incorporating the microclimatic parameters encompassing a space to reduce the energy utilization on a variety of surfaces and improve the comfort qualities of such environments (CRESS, 2010).

Passive design is recognized to be one of the approaches applied to attain a bioclimatic design. A bioclimatic practice comprises thermal and visual comfort, economic, social and environmental advantages and energy saving. Applying the values of such techniques would help and probably assure gaining the earlier noted advantages contributing to a sustainable fostered environment.

Accomplishing a bioclimatic practice for the design of outdoor spaces is mainly based on an accurate knowledge on all the factors of the surrounding environment. Two parameters must be taken into consideration concerning a sustainable design proposal;

the natural parameter like the microclimate of the area and the human-made parameter which is the urban situation compassing the area. Both parameters contribute to acquiring a passive landscape design (Gaitani et. al., 2005).

It is known that the growth of urban towns enormously alters the climate of the town and surroundings. The rise in the impervious segment of the ground surface made by buildings, roads and pavements considerably decreases evaporation from the ground surface and accordingly enhances temperature of the beneath layer. This layer rises the temperature of the ground surface more than the earlier vegetated surface, therefore raising the sensible heat exchange among the environment and the ground surface and the uphill long-wave radiation.

The urban climate is a blend of the microclimates that are created in the open spaces between buildings based on the conditions of their direct morphological, physical, surroundings and practical features and mainly shape the Urban Heat Island. Several investigations have delivered the impacts of vegetation, water and surface materials in the urban microclimates (Yannas, 2001 and Chatzidimitriou, 2012).

In fact, the division of bio-climatically landscaped areas in the city in accordance with the built areas can affect the ambient temperature of the environment. These temperatures can affect the inhabitants' thermal comfort and thus it is important to recognize how the design of these places can modify the temperature.

The United States Environmental Protection Agency (EPA) established a report capturing 'Reducing Urban Heat Islands: Compendium of Strategies' that presents convincing reasons to mitigate the urban heat island effect (EPA, 2014). The EPA report details several strategies to mitigate the effect of urban heat islands which include:

1. Design and material selection for roof structures and surfaces;

2. Design and material selection for pavement surfaces; and

3. The incorporation of more trees, planting and landscaping elements in urban communities.

What these steps demonstrate is the need for a comprehensive approach to mitigate the urban heat island effect.

In addition, the U.S. Department of Energy (DOE) provides several recommendations for reducing urban heat islands. The program suggests that by replacing dark colored pavements and roofing with light and heat-reflective concrete based materials, along with careful planting of trees, the average summer afternoon temperature in urban areas can be significantly reduced.

Akbari et al. (2001) revealed that planting of urban vegetation and applying high albedo (solar reflectivity) urban surfaces are efficient plans that can reduce the temperature of the microclimate. The impacts of moderating the landscape areas by planting trees and enhancing albedo are optimum solutions in terms of direct and indirect efforts. The direct impact is to modify the energy balance and cooling demands of a specific building. Although, when vegetation is applied and albedo is altered in the whole city, the energy balance of the entire environment is improved which creates city-wide alterations in the climate. Cases related to city-wide alterations in climate are mentioned as indirect impacts since they influence the energy use in a single building indirectly. Direct impacts provide instant advantages to the building which uses them, whereas indirect impacts attain advantages only with extensive consumption.

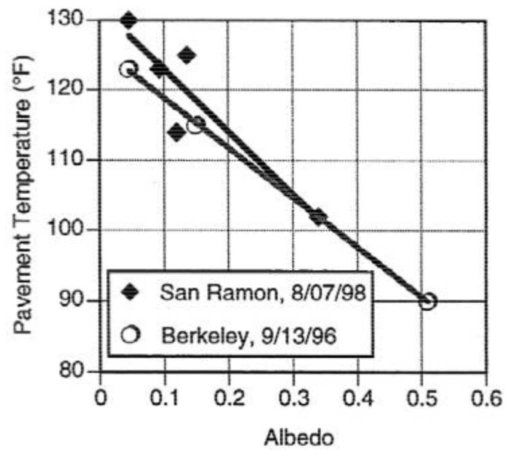


Figure 2.1 – Dependence of pavement surface temperature on albedo. Data were taken about at 3 pm in Berkeley, California, on new, old and light-color coated asphalt pavements. The data from San Ramon, California, were taken at about 3 pm on four asphalt concrete and one cement concrete (albedo=0.35) pavements (Akbari et al. 2001).

2.5. Parameters Affecting the Microclimate in Hot Arid Areas

The outdoor context is a broad area of research. Several numbers of irrepressible parameters available in the outdoor environment win over those available in the indoors. The physical parameters of the microclimate are yet huge in quantity and that increases the complication of the outdoor research and requires more studies. Scholars recognized the most important parameters affecting the microclimate and particularly outdoor thermal conditions as following:

Relative Humidity: It makes a minor effect in the absence of sweating, so the only two transfers associated with humidity are the respiratory exchange and the insensible skin perspiration. Or else, the air humidity strongly influences the sweat evaporation and therefore the skin wetness.

Ambient Air Temperature: It affects the heat transfer coefficient as well as the humid and dry exchanges.

Mean Radiant Temperature: In the outdoor space, the mean radiant temperature indicates the similar surface temperature of an imaginary area in which all the surfaces of the space have the same temperature (Matzarakis and Mayer, 2000).

Air Velocity: It affects evaporative and convective loses to a great extent. Due to a natural air movement in all places, a minimum speed of 0.1 m/s exists at all times.

In general, the air temperature is considered to be the most dominant factor within a space affecting the microclimate (Mahmoud, 2011). Also, studies done by Nikolopoulou and Lykoudis (2006) focusing on enhancing thermal conditions of outdoor spaces recognized the air temperature factor as the most influential parameter affecting the microclimate. Studies discussed that minor differences in other factors such as humidity and wind speed could not be understood by the users particularly if the temperature values were within the human comfort levels. Due to the dissimilarities of the climatic conditions in various regions, some parameters are thought to be more important than others whereas in some areas those similar parameters are considered to be less important. The parameter that should always be focused on in all climatic conditions is air temperature.

Feeling Comfortable Overall (%)								
	000	001	010	011	100	110	101	111
Athens	26	57	45	95	79	82	97	96
Cambridge	76	80	77	67	100	96	96	95
Fribourg	50	33	49	56	67	70	82	84
Kassel		0	0	40	0	77	100	88
Milan	11	0	21	33	57	73	69	84
Sheffield	18	33	55	69	58	79	78	91
Thessaloniki	18	29	41	28	72	81	86	86

Figure 2.2 – Percentage of people in overall comfort state and their evaluation for comfort or discomfort presented with a binary code (0 for discomfort – 1 for comfort) in relation to thermal (1st digit), wind (2nd digit) and humidity (3rd digit) sensation (Nikolopoulou and Lykoudis, 2006).

Commonly, the main principle for bioclimatic design goes with regards to the usual comfort levels and recognizing the characteristics of the region’s climate. The concentration on the microclimatic factors of the area of study is then to pursue. The sequential method of an ecological design concept increases the recognition of the different factors of the design. Establishing an ecological design concept in residential urban areas of Dubai first of all demands concentrating on the ecological situations of the area under study. Then, the conditions of the current design that interprets to the functional needs of the site should be considered.

2.6. Urban Space Components and Their Impacts on the Microclimate

Experimental studies have been stacking lately attempting to realize the relationship between the urban structures and its climate. Building contexts compose urban environments that control the solar gain; thus the energy consumption of the indoors and thermal comfort levels of the outdoor spaces. The urban design practice is needed to locate structures where surrounding spaces exist in the master plan. The arrangement of the space, its ingredients and materials are the most significant parameters controlling the microclimate of outdoor urban areas. The results of the bioclimatic outdoor spaces donate positively to the adjacent environment. Therefore, studying these parameters is assumed to have an important impact in moving towards a sustainable future. The ecological guidelines and suggestions must be established for urban practitioners and requires more investigations.

The present study is more on incorporating the ecological enhancements rather than an investigation of each factor independently. From previous research studies, factors that revealed to contribute a positive influence on the microclimate of outdoor environment were assumed to be more than the rest. The theory of blending these factors recognizes the potential of ecological design practice to promote the temperature of outdoor environments in Dubai. Factors that affect the temperature in outdoor areas were found to be many. Those mentioned here will be examined in an arranged form at a bigger scope.

2.7. Landscape Surfaces and Urban Microclimate

In general, urban surface is covered by various land uses from natural to human-made surfaces. Climate in urban environments is usually specified by various land uses. Urban climate scholars consider that urbanization has an important impact in changing the urban climate from natural to human-made. They believe that man-made modifications alter the energy balance, the structure and the materials of the urban environment and the combination of the atmosphere compared to the rural and the suburban natural setting. Hence, these parameters define a different local climate in several cities in the world which so called as urban climate or urban microclimate today.

In developing cities, bare ground, built up spaces and paved surfaces substitute the natural landscape. The infrastructure absorbs the heat from sun which makes their temperature to gradually increase with more exposure. While ambient air temperature is about 30°C in hot arid regions, surface temperatures of dark urban materials such as pavements, car parks, concrete buildings and roads can reach to 60°C in the middle of the day. This is as a result of the ability of those surfaces to store and reradiate huge amount of heat into the environment causing the urban temperature to rise 10°C or more than rural and suburban areas (Ahmad et al. 2010).

The research on urban microclimate could be conducted on different subjects including air pollution attention, occurrence of rainstorms and thunderstorms, changes of urban temperature, thermal comfort in urban areas urban indoor environment and so many more. Many studies from all around the world witnessed that urban temperatures were the clearest modification revealed as Urban Heat Island (Saaroni et al. 2000, Shaharuddin et al. 2007, Rizwan et al. 2009 and Zeng et al. 2009).

Urban surfaces and materials greatly influence outdoor thermal environments. It was revealed that there were obvious impacts of hard versus vegetation surfaces on ambient temperature and mean radiant temperature through filed measurements conducted in Singapore (Wong et al. 2003). Ramadhan and Al-Abdulwahab (1997), performed a fiend experiment in Saudi Arabia which concluded that there is a positive relationship between pavement temperature and ambient air temperature. Using numerical modeling, the characteristics of heat and water transfer processes in asphalt, porous block pavement, ceramic porous pavement and grass was evaluated. The study showed that the surface temperature of permeable pavement is considerably less than that of impermeable pavement (Asaeda and Ca, 2000).

Tzu-Ping et al. (2007), carried out an empirical study which analyzed the seasonal effects of five pavement materials on outdoor thermal environments in three areas of Taiwan. The research discovered that concrete and asphalt concrete have higher temperature than interlocking blocks and interlocking blocks with grass filling which grass constantly has the least temperature. Also, the surface temperature of vegetation surfaces was 10°C lower than that of artificial pavements at noon during summer. Another study in Singapore demonstrated that concrete interlocking blocks, terracotta bricks and granite slab provide lower heat output and surface temperatures than the usual asphalt pavements (Tan and Fwa, 1992).

In theory, throughout the day built-up surfaces in outdoor environment are warmed by the absorption of extreme solar radiation, therefore heat faster than green areas, open spaces and water bodies. In the UAE, it is appropriate to choose materials that can result in a decline of heat gain into the building which will as a consequence, enhance indoor thermal comfort levels and decrease taxation to the mechanical cooling systems.

2.7.1. Impact of Cool Pavement Material on Reducing the Temperature in Urban Areas

The level of vegetation in hot arid regions is generally smaller than in moderate climate environments, therefore the relative significance of solid materials like roofs and paved surfaces enhances. The function of solid materials in the structure of the urban heat island has been the topic of many studies.

Many studies have reconsidered the literature for the solar reflectance of several standard and reflective paving materials. They describe that the solar reflectance of newly built asphalt pavement is 0.05 while this value for aged asphalt pavements is between 0.10-0.18 based on the type of aggregate applied in the asphalt mix. Also, the initial solar reflectance of a light color concrete pavement is 0.35 to 0.40 that will age to around 0.25-0.30.These studies advocate in order to increase the solar reflectance of paved surfaces by about 0.15, cool pavement materials in the urban environments must be used (Akbari et al. 2009, Pomerantz and Akbari. 1998).Existing pavement construction criteria do not score for the solar reflectance of pavements. Although the highest surface temperature of a pavement and the diurnal value of pavement temperature are significant factors in designing pavement materials. Laboratory experiments have revealed that cooler pavements have a more extended life cycle. LEED's Green Building Rating System in its Sustainable Sites Credit defines a rating point for the application of cool pavement materials. LEED version 2.2 (2005) employs Solar Reflectance Index rather than solar reflectance to determine a cool pavement. Solar Reflectance Index is a comparative index of the permanent state temperature of a roof's surface on a normal summer afternoon. LEED determines a minimum SRI 29 for a pavement material to be cool.

Based on the primary energy balance, a one-dimensional mathematical model was fostered by Gui et al. (2007) to calculate the surface temperatures applying hourly measured air temperature, solar radiation, wind velocity and dew point temperature. To predict the diurnal temperature impacts of thermo-physical properties of pavement material, an evaluation was done with the aim of finding the best combination of pavement materials for future urban developments. They stated that suitable pavement materials have the capability to reduce high surface temperatures and heat absorption leading to the UHI effect and human thermal comfort. The findings showed that both emissivity and albedo respectively have the highest positive impacts on pavement minimum and maximum temperatures, whereas promoting the diffusivity, volumetric heat capacity and thermal conductivity assist in reducing the maximum but not the minimum pavement surface temperature.

Researchers at LBNL have estimated that every 10 percent increase in solar reflectance could decrease surface temperatures by 7°F (4°C). Further, they predicted that if pavement reflectance throughout a city were increased from 10 percent to 35 percent, the air temperature could potentially be reduced by 1°F (0.6°C) which would result in significant benefits in terms of lower energy use and reduced ozone levels (Killingsworth, 2011).

Lin et al. (2010), carried out a study which focused on four various pavement materials including concrete, asphalt, interlocking blocks and grass situated in a university campus to measure the thermal physical parameters and albedo value. The net radiation was calculated using CNR1 with short and long wave radiation and up and down side. The field study was performed during different seasons and the albedo value for all pavement materials was measured. At the same time, using the Rayman model which has been adjusted with the native climate, the lasting thermal comfort was measured. The analytical outcome demonstrated that asphalt as the low albedo pavement results in longer time for hot hours than grass as the high albedo pavement. Their conclusion could be useful in the design of landscape areas for the reduction of Urban Heat Island and enhancement of thermal comfort.

A redesign project for two public squares in the campus of the Aristotle University of Thessaloniki in Greece has been suggested. The project was conducted in the agenda of a national level program for the enhancement of outdoor open spaces according to bioclimatic criteria. The proposal was analyzed in terms of upgrading the microclimate, building energy savings and pedestrians' thermal comfort in hot summer period. The involvements were including adding up various types of trees, different shading canopies, water elements such as fountains, ponds and wet pavements, low vegetation as well as green walls, substitution of most solid pavements with permeable surfaces and natural soil and substitution of the rest pavements by cool pavement with high emissivity and high albedo. The impacts of the proposed redevelopments on surface and air temperatures and on indices were evaluated by comparing microclimate simulations of present and proposed plans applying the ENVI-met software for two typical and extremely hot summer days. The result of simulations showed that the mean surface temperature reduction during extreme conditions in the two squares was approximately 14 °C and 18 °C, while the mean air temperature reduction was 2.6 °C and 1.7 °C. Moreover, a 36% and 34% enhancement on pedestrian comfort was shown based on the average PMV indices decrease during a normal summer day, in addition to a 32% and a 26% decrease of the cooling level hour's daily sum in normal summer climate, specifying important savings on cooling loads of the neighboring buildings (Chatzidmitriou, 2012).

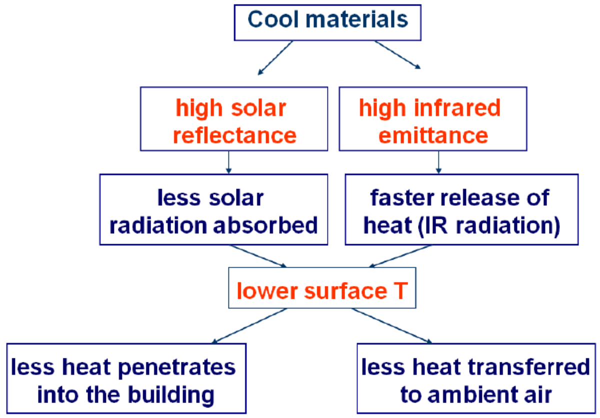


Figure 2.3 – Impact of Cool Materials on the outdoor Environment (Author, 2015)

Doulos et al. (2004) performed a comparative investigation aiming to study the appropriateness of pavement materials used in urban spaces in order to reduce ambient temperatures and mitigate heat island effect. A total of 93 widely used pavement materials in outdoor spaces were tested throughout the entire summer season f 2001. Infrared thermography procedures were used to measure the thermal performance of the materials. Later, using statistical programs the collected data were comprehensively evaluated. Comparative studies have been carried out to discover the main advantages and disadvantages of the materials investigated. Materials have been categorized based on their physical properties and thermal performance to 'cool' and 'warm' material.

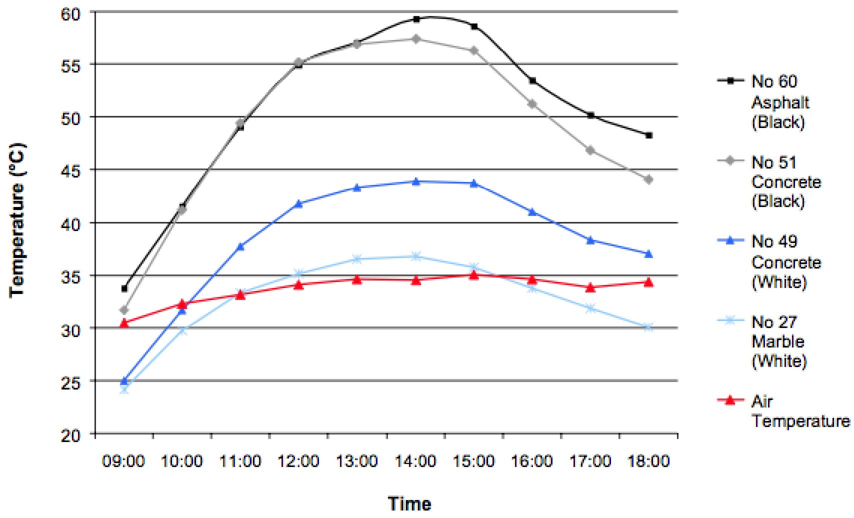


Figure 2.4 – Distribution of surface temperatures within 9:00 to 18:00 of 7th August 2001, between selected material tiles (Doulos et Al. 2004)

Moreover, the effect of sizing, color and surface roughness has been evaluated. It was observed that the majority of the materials tested were distinguished by higher average surface temperatures than the average air temperature. The maximum temperature difference between the ambient air and the light materials was about 6.9 °C. While, the maximum temperature difference for dark materials was for asphalt equal to 15.5 °C. In general, the light colored, flat and smooth surfaces showed to attract less solar radiation than the dark colored and rough surfaces. Based on their construction material it was discovered that pavements made of mosaic, stone and marble were cooler than those made of asphalt, concrete and pave stone. Also, according to their texture, those materials with smooth and flat surfaces were cooler. It was concluded that the application of cold materials is essential in outdoor spaces particularly in hot regions. Due to heat transfer phenomena the use of cold materials contributes to decrease in the air temperature. However, most warm materials are used in outdoor environments. The reason is either poor environmental planning or economic and aesthetic purposes. As an outcome, the temperature in the urban microclimate is increased and therefore the need for indoor cooling loads is greater.

The tradition of extensive paving of outdoor spaces with asphalt started only during the past century. The benefits of the smooth all-season surface for the travel of vehicles are clear, however many of the featured issues are probably not so well perceived. A disadvantage of coating street with dark asphalt surfaces is the promoted temperature of the city by daylight. A dark pavement gets warmer by absorbing light. The material in response heats the air and contributes to forming the Urban Heat Island. If outdoor spaces were lighter in color, most of the arriving light would be returned back in the space therefore the pavements and the atmosphere would be cooler. This phenomenon would decrease the demand for air conditioning. Outdoor pavements are principally produced of asphalt concrete.

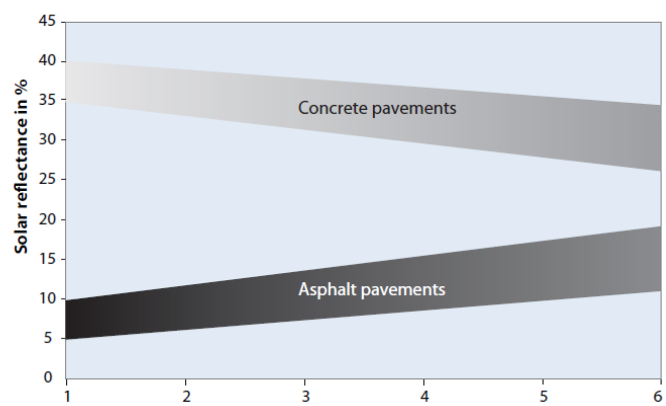


Figure 2.5 – Typical Solar Reflectance of Conventional Asphalt and Concrete Pavements over Time

An estimate of the advantages of cool pavements can be found by discovering the temperature reduction that takes place if the space was resurfaced with additional reflective pavement. Cool pavements present indirect impacts only by decreased ambient temperature. Decreased temperature has two impacts: reduced requirement for air conditioning and reduced creation of smog. Other benefits of cool paving materials that are known include: elevated life expectancy of pavements (Bally, 1998) and enhanced visibility at night in weather affecting the need for street lighting (Akbari et al. 2001).

The savings from cool pavements is meant to enhance, more pavements and roads are then built for accessibility with the development of urbanization. It is realized that the additional amounts of pavement materials lead to 29-45% of the urban structure (Gui et al. 2007).

In light of the high potential benefits gained from cool pavements, many studies have been widely performed for exploring techniques to reduce and predict the high pavement surface temperatures. One of these techniques proposed is the use of permeable materials for pavement construction which permits water exchange between the bottom soil coating and ground surface accordingly increasing evaporation (Asaeda and Thanh, 2000). On the other hand, a study by Kinouchi et al. (2004) involved altering the pavement's albedo specifications through a particular paving method that permits exposure of light colored high albedo aggregate on the surface. Also, Schindler et al. (2004) brought up mathematical programs to model and forecast the pavement temperatures with different material including vegetation, multi-layer shading elements, fast background hydraulic cement concrete and Portland cement concrete.

2.7.2. Impact of Vegetation on Temperature Reduction in Urban Environments

With growing urbanization and predictions of augmented frequency of heat waves under highlighted climate change cases, one approach that has been recommended to deal with both reduction and adaptation for urban fabrics is the enlarged use of vegetation such as gardens, parks, green roofs and street tree plantings.

Vegetation contributes to the alteration of urban climate in principally offering shading, directing wind (both as a wind guide and as a wind break) and evapotranspiration (McPherson et al.1994). The most significant exclusivity of the tree is its ability as a shading element. In this regard, the important feature of the plant is its volume, shape and leaf density. Several studies have investigated this approach through the use of analytical, empirical or numerical methodologies.

According to Ong (2003), the significance of braiding green space into the urban fabric is important in planning as much as is it is with the built structure. Greening the cities or sustainable development have greater interest lately due to the promoting environmental concerns. The advantages of growing vegetation in the urban fabric are not only environmental but recreational, emotional and aesthetic as well. He also states that the major reason of heat build-up in urban areas is insulation where the solar radiation is absorbed by the asphalted roads and building facades and the storage of this heat in the material and its re-irradiance.

The tempering effects of vegetation in urban areas were studied by Shashua-Bar and Haffman (2000), at different locations in a hot arid urban environment. They found that the moderating effect of vegetated urban streets was around 1 to 3 k. They concluded that the local cooling effect is primarily attributed to the shading characteristics of the plants rather than evapotranspiration. So, the best use of plantation is for its shading properties to decrease the short-wave solar radiation and blocking the long wave radiation from different surfaces in summer in hot arid climates.

The influence of an urban park on the summer climate was determined through field observations at many locations in a city in the west of Tokyo. The potential of reduction in air conditioning energy was studied through meteorological parameters such as: measuring relative humidity and air temperature. The findings revealed that vegetation could enormously modify the urban climate. It was observed that the ground surface temperature of the grass field was 19 °C less than the surface temperature of asphalt and 15 °C less than the surface temperature of concrete in the parking areas or commercial districts at noon. Meanwhile, the air temperature calculated 1.2 m over the ground at the grass field in the park was about 2 °C less than the one calculated at the same height in the nearby parking and commercial areas. The ground surface temperature of the grass field at night happened to be less than that of the air and the park turned out to be a cool island while concrete surfaces or paved asphalt in the city stayed warmer than the covering air even during the night. At noon, the air temperature at the park with a size of about 0.6 km^2 was decreased by up to 1.5 °C. This contributed to a huge reduction in air conditioning energy demand in commercial area (ThanhCa et al. 1998).

The soil quality of a spot is one of the major issues influencing the microclimate. Further studies carried out by Robitu et al. (2006) revealed that the cooling impact gained by a green site is because of the weak skill of its soil to absorb heat whereas the vegetation surfaces have confirmed to absorb much less heat as a result of several factors.

In fact, the biological structure of plants decreases their potential to stock heat in due to the evapotranspiration ability.

In addition to satellite images, field measurement was used to obtain the actual temperature distribution across the National University of Singapore complex to study the impact of greenery on ambient temperature. Also, computer simulation was utilized to predict some scenarios of various situations. The results revealed that buildings surrounded by or close to vegetation have lower ambient temperature than those far from the vegetation and it is a useful approach to lower the ambient air temperature (Wong et al. 2007).

Shashua-Bar et al. (2009) declared the demand to investigate the impact of plants on the microclimate in relation with site characteristics, elements, conditions and the existing materials. As a passive cooling factor, greenery has a group of interactive connections with its environment concerning with several proscribed and abandoned parameters. While the used materials in the site (albedo, stone or grass), the orientation, its geometry and the structure of the nearby buildings can influence the cooling effect of a number of trees. The rebounds between those parameters are assumed to perform a complicated task on the heat received and lost. Their study concluded that a balance between trees and grass inputs is the most successful in terms of improving the microclimatic conditions of hot arid areas. Figure 2.3 demonstrates the cooling efficiency amounts due to the applied landscape criteria.

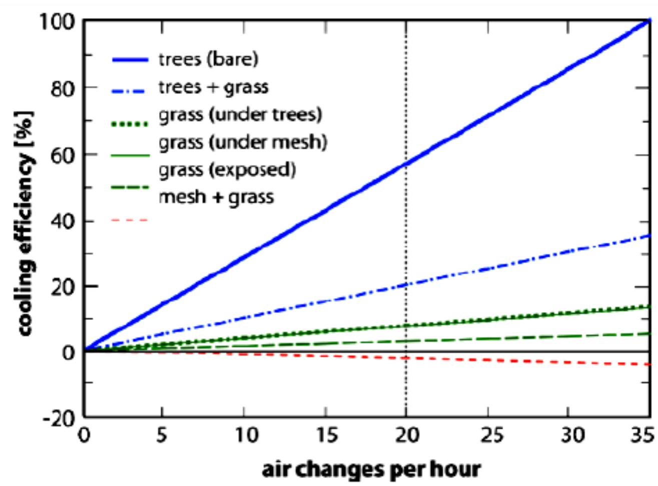


Figure 2.6 – The Effect of Calculated Cooling Efficiency of Various Considered Air Change Rates in the Courtyards (Bar et al. 2009)

Another parameter to be considered is the distance between the plants. Goergi and Dimitriou (2010) has investigated a site with 100 m² area and suggested in order to accomplish appropriate thermal comfort balance all through the year, 8 trees can be spaced with 5m interval. The layout of the planted area has to be commenced from a holistic perspective despite the types of trees. Other researchers showed that it would be useful in the cooling progression if positioned with appropriate intervals (Hoffman and Shashua-Bar, 2000).

In a dense urban community, vegetation can be located in different places such as in parking areas, in rows along the sidewalk and at street roundabouts and intersections. Hence, in order to obtain these advantages of urban vegetation, specific attention must be paid to the requirements of properly planting and maintaining healthy greenery in an urban context to create the desired temperature reducing effects.

2.7.3. Impact of Water Features on Reducing the Temperature in Urban Areas

Hot arid environments are known for lack in water balance which causes higher temperature, dryness, and therefore affects the surrounding structures such as the soil formation and its properties. The lack of water balance means that the water is evapotranspiration instantly. As a result, attaching water bodies to the outdoor space is extremely advised in hot arid environments which enhances the cooling sensation of the air.

Many studies revealed that evaporative cooling is debatably among the most effective methods of passive cooling for urban spaces in hot arid environments (Givoni, 1991; Kimura, 1991).According to Robitu et al. (2006), water surfaces improves the urban climate and reduce the energy need for cooling by absorbing, transmitting, and reflecting the radiation using water ponds. The study was achieved by using coupling methodology to simulate the solar, thermal radiation, and air flow for the three layer water pond. Simulating the method using a numerical procedure implemented in CFD, the surface temperatures were initialized to evaluate the radiosity in the long wave radiation to recalculate the temperature until the result validates the assumptions made. The results showed that at noon, the first layer of the water pond absorbed 30% of the solar radiation incident, while the second layer absorbed 13%. Finally, the third layer absorbed 39% with 18% being reflected back into the atmosphere.

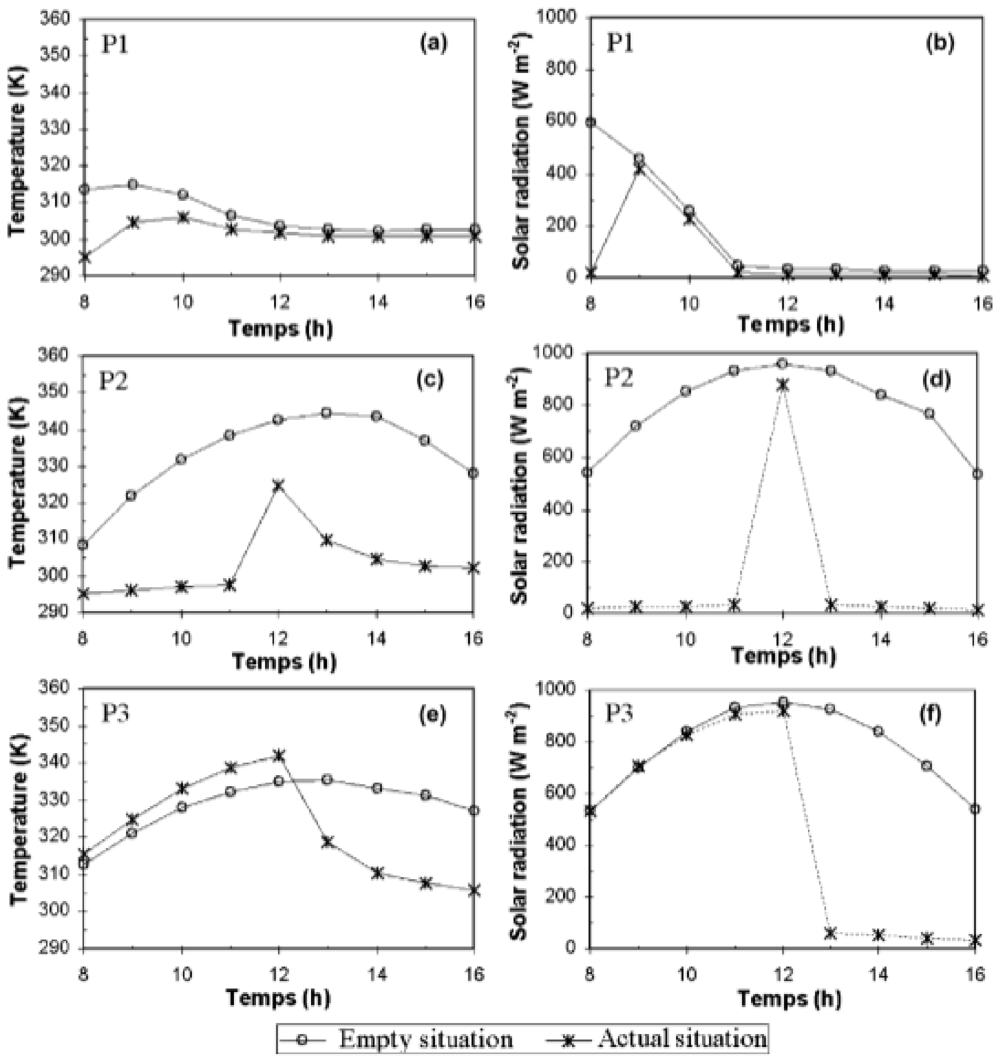


Figure 2.7 – Surface temperature and solar radiation: empty and actual cases (Robitu et al. 2006)

Moreover, Givoni and La Roche (2000) investigated the performance of an indirect evaporative cooling system with an outdoor pond which is suitable for climates with high relative humidity such as Dubai. The study was experimented in the summer of 1999 at the University of California at Los Angeles using a 6.88 m^3pond and a 4.46 m^3 test cell. The test cell wall was made of fiberglass from the inside and plywood from the outside, while the roof was made of concrete with tubing for cooling. The aim of the experiment is to determine the applicability of the evaporative cooling systems in different climates. The system was compared with the outdoor temperature. The results showed that the maximum temperature including the water pond decreased by 3.9 K compared to the maximum outside dry bulb temperature. The authors concluded that the to ensure a passive cooling of a building, the indirect cooling systems are suitable to combine with thermal mass to achieve the desired outcome.

In 1998, Nishimura et al.suggested innovative water amenities such as spray fountain and waterfall to create comfortable urban microclimate. The air temperature measurements on the sheltered side underlined a3K reduction in the temperature in the water evaporation period and that the result of the water feature from 14:00 to 15:00 PM could be sensedtill about 35m of the water feature.

Using a numerical approach based on coupling the CFD model, the useful effect of water ponds in urban spaces during summer season was investigated experimentally in situ in Nantes, France. The model was applied to evaluate the effect of water ponds in an actual town square. The results demonstrated that water ponds should be considered as real means for the improvement of microclimatic conditions in outdoor spaces (Robiu et al. 2006).

In a parallel study done by Fernandez-Gonzalez and Costache (2011), the cooling performance of wet and dry roof ponds in University of Nevada, Las Vegas were evaluated through experimental approach. The set up involved two duplicate test cells each with a 6 inch deep roof pond and removable surface. The two cells were different in having dry and wet roof ponds. During the astronomic summer (June 21^{st} till September 21^{st}), the indoor and outdoor bioclimatic results were tentatively investigated. The outcomes showed that a dry roof pond has the capability to maintain the maximum indoor temperature almost 12 °F lower than the maximum outdoor temperature. It was also revealed that by reducing the maximum indoor temperature an extra 8 °F, a wet roof pond is capable to improve the performance of the dry roof pond.

2.8. Aim and Significance of the Study

The following research questions need to be answered in order to achieve the purpose of the study:

- What principles should be considered when designing for a bioclimatic landscape in hot arid regions?
- How can the application of vegetation, cool pavement and water features enhance the mean radiant and ambient air temperatures of urban outdoor spaces?
- To what level the treatment of landscape surfaces can reduce the mean radiant temperature in hot arid environments?
- Which proposed scenario has the most influence on reducing the mean radiant and ambient air temperatures of the current case study?
- Does the implication of treated landscape surfaces make a significant contribution to lowering the ambient air temperature of the community?
- To what extent are the landscape surfaces of Dubai's residential neighborhoods bioclimatic?

The aim of the study is to redesign the landscape surfaces of Dubai residential neighborhood based on bioclimatic interventions in order to achieve lower surface and air temperature in hot arid contexts. Therefore, the research objectives are:

- Determining the influence of meteorological factors on outdoor thermal performance in hot arid environments.

- Presenting an optimum scenario for the landscape of the selected case study based on bioclimatic parameters to carry out a comparative study that will assist in:
- Analyzing the amount of progress in reducing the surface and air temperature accomplished by each and all parameters.
- Recognizing the performance of the parameters examined.
- Demonstrating a successful proposal to promote appropriate landscape land use design including pavement materials, greenery application and water features of a typical gated urban community in Dubai.
- Assessing the advantages of bioclimatic landscaping against the paradox of the region's contextual climate.
- Establishing a series of recommendations and innovations embracing benefits of bioclimatic landscape design for the professionals in the region.

Although numerous cities worldwide have studied and investigated the impact of urban surfaces on microclimatic factors, it is still considered to be a new phenomenon in many developing countries. In the Middle East within the last decade most of cities have been developing rapidly; Dubai stands out among these cities in terms of development within a short time frame. Incredible development has occurred throughout Dubai from 2000 to 2012. Throughout this period, huge additions to the built up area at urban scale have been made and therefore natural landscape surfaces have been rapidly modified and replaced by artificially engineered materials. Urban structures and skyscrapers have been constructed with minor attention on environmental aspects affecting both community occupants and native Dubai landscape. Causing negative impacts on microclimatic conditions is an obvious example of such a rapid urban development to its surroundings. Consequently, in order to mitigate the negative impact of urban surfaces on outdoor thermal performance a series of regulations and considerations should be followed.

The significance of the study in particular in Dubai is remarkable. By implementing the guidelines and suggestions presented, the urban planning and urban design authorities will be able to grow their environmental objectives of creating a sustainable future for Dubai. Understanding such principles is not just useful to the government and authorities but can benefit developers within country as well. Urban and landscaping projects could accomplish more profits due to cooling reserves that can be executed. On a higher level, this research symbolizes a hot arid climate where executions can be developed in areas with similar climatic criteria. The Gulf countries possess similar climatic characteristics and are also recognized with a fast rate of urban development and evolution. While the scope of this study focuses on a residential community, the ecological principles can be used at a larger urban scale. Knowledge and awareness achieved in the present study with regards to the microclimatic factors, their performance and impacts will greatly benefit environmental researchers.

Chapter 3 – METHODOLOGY

3.1. Literature Review on the Methodology

The current section presents a literature review of various research methodologies applied to conduct studies related to this topic. Depending on the research resources some of the methodologies that can be investigated include: observational methods, field measurements, case studies, computer simulations, numerical methods and etc. In the following, we will only discuss the methodologies which were used the most in similar studies. It is important to get an overview of methods used by other researchers to accomplish similar goals and guarantee the quality of study added to the research field. Here we will critically identify and justify the tools and techniques used in each stage of research. For each category the most common methodologies used to carry out similar investigations will be justified and the ideal research method will be clarified separately.

3.1.1. Experimental Method

Due to the high rank of experimental control attained, experiments have high validity of outcomes and huge scientific reliability. Experimental method is one of the most applied methodologies used to conduct research during the past. The idea of repeatability provides the possibility of test and error which skilled humankind remarkable findings. The controlled conditions found in a laboratory generally assured the level of correctness of the outcomes if correctness has been achieved during the examination procedure. However, the high level of correctness beside the money and time required for applying such methodology, leads to a problem under several circumstances. Experimental method can be used to verify the hypothesis of this study.

Similar to a lab outdoor urban environment can be prepared to compare the existing scenario with the optimized one. These outdoor experiments have the benefit of availability of several outdoor variables in the testing model which can reduce errors enormously. The results gained with this method can be more related to a particular location of the experiment rather than a universal theory.

The number of research papers used experiments to study the impact of outdoor parameters than improve the landscape of urban spaces environmentally. Essentially due to unavailability of other methods and limitations, old research had used experimental methods.

Doulos et al. (2004) performed a comparative study using experimental method to study the cooling effects of cool pavement materials in outdoor urban environment. They measured the thermal performance and physical properties of 93 different pavement materials during summer. To implement their measurements they used an infrared camera and a contact thermometer to consider minor errors generated with reflected infrared radiation. The measurements of the surface temperature were conducted hourly from 9:00 to 18:00.A meteorological station at the university campus was in charge for recording the low relative humidity, high air temperature, wind speed, clear sky and direction. The study contributed to selection of more suitable pavement material for outdoor spaces and thus to reduce the UHI levels and promote outdoor thermal comfort conditions.

Shashua-Bar et al. (2009) organized an open space in a hot arid environment to examine six various landscape metrics. The study was controlled and conducted in two neighboring semi-enclosed courtyard type areas with similar orientation, geometry, material features and relation to the environment. However, different landscape treatments were applied to both spaces. The measurements were taken in the two spaces at the same time giving both three landscape configurations. The theory of merging many configurations weakens the reliability of the outcomes. Since it needs an approximation of the air change rate which is very complicated to measure in an open area the cooling efficiency has not been measured straight.

The experimental methodology is believed to be very serious because it needs very difficult experimental circumstances. The outcome of such experiments can direct to unsure results except if the setting is controlled and the hypothesis simply involves a single variable.

3.1.2. Social Surveys

The temperature reduction gained by any of the landscape parameters demonstrates that human factor has an effective role in investigating in qualitative or quantitative information gathered. The term ‘thermal comfort’ describes earlier was one of the major motivation for several studies. Subjects linked to the thermal comfort levels relying on the human factor engage social surveys. The aim of using this methodology is to collect data about inhabitants’ answer to the outdoor variables. Questionnaires were applied comprehensively to encompass the topic of outdoor thermal comfort levels. Although this method might occasionally not have scientific reliability due to amount of bias found, it is extremely flexible in terms of location, time and duration. A preset sampling standard should be assigned and be precise just before the taken analytical procedure to the information attained in order to avoid the drawback of the previous process. Gender, age, clothing and other parameters influence the correctness of the data collected. Due to the great number of unbalanced dependent parameters, documenting the psychological dimension is believed to be more complicated than the physical dimension. Social surveys often deliver subjective rather than objective outcomes and that is where it is short of scientific reliability.

Baker et al. (2001) concentrated on studying the human dimension by conducting a research on thermal comfort in outside areas. They applied an entirely physiological scale that was realized to be insufficient in describing thermal comfort levels in urban open spaces. The model verified to have various reasons for employing the open spaces which managed their level of approval for the microclimate. On the other hand, in a study by Nikolopoulou and Spyros (2005), a considerable database including 10,000 questionnaires in a number of cities was used. They proved that using a single factor as a determinant for comfort is inadequate to evaluate thermal comfort levels. However, they used field measurement along with social surveys that confirmed to have a relationship between psychological and physical factors for studying the use of outdoor areas.

Several software were used to identify the outcomes in scientific components. The software were applied to control the relationship between the quantitative data measured and the qualitative data obtained from social surveys. Thermal indices which were developed to regulate thermal comfort levels included Physical Menu Vote (PMV), Predicted Percentage of Dissatisfied (PPD), Physical Equivalent Temperature (PET) and Actual Sensation Vote (ASV). As bioclimatic indices, Geitani et al. (2005) employed the Comfa and Thermal Sensation to specify the levels of satisfaction and dissatisfaction. Bastos et al. (2006) applied PMV as a prediction of comfort by using the software created to put in data gathered from social survey. The results were used to enhance the urban microclimate by employing passive cooling practices throughout a simulation process.

Each study confirmed that applying social survey method is not merely enough to designate thermal comfort levels of urban environments.

3.1.3. Computer Simulation

This method is based on accurately translating all the environmental parameters into the language which the computer recognizes to analyze it under particular variables. Through this translation an important choice of which of the related variables should be duplicated and which will be removed while assure those removed variables do not change your outcomes. Computer simulation method permits the researcher to create some hypotheses that require to be considered cautiously. This method has the capability to manage complicated investigations fast with complicated parameters with more effectiveness than experimental methods which is the reason it has been widely used in recent times. Also, it can predict conditions that have not happened so far and predict parameters that are against the environment.

Simulations are now being used in different fields of study. Researchers come across it as an undemanding and economical way to run experiments in a practical standard rather than realism. Improvements taking place within the existing software is assisting this to occur. Acknowledgment by certified associations towards these syllabuses attains the justification of the outcomes achieved. The huge amount of precision of the performance is a further evidence for it validation. Flexibility and duplication of the simulation method makes it a scientifically consistent research process if the instruments and software applied are certified. It can be used to study complex variables that are sometimes not possible to investigate which is the state of outdoor urban spaces. Meanwhile, the practical form of information and parameters can in some cases be risky to the researcher and might establish wrong result.

In a study by Wong et al. (2007), Envi-met a three dimensional urban microclimate developed to simulate the surface-plant air temperature in the urban environment was used. The input data was according to information and electronic map presented by the Estate and Development office. The simulation carried out by four different scenarios including the present case. Other than the present scenario, three proposals were simulated based on the data collected by satellite images indicating high temperature points. A best and worst case scenario were checked in places recognized to demonstrate high thermal stressed through day and night. In addition, field measurement was conducted on a particular day to validate the results of simulation. In terms of simulating the green roofs in some buildings the software used was limited and would have had more potential.

Applying simulation methodology, Spangenberg et al. (2008), focused on the effect of vegetation as a key factor in designing sustainable landscapes which enhances urban microclimate and improves outdoor thermal comfort levels in hot arid environments. The study using ENVI-met Analysis was conducted in several geographical locations including Thessaloniki of Greece, Rio de Janeiro and Sao Paulo of Brazil. The results established an idea about the different microclimatic conditions of three cities and concluded that the shading and evapotranspiration leads to lower ambient temperature and improvement in humidity. Due to the potential of simulations that were able to be carried out for different case studies, the paper was an excellent example of research work. It enabled the researchers to analyze their findings more accurately.

Robitu et al. (2005), connected the thermal radiation and airflow models to examine the impact of greenery and a water pond on the urban microclimate. A compound geometry of outdoor spaces has been simulated using computational fluid dynamics CFD model for the airflow implemented in FLUID environmental software and SOLENE software for the thermal radiation. Two scenarios were proposed: one which enhances the microclimate and adds trees and a water pond and one with no trees and water pond. The study mentioned to require one week simulating one scenario only. Although the computing method has some drawbacks, it can provide valuable quantitative data for urban design analysis.

To inspect the passive cooling effect of orientation, geometry and vegetation in outdoor space, the Cluster Thermal Time Consultant (CTTC) model is a different simulation software used and has been conducted by Bar and Hoffman (2003). The model predicts the air temperature by calculating the heat obtained from outdoor environment mostly net solar radiation and anthropogenic heat release. The selection of the simulation software used to certify or falsify the hypothesis was according to the abilities of the software in subject.

All available software for simulating the outdoor urban areas need various kinds of data and therefore gives different results. Through studies evaluated, selection of the appropriate methodology is relied on the resources available for the study.

3.1.4. Field Measurement

Onsite data collection is known to be a significant method for the majority of the scientific research works. It is basically the analysis of the existing condition into data which can be later used in a new research. Therefore, field measurement is generally a complementing yet necessary method to the main one. It can be applied individually to declare specific existing theories or hypotheses. The correctness of this method depends on the accuracy of the measuring instruments. Due to its simplicity, the field measurement methodology possesses scientific validity. When this method is applied for a study therefore it pursues the thermal comfort records that are supposed to include different climatic conditions. The time interval needed to study specific phenomena are usually long.

Climatic records have to be measured with caution when investigating thermal comfort in urban areas. Thus, the onsite analysis becomes important and needs high levels of precision. The time interval in information gathered requires being extensive enough to gain reliable measurements. The availability of many dependent and independent parameters in the field needs the understanding of the researcher on how they can influence the results. Field studies inspecting the outdoor variables have usually been incorporated with simulations or social surveys.

Bastos et al. (2006) applied the Actual Sensation Vote (ASV), the Predicted Percentage of Dissatisfied (PPD) and the Predicted Mean Vote (PMV) as the index to the outdoor thermal comfort levels. Field measurements have come with the executed questionnaires to observe the physical condition of the landscape environment. Applying an intercourse of scientific methodologies like simulation or field measurement as well as social survey has reduced the possible impressed outcomes attained from questionnaires. Gaitani et al (2007), employed simulation in addition to the ‘Comfa’ method in a challenge to enhance the outdoor thermal qualities. Their research contained some bioclimatic guidelines that removed the discomfort feeling investigated in the primary step of the study which authorized the results of the research.

A large application of reflective materials in hot arid climate was investigated by Santamouris et al. (2012) with the aim of enhancing thermal comfort conditions, reducing the UHI levels and promoting the environmental quality. Detailed measurements of the microclimate were performed prior to and after the installation of proposed pavement material. It was found that the use of cool paving materials leads to the decrease in surface temperature by 12 k during a typical summer day which significantly improves thermal comfort conditions.

Suscaa et al. (2011), used field measurement to demonstrate the positive impacts of vegetation throughout monitoring both the air and surface temperature of three roofing systems in New York City. Besides, in order to provide data about appropriate environmental alternatives three types of roofs were considered: a high-reflective, a black and a complete green roof. The impact of surface albedo on radioactive forcing was established, the surface temperature of the three roofs was investigated and the difference of heat fluxes and its impacts on the life span of the roofs' material was calculated. The findings revealed that green roofs considerably mitigate the Urban Heat Island Effect.

Nikilopoulou and Lykoudis (2007) focused on the impact of the microclimate parameters and the application of the outdoor factors. The findings of the RUROS project, showed the huge reliance of the treatment of space on the microclimatic parameters. Field measurements have been carried out in addition to social surveys in many regions. The significance of the physiological and psychological variables for the thermal comfort sensations stays reliable, thus it is essential to improve the physical microclimatic factors of the landscape in order to encourage public to use the place. Offering a diversity of microclimatic alternatives to assist in different users' preferences has been suggested and therefore requires more surveys. In a study by Nowaka et al. (1996), field measurement was used to identify urban vegetation covers of the entire US and Europe through overlaying aerial photographs. In their study, the level of line crossing tree heads were divided by the total level of the line produced percent tree cover. Some errors occurred from the difference of the total length of cut off on different lines. However, better accuracy was obtained from more short lines than fewer long lines.

Pedestrians' thermal comfort was investigated in an urban park in Cairo by Hassan and Mahmoud (2011). The study was done in hot and cold seasons using field measurement and social surveys. The subjective survey consisting of questions on the thermal condition perceptions using ASHRAE 55 Thermal Sensation Vote (TSV) in nine various spots of the park. The thermal condition factors: solar radiation, wind speed, air relative humidity and air temperature were calculated. Throughout the information -using the RayMan model - the values of the Physiologically Equivalent Temperature (PET) were measured in every spot. The users' clothing and metabolic rate were also monitored. The outcomes of the field study were compared with predictions about the thermal condition. Due to wind speed and different sky view factors, difference in the PET index among these spots was revealed. Results demonstrated a change in human comfort sensation among various landscape spots. The research advised that when designing landscapes for the future urban open spaces in the hot arid environments, the thermal demands of users and conditions of the local climate should be cautiously taken into consideration.

Many researchers used the field measurement as an assisting instrument to their core method which is the computer simulation. In fact, field measurements are the source of the input information needed for simulations. The concept of measurements done to be inserted in the software makes the findings more reasonable than having to put in total measurements. Studies conducted by Bar and Hoffman and Wong et al. based their software simulations on experimental monitoring done in the field of study.

3.2. Selected Methodology

Taking into consideration the complication of the outdoor landscape environmental factors, the research purposes and restricted resources, some of the research methodologies were eliminated from this study. Applying social surveys is not appropriate for measuring the physical environmental factors like air temperature. Although, the thermal comfort levels confirmed by previous surveys would be counted as the background of the thermal sensation. Experimental method requires great time and financial resources which are not practical and accessible in the existing condition.

Computer simulation has been regularly used in parallel surveys and was chosen for the present study due to the different benefits over other methodologies. The research hypotheses mentioned previously is to study the microclimatic impact of sustainable landscape design principles on outdoor environment. To investigate the environmental principles that would improve the air temperature of the landscape, each principle has to be examined and authorized independently. The importance of a controlled condition for such studies has promoted the application of computer simulation for this topic. The simulation method also has the benefit of analyzing a large number of parameters of the hypotheses in a short period however precise enough to popularize the findings to such climates.

In the current study, surface temperature and ambient air temperature of the existing and the proposed landscape scenarios with different surface vegetation cover, pavement material and added water bodies and subsequently the resulting impacts of these variables on the microclimate will be investigated for the longest day of the year.

The first scenario is the base case which investigates the existing landscape condition and simulates the scenario to attain results on the surface temperature and finally ambient air temperature during the peak summer season. The second scenario proposes a case in which the existing asphalt road is replaced by concrete pavement while all other parameters are remained the same. The third scenario attempts to alter the landscape in terms of vegetation and then simulating it to attain the surface temperature and accordingly the ambient air temperature of the environment. The forth scenario subjoins a number of water features to the base case. Lastly, a combination of the three interventions to the base case was simulated as the optimum landscape surface scenario of the site. A comparison of the results of the aforesaid scenarios was done to establish conclusion and recommendations on what incorporates temperature reducing landscape surface for hot arid environments.

3.3. Selected Software

The requirement of the current study is to simulate outdoor urban microclimate. City SHADOWS, SOLENE, ENVI-met, City CAD, CFD and Ecotect Analysis are simulation software used previously for this purpose. Ecotect Analysis is considered to be very restricted in terms of measuring precise wind and temperature variations in outdoor space. City SHADOWS is used to simulate solar exposure. These take general data of the climate with no variations in every climatic area. City CAD does not have the ability to simulate air temperature and wind variations. Computational Fluid Dynamics (CFD) is the most usual software applied for investigating Urban Heat Island effect. On the other hand, CFD is not really useful in testing the microclimatic impacts of vegetation in urban landscape.

ENVI-met software was realized to be the most appropriate for the factors recognized compared to other tools for calculating outdoor variables. It is often updated free software developed for conducting outdoor studies which concentrates on all the environmental dimensions such as the soil, the atmosphere and all surfaces in the space. ENVI-met integrates all the essential factors available in the outdoor space which provides reliable findings. ENVI-met is 3D software analyzing micro-scale thermal connections in urban environments. The model utilizes both the thermodynamic procedures happen at the ground surface, walls, roofs and plants, in addition to the calculation of fluid dynamics features like turbulence and air flow. The software considers all kinds of solar radiation: direct, reflected and diffused. ENVI-met estimates the average radiant temperature. The calculation of radiative fluxes incorporates the plant shading, shielding and absorption of radiation plus the re-radiation from other plant layers. It also has the benefit of integrating various types of vegetation estimating the plants temperature, the vapor and heat exchange in the air canopy which is an essential parameter for the current study. Additionally, the software is planned for micro-scale with a general time frame of 24 to 48 hours with a maximum time stop of 10 sec and a usual horizontal resolution from 0.5 to 10 m. The resolution provides for calculating small scale relations among plants, buildings and surfaces that is suitable for this study (Bruse 2007). In parallel to ENVI-met, Ecotect Analysis was used to obtain the general climatic information for this study.

3.4. Envi-met Software Validation

The validity of Envi-met software perches under the inspection of many scientific articles, government associations and scholars. In investigating the reliability of the software, these key contributions were affirmed: reliability and factors examined, founder capabilities and certificates and software potentials. Possessing a background in climatology and geography, Dr. Michael Bruse developed Envi-met depending on his broad study and mathematical equation like Navier-Stokes formulas that calculate the obligatory output for the factors experimented and a straightforward upstream advection system is utilized to measure the pollutant diffusion.

Using Envi-met software, Bruse and fleer (1998), modeled surface plant air interfaces in the urban context applying a 5m grid concentrating on the temperature distribution and horizontal and vertical wind flow. The research illustrated that all inputs such as building a small green area next to the site of the study are considered in the simulations. The software was proficient to simulate the effect of the orientation and aspect ratio of a street valley where the outcomes obtained agreed with the outcomes achieved by Masdoumi and Mazouz (2004) applying the SOLENE software to study the exact variables. Bruse (2009), conducted a research on the evaluation of effect of urbanization on environment: utilization of bioclimatic directory testifying to Envi-met validity.

Results obtained by the software have evidenced to be in accordance with research performed using different research methods or different software. The single drawback of Envi-met is displayed in the values of a few outdoor factors where some papers discussed to be higher than or below the current conditions. Thamper and Yannas (2008), analyzing the urban infrastructure of Dubai where obtained results were nearly analogous to those calculated from the field study but with a minor decrease. A further research performed by Hein and Jusuf (2007) in National University of Singapore using Envi-met compared the existing outcomes of the current situations to the promoted scenario which confirmed to deliver a higher value by 1 °C. Many researchers suggested the demand for alterations of the results achieved by Envi-met (the problem with all software simulations) with field measurements. The cause of such shortcoming can be as a result of preventing the heat storage of the buildings that would lead to further heat radiation in outdoor spaces.

3.5. Data Collection

3.5.1. Study Area

Located on south of the Persian Gulf and Arabian Peninsula, Dubai is the second largest emirate and economic capital of the United Arab Emirates. The city with the largest population among other emirates has been currently recognized as a business and tourism hub in the region. However Dubai’s economy was erected by the oil discovery, its formula for business runs the emirate’s economy at the present. Therefore, its main revenues results from free trades, real estate and tourism industry. Dubai is now a city that grabs the world’s attention by its unmatchable architecture, remarkable hotels and world-class entertainments and events (Dubai.ae, 2014). However, Dubai perches exactly within the Arabian Desert; its topography is considerably different from southern part of the UAE in which much of Dubai's landscape is underlined by sandy desert prototypes, whereas gravel desert leads at the southern region of the country (Wikipedia, 2014).

Figure 3.1 – LEFT: Location of UAE on the World Map; RIGHT: Location of Dubai on the UAE Map (Source: Google Maps)

Dubai's weather is generally hot and sunny because the line of the Tropic of Cancer crosses the UAE. Dubai has only two seasons, summer and winter. It brings irregular rainfall in the form of short gushes and infrequent thunderstorm which is annually less than 0.1mm and mostly occurs between December and March. The weather in Dubai is very hot and humid during summer and the temperature can reach to 50 °C with 90% relative humidity. While in winter, it has an average temperature of 25 °C. The Dubai prevailing wind comes from Northwest with an average speed of 10 km/h and it sometimes reaches at its peak at 20 km/h.

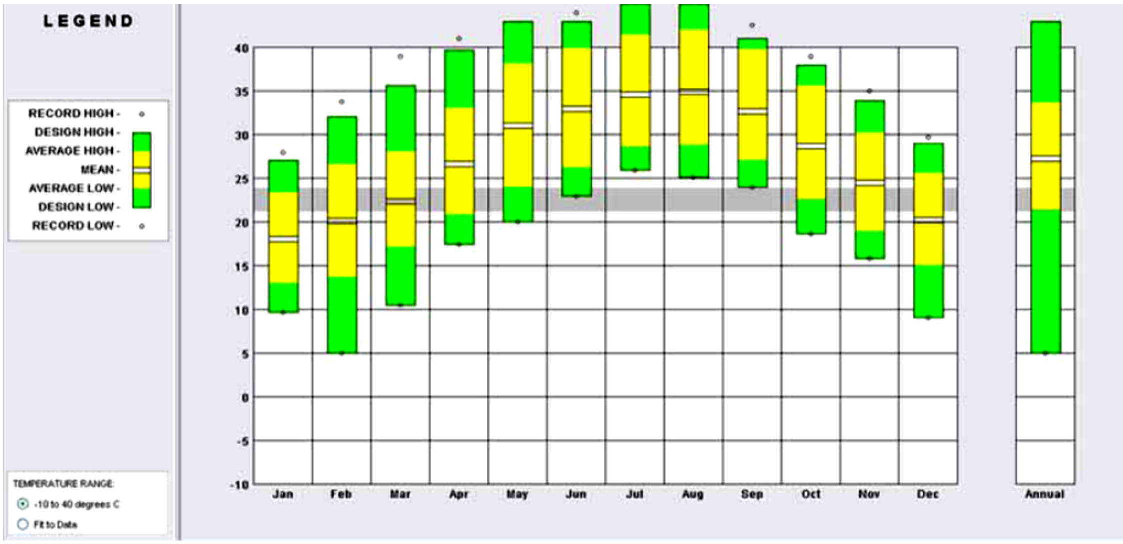


Figure 3.2 – Monthly & Annual Temperature Values of Dubai City (Source: Climate Consultant Software)

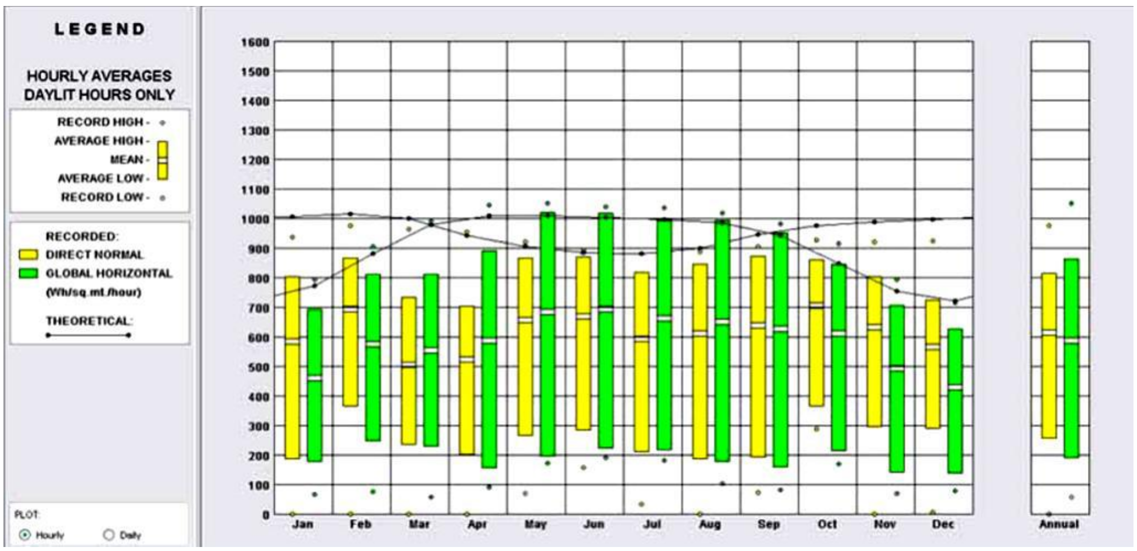


Figure 3.3 – Monthly & Annual Daylight Hours (Source: Climate Consultant Software)

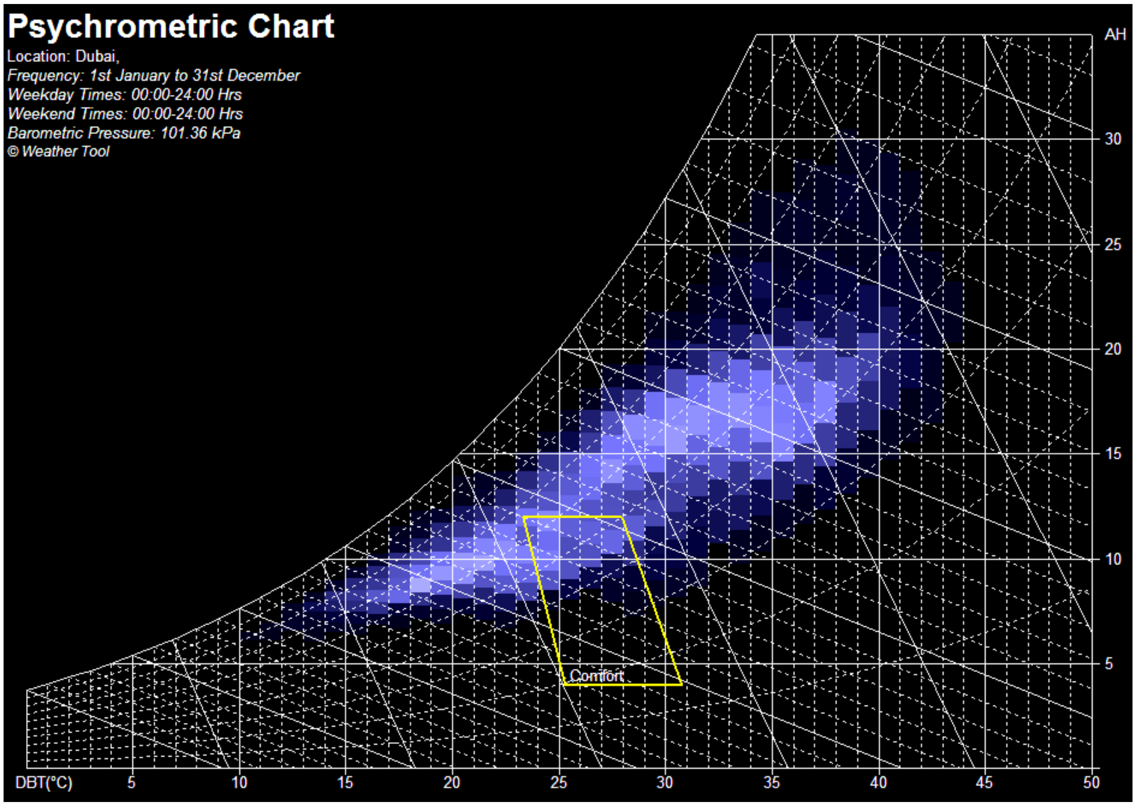


Figure 3.4 – Psychometric Chart of Dubai (Source: Climate Consultant Software)

3.5.2. Case Study: Jumeirah Village Circle Villas

The development includes a sequence of villages connected to each other by conquered landscaped spots and canals. It offers 3,184 one or two bedroom townhouses and 2,883 two to four bedroom independent villas. Located in one of the most accessible districts of Dubai, the Jumeirah Village Circle was planned to offer a sense of community in a quiet village setting. In terms of the design, the community conquests a sense of equilibrium through a radial layout with roads that finish at a central community center.

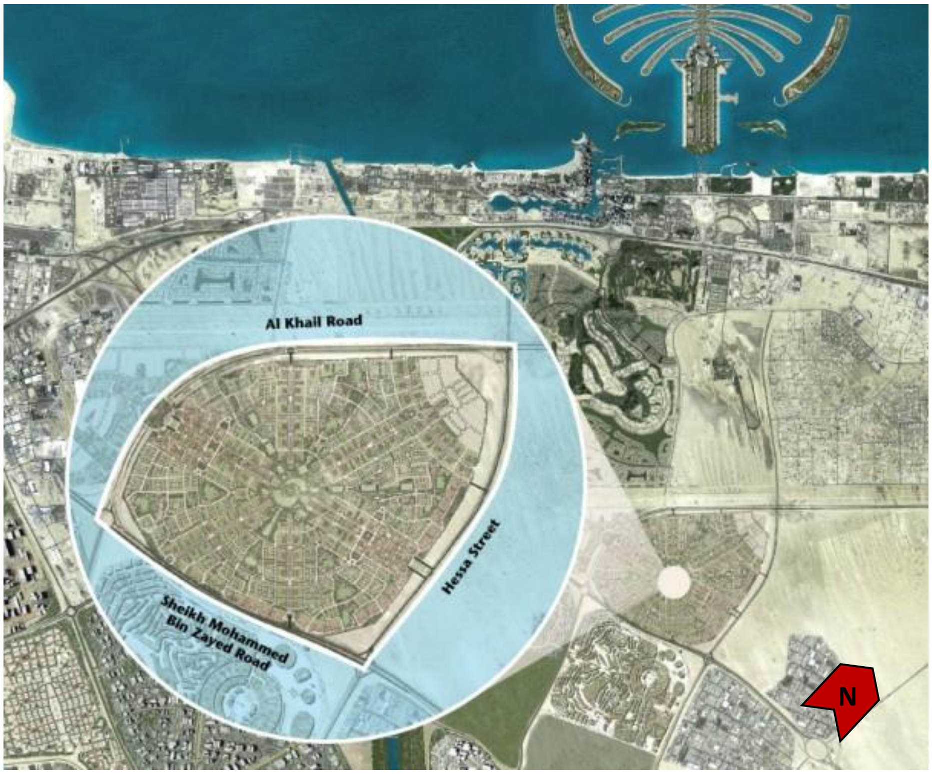


Figure 3.5 – Jumeirah Village Circle Community Location Map (Source: Google Earth)

Jumeirah Village Circle proposes a wide range of villas that guarantee privacy and easy access to public space. The houses are a blend of Mediterranean and Arabian architectural styles and themes. They highlight carved doors, arches, red-tiled roofs, tiled floors and walls and ornamental spiral columns saturating the traditional Middle Eastern elements and patterns. In the heart of new Dubai, with its own distinctive architecture and host of amenities, the community provides a self-contained environment for inhabitants. The development is supposed to provide a healthy lifestyle through its parks, schools, medical facilities, leisure amenities and mosques with 24/7 security. The houses at the Jumeirah Village Circle were designed to encompass the standards of village life in an urban context.

Figure 3.6 - Zoom in Shots of the Study Area at Jumeirah Village Circle (Source, Google Earth)

Since the district is a recently developed residential community, it has a great potential for future landscape developments and the current study will be beneficial to understand what would be the best solutions that can be implemented. Children can enjoy in vegetated open spaces and the residents can benefit from the greenery and reduced ambient temperature. Also, since the site is located in outer line of the city surrounded by sandy desert, landscape plays an important role in effecting the human comfort in such residential communities.

Chapter 4 – Computer Model Setup

4.1 Modeling the Context Using Envi-met

Simulating the JVC context with Envi-met engages fluid dynamics calculations and thermodynamic procedure at plants, surfaces, walls and roofs (Bruse, 1999). The determined procedures of the simulation phase are described below:

4.1.1. Model Area Inputs

The area input context is sensitive and depends on the model dimension, size, location and environment (Bruse, 1999). Height of the buildings, types of soil profile, vegetation and the conditions of surface materials can be characterized in the area input editor (eddi).

4.1.2. Model Configuration

A model configuration file is designed to contain the metrological index of Dubai on a specified date. Incorporating this data helps the model operate an analysis for the specified time to check the thermal conditions of the area (Bruse, 1999). For this purpose, the calculated performance variables are surface temperature and ambient air temperature.

4.1.3. Model Run and Outputs

The built model from the Envi-met editor is analyzed and operated in model run phase following the obligatory input data described in model configuration (Bruse, 1999).

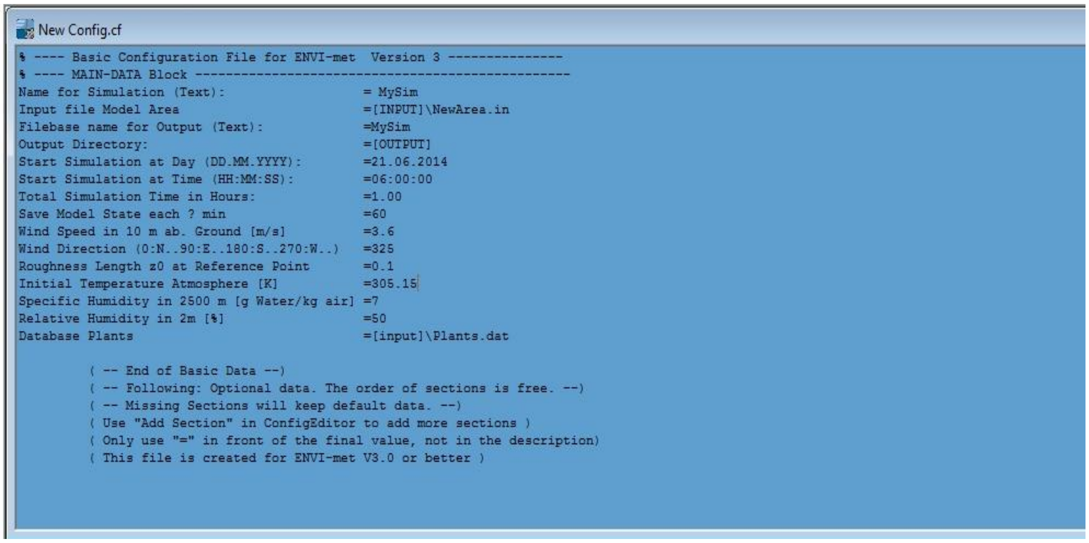
This process follows the given time frame inserted in the configuration and produces the required output data for the analyzed variables determined in model configuration.

4.1.4. LEONARDO Visualization

The output files produced in the model run are then visualized by LEONARDO. The three key output data folders prepared for visualization include soil conditions, surface data and atmosphere (Bruse, 1999). Visuals of all variables can be observed on hourly basis according to the specified time order assigned in the configuration.

4.2 Model Setup Details

The model is set up according to the main configuration for the Jumeirah Village Circle Villas. The inputs for the configuration are as follow: model area input, simulation time frame, Dubai climate data, building surface temperature, plant and soil profile data.


New Config.cf

```
% ---- Basic Configuration File for ENVI-met  Version 3 ---------------
% ---- MAIN-DATA Block -------------------------------------------------
Name for Simulation (Text):                    = MySim
Input file Model Area                          =[INPUT]\NewArea.in
Filebase name for Output (Text):               =MySim
Output Directory:                              =[OUTPUT]
Start Simulation at Day (DD.MM.YYYY):          =21.06.2014
Start Simulation at Time (HH:MM:SS):           =06:00:00
Total Simulation Time in Hours:                =1.00
Save Model State each ? min                    =60
Wind Speed in 10 m ab. Ground [m/s]            =3.6
Wind Direction (0:N..90:E..180:S..270:W..)     =325
Roughness Length z0 at Reference Point         =0.1
Initial Temperature Atmosphere [K]             =305.15
Specific Humidity in 2500 m [g Water/kg air]   =7
Relative Humidity in 2m [%]                    =50
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 )
```

Figure 4.1 - Envi-met Configuration Setup for June 21st, 2014

Following the categorization of landscape surfaces, the following ENVI-met modeling scenarios were developed in order to compare the impacts of incorporating different alternatives of landscape surfaces. These modeling scenarios were created based on achievable and realistic landscape surfaces interventions that could be executed to all study areas:

1^{st} Scenario: Existing landscape surface configuration as a base model; adjusted with site data.

2^{nd} Scenario: The asphalt paved driveways are replaced by concrete pavement; other characteristics of the site remain constant.

3^{rd} Scenario: Auxiliary vegetation is exerted to the field in addition to the current plantation; other characteristics of the site remain constant.

4^{th} Scenario: Implication of urban water features is applied into certain spots of the landscape; other characteristics of the site remain constant.

5^{th} Scenario: Combining the 2^{nd}, 3^{rd} and 4^{th} scenarios together as an environmentally enhanced landscape surfaces proposal for the JVC community.

Recording the parameter inputs on hourly fundament, the model is allocated a 12 hour timeframe. For this purpose in order to obtain a more accurate assessment of the whole scope, a profile is installed for temperature deferential at various times of the day. The internal building properties are determined for all buildings within the model area and cannot be modified on single account. The simulation is fixed for clear sky conditions on the ENVI-met model considering no cloud cover is registered.

The warmest season summer is selected to validate thermal performance levels of different surface materials during daytime when they receive the solar radiation from the sun in the Northern hemisphere. Moreover, many human activities happen during daytime in urban areas. The experiment is going to be performed only in the daytime therefore the simulation date is put during the summer solstice June 21^{st}, 2014 since has the longest daytime during the whole year as displayed in Figure 4.2. Running the simulation on June 21^{st} is also due to the error happening in ENVI-met program when the temperature goes too high. Moreover, if the proposed scenario is tackled and availed on June, 21^{st} then the proposal can be applied during the other parts of the year.

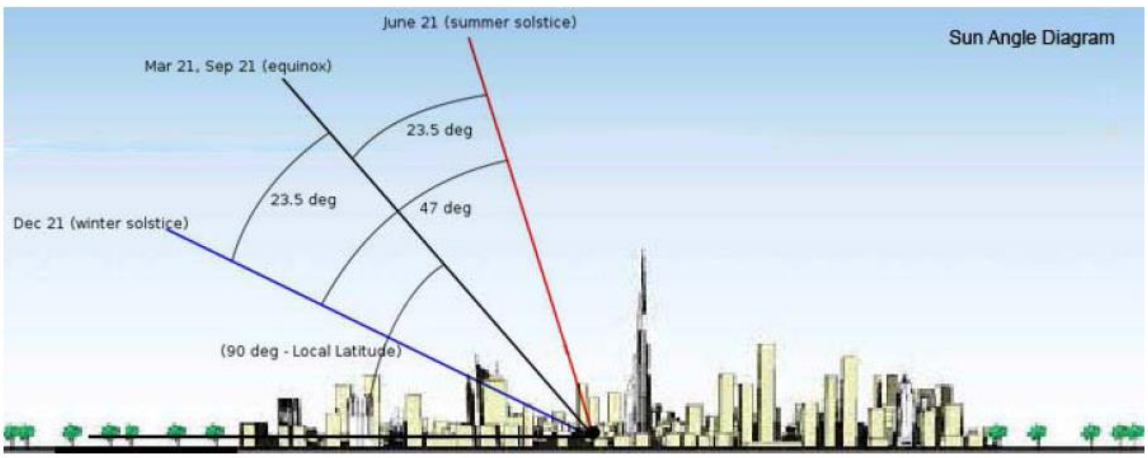


Figure 4.2 - Sun Angle Diagram (Author, 2014)

Direction, wind speed and relative humidity specifications are set according to UAE weather data. The Envi-met configuration setup in Figure 4.1is used for five model scenarios: a base condition representing the existing scenario, a case including optimized surface pavement material, a modified case with enhanced surface vegetation, an alternative scenario which includes the application of water features and finally an optimum scenario which combines all the proposed solutions. The area inputs are debated in the following section.

4.3 Study Area

Figure 4.3represents the density of Jumeirah Village Circle development. Since the community was specifically planned for low to mid-rise residential units, the height of villas for all building profiles does not exceed more than 2 floors. It is assumed that each floor is 3 meters height; therefore the building profile in Envi-met simulation is assigned to be 6 meter. The highlighted segment (120 x 180m) is selected for Envi-met evaluation with an area of 21,600 m^2. In the next sections, more information about the site area for Envi-met will be given discussing the base model setup and three modified scenarios.

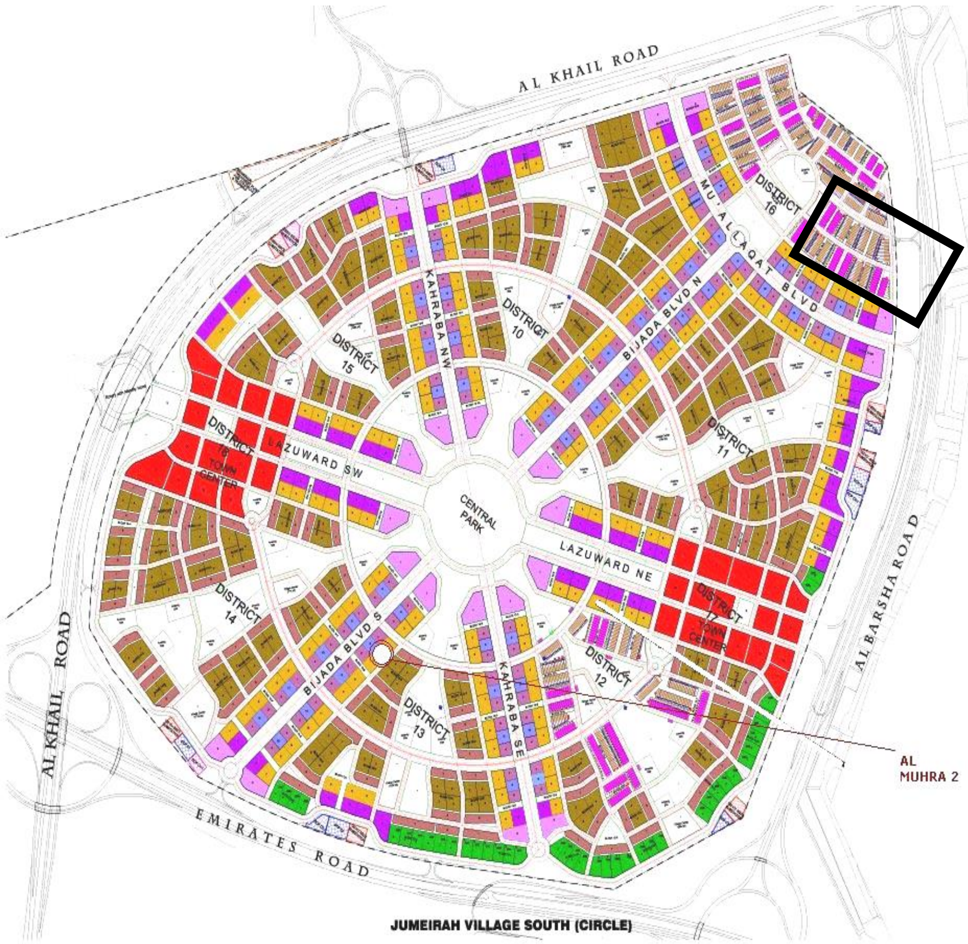


Figure 4.3 - Site Area and Density of Jumeirah Village Circle Community (Author, 2014)

4.4 Existing Case Model Setup

The area of the selected case study is 140 by 200 meter. The Envi-met main model was created using 100x100x30 area. The grid size for the simulated area is x: 2, y: 2 and z: 1 where each individual grid size in length and width was modeled at 2 meter, while each grid size in height represents 1 meter. The simulated building structures are similar in area and shape but slightly vary in orientation as existing. The inserted map for tracing was rotated at 100 degree clockwise to help in making the layout easier. Once the base map was inserted and the building profile was determined, the surfaces were characterized. The surfaces were primarily soil condition, asphalt road, concrete pavement and vegetation. Afterwards, the model was set to run on the June 21st, 2014 for a total 12 hour period in order to test conditions during daytime starting from 6:00 AM to 6:00 PM. Although, the results at only four hours with 3 hours interval were selected for analysis and investigation of material surface temperature (the results at 6:00 am are neglected due to Envi-met at the start time).

4.5 Modifying the Base Case by Enhancing Surface Materials

The modified scenario models integrate the initial existing case inputs with different surface profiles independently. The setup for each surface profile will be individually described below. The simulation configuration settings remain similar to what was previously described for the existing case, where the simulation time was selected during summer solstice June 21st, 2014 and set to run for a daytime period of 12 hours when the sun exists. It is clearly understood that the peak duration of the sun’s presence is between 8:00 to 16:00 based on the fact that the solar radiation increases during these hours in a mid-summer day. Therefore, the Envi-met simulation was run two hours prior and two hours subsequent to that duration due to the program’s errors at the start time of the experiment. In addition, all calculations are measured on clear sky conditions.

The Jumeirah Village Circle neighborhood was selected for the current study as an ideal spot due to its huge untreated spaces, building proximity, climatic factors, high demands and newly developed. The current situation of the site consists of lack of proper and adequate vegetation coverage, absence of water features or water bodies throughout the whole plot, presence of traditional asphalt roads and existence of many untreated spots covered with sandy soil. In the next chapter, the simulation outputs and results of the existing case and the proposed scenarios will be delivered. The results then will be investigated based on the measured parameters to specify the impact of landscape surfaces on the ambient air temperature of the environment.

4.5.1 Pavement Material

The U.S. Department of Energy suggests that by replacing dark colored asphalt roads with light heat-reflective concrete pavements the average summer temperature in urban areas can be considerably dropped. The current pavement material for the existing roads in the main model is set to be asphalt road. In the first proposal the existing asphalt is replaced with concrete pavement which is the suitable available alternative solution.

4.5.2 Vegetation

Further to the limited and inadequate plantation existing in the main model, additional vegetation will be incorporated as an alternative. The proposed vegetation profile will be put in instead of the existing sandy spots of the backyards, the central boulevard and other untreated spaces as required in the main model.

4.5.3 Water Feature

The base case scenario was designed with absolutely no water elements. The third proposal suggests incorporating water bodies into the site were needed. The added water bodies will be principally situated in the backyard of each villa in the form of swimming pool or water ponds since there are enough spaces.

4.5.4 Combined Scenario

The conventional scenario or the optimum case will comprise all the three proposed plans in one setting. In this case, the asphalt road is modified, the vegetation coverage is enhanced and the water bodies are added. This scenario is expected to provide the best performance in terms of reducing the surface temperature and consequently the ambient air temperature of the landscape in the defined area. The results of Envi-ment simulation for this proposal and the other four proposed plans will be then compared to each other in order to find the differences in effectiveness of each plan.

Chapter 5 – RESULTS & FINDINGS

5.1. Introduction

This chapter delivers the details of Envi-met results of the main case and the four proposed scenarios. The main case is the existing condition of the Jumeirah Village Circle Villas which can also be considered as the conventional or typical urban community in Dubai. In the four proposed scenarios, the landscape surfaces are treated using complimentary pavement material, landscape vegetation, and water feature strategies.

The results of all the simulations will be investigated every 3 hours interval at 8:00, 11:00, 14:00 and 17:00 hours on June 21st, 2014 when is the summer solstice. During the simulation phase, the following parameters for all five models will be tested: mean radiant temperature and ambient air temperature. A comprehensive analysis will be conducted related to these investigated parameters. The analysis will be a detailed study on the inputs and the obtained results, therefore generating a discussion comparing the impacts of the main model and the proposed scenarios.

5.2. Scenario 1 - The Main Model

The condition of the base case was inserted into the three-dimensional Envi-met software at 8:00, 11:00, 14:00 and 17:00 hours on June 21st, 2014. The main model represents the existing condition of the JVC siteincludingpoorly vegetated landscape, widespread sandy areas, typical asphalt roads and absence of water bodies. The available roads at the site are given asphalt profile along with continuous narrow concrete paved areas in front of the houses. In between the asphalt roads, a sandy boulevard is located which is sparsely planted with date palm trees. The backyard of each villa also has sparse vegetation and principally covered by sand. These criteria were translated into Envi-met model area for simulation. Various surface profiles at the site were distinguished in the Envi-met input as the following: sandy soil (sd), asphalt road (s), concrete pavement (p), light tree with leafless base (l1) and very dense tree with leafless base (T1). The Envi-met model is an extremely conceptual development in which the below parameters are calculated.

5.2.1. Parameter 1: Mean Radiant Temperature

By analyzing ENVI-met simulation and the generated graphical representation of the existing landscape condition, the Mean Radiant Temperature which measures the heat emissivity from long wave radiation was calculated at selected three-hour intervals from 6:00am till 6:00pm as shown in Figure 5.1.

The attained results for the aforementioned conditions at 8:00 AM yields a Mean Radiant Temperature of 298.50 K, with a maximum of 298.94K, and a minimum of 298.16K. While for the mean radiant temperature at 11:00 AM an average of 304.76K, a maximum of 305.47K and a minimum of 304.38K were obtained. Likely, the Mean Radiant Temperature at 14:00 is 304.76K with a maximum of 305.47K and a minimum of 304.38K. The identical results between the two timings confirm that the mean radiant temperature remains at its highest during the three-hour interval (11:00 AM-14:00 PM). In addition, this parameter at 17:00 was calculated to be 303.90K, where the maximum is 304.49K and the minimum is 303.47K.

5.2.2. Parameter 2: Ambient Air Temperature

An analysis on the Ambient Air Temperature was conducted to investigate the impact that the current landscape surfaces have on the temperature of the surrounding environment. Figure 5.2 illustrates the average Ambient Temperature at the selected three-hour intervals.

The results obtained for the existing condition at 8:00 AM yielded an average Ambient Air Temperature of 299.27K, with a maximum of 299.29 K and a minimum of 299.24 K. The minimal deviation in the data generated by ENVI-met endorses the accuracy of the simulation. Also, the average Ambient Air Temperature at 11:00 AM is 302.09K, with a maximum of 302.18 K and a minimum of 302.06 K. The results generated for the same parameter at 11:00 AM validates the accuracy of the ENVI-met simulation which shows a difference of 0.2 K between the maximum and minimum Ambient Air Temperature.

At 14:00 PM, the figure shows a value of 303.67K for the ambient air temperature, with a maximum of 303.77 K and a minimum of 303.645 K. The average ambient temperature was calculated to be 303.67 K, with a maximum of 303.70 K and a minimum of 303.66 K at 17:00 which reveals that this value remained constant.

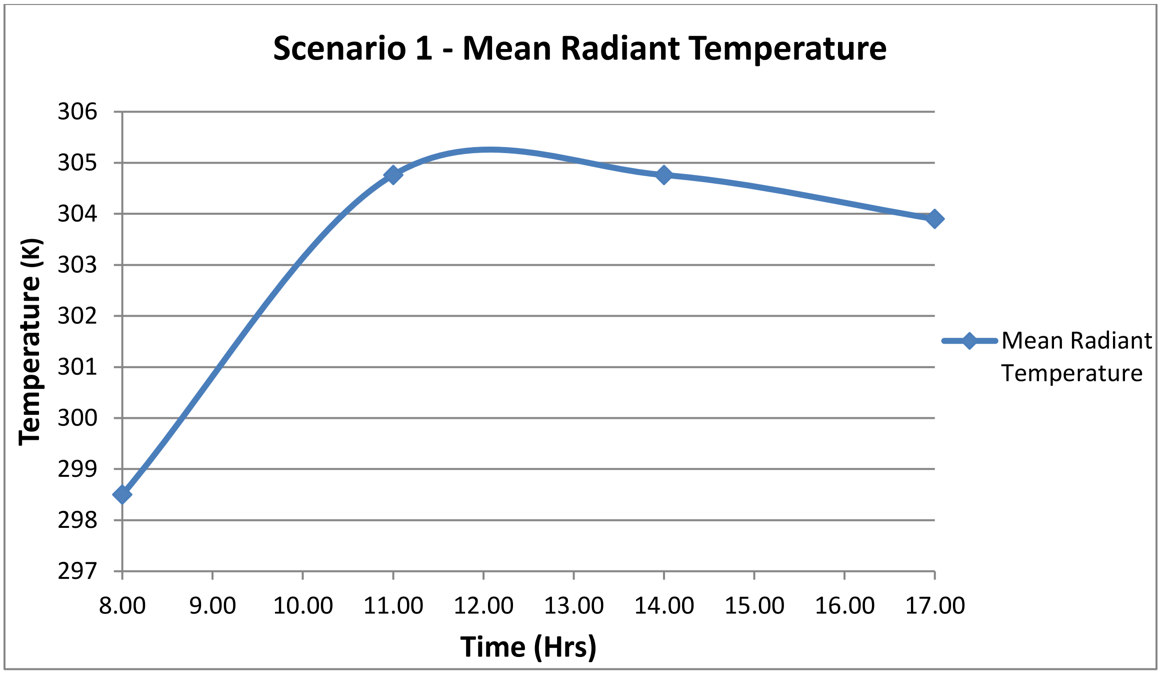


Figure 5.1 - Mean Radiant Temperature Distribution for Scenario 1, (Author, 2015)

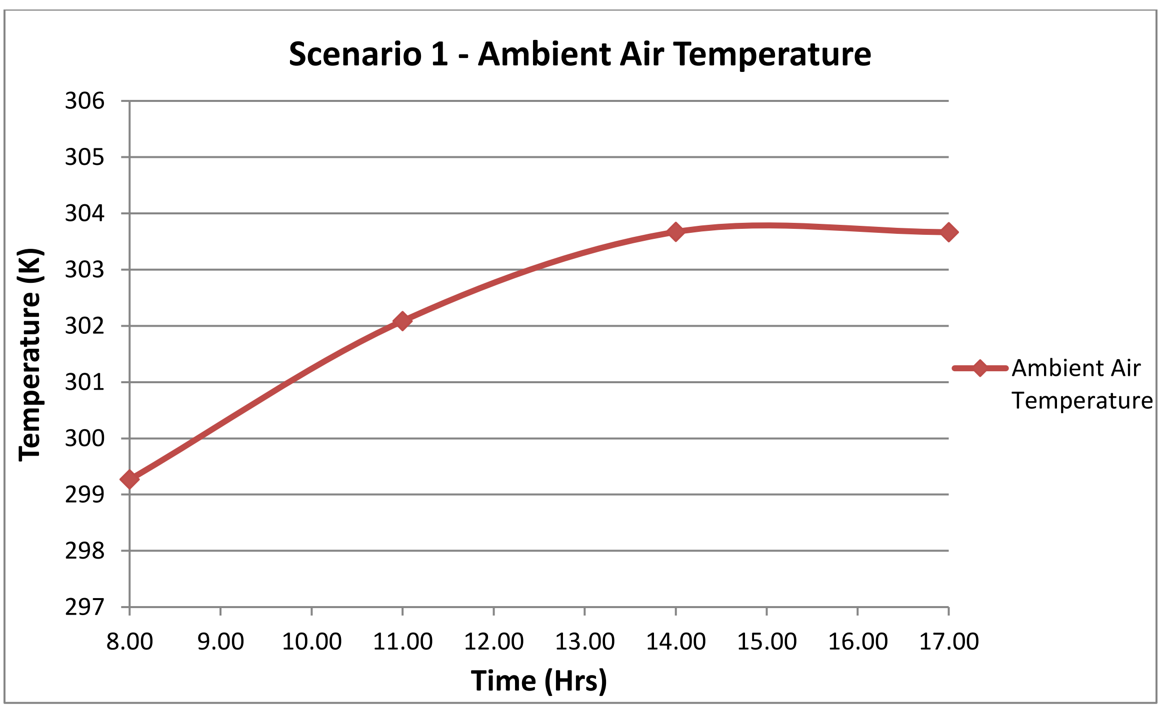


Figure 5.2 - Ambient Air Temperature Distribution for Scenario 1, (Author, 2015)

Upon completing the analysis for the main model at the four specified intervals, the difference between the average, maximum, and minimum for the Mean Radiant Temperature and the Ambient Air Temperature at all intervals can be found in Figure. The analysis yielded a difference of 0.81 K between the averages of the both parameters. Furthermore, the analysis of the maximum temperatures between parameter 1 and parameter 2 returned a difference of 1.1 K, whereas the analysis of the minimum temperatures between the two parameters generated a difference of 0.77 K. The differences in the average between the Mean Radiant Temperature and the Ambient Air Temperature are as expected due to the poor vegetation, sandy areas, use of asphalt roads and the absence of water bodies.

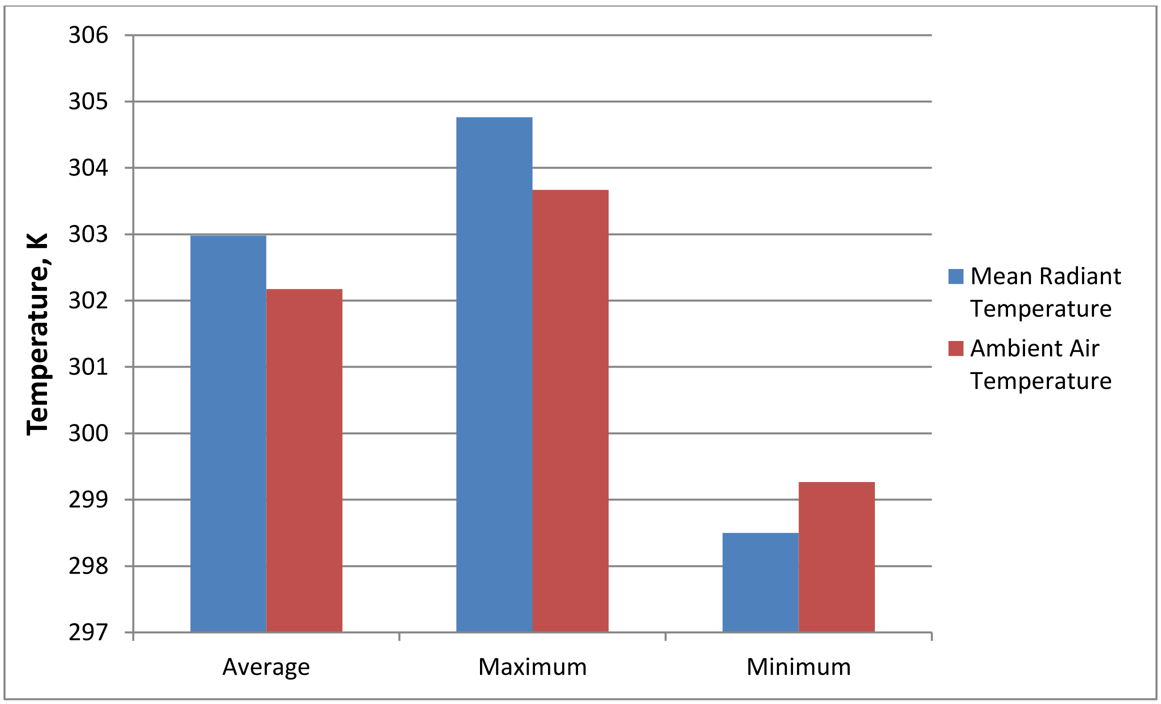


Figure 5.3 - Comparison between the Mean Radiant Temperature and Ambient Air Temperature for Scenario 1, (Author, 2015)

5.3. Scenario 2 - The Enhanced Pavement Material

In this proposed scenario, paved concrete road profile was incorporated into the three-dimensional Envi-met software at 8:00 AM, 11:00 AM, 14:00 PM and 17:00 PM on June 21st, 2014. The current situation of the study area contains asphalt surfaces all over the community as the primary surface material for the whole roadways. In the first suggested scenario, these surfaces are considered to be substituted with the conventional concrete paved roads. Therefore, the surface profile for the roads in the Envi-met model area input file is assigned to be concrete pavement (p). Following is the result of the conducted simulation for the Mean Radiant Temperature and Ambient Air Temperature parameters within this scenario.

5.3.1. Parameter 1: Mean Radiant Temperature

Following the same procedure used in the main model, an analysis of the ENVI-met simulation and the graphical representation was conducted after replacing the asphalt paved driveways with concrete pavement while maintaining the remaining site characteristics constant. The mean radiant temperature which measures the heat emitted was calculated at the selected three-hour intervals from 6:00 AM till 6:00 PM as shown in Figure 5.4.

The graph shown above for the concrete pavement scenario yielded a Mean Radiant Temperature of 298.22 K at 8:00 AM, with a maximum of 298.69 K and a minimum of 297.81 K. The same parameter obtained at 11:00 AM recorded an average of 302.49 K, with a maximum of 303.22 K and a minimum of 301.92 K. At 14:00 the average value is 304.07 K, with a maximum of 304.85 K and a minimum of 303.36 K. The Mean Radiant Temperature for 11:00 AM and 14:00 PM in the main model was similar; however this is not the case in this scenario due to the introduction of alternative landscaping solution. Moreover, the Mean Radiant Temperature at 17:00 PM was calculated to be 302.97 K, with a maximum of 303.71 K and a minimum of 302.28 K.

5.3.2. Parameter 2: Ambient Air Temperature

The results achieved for the second parameter of the concrete pavement scenario at 8:00 AM yielded an average Ambient Air Temperature of 299.13 K as shown in Figure 5.5 with a maximum of 299.18 K and a minimum of 299.08 K. Then at 11:00 AM, the average Ambient Air Temperature is 301.80 K, with a maximum of 301.91 K and a minimum of 301.76 K.

At 14:00 PM, Figure 5.5shows an average Ambient Temperature of 303.18 K, with a maximum of 303.29 K and a minimum of 303.13 K. Whereas, at 17:00, the average Ambient Temperature was calculated to be 302.99 K, with a minimal difference since the maximum and minimum ambient temperatures are almost similar to the average Ambient Temperature. The maximum ambient air temperature at 17:00 is 303.01 K, while the minimum is 302.98 K.

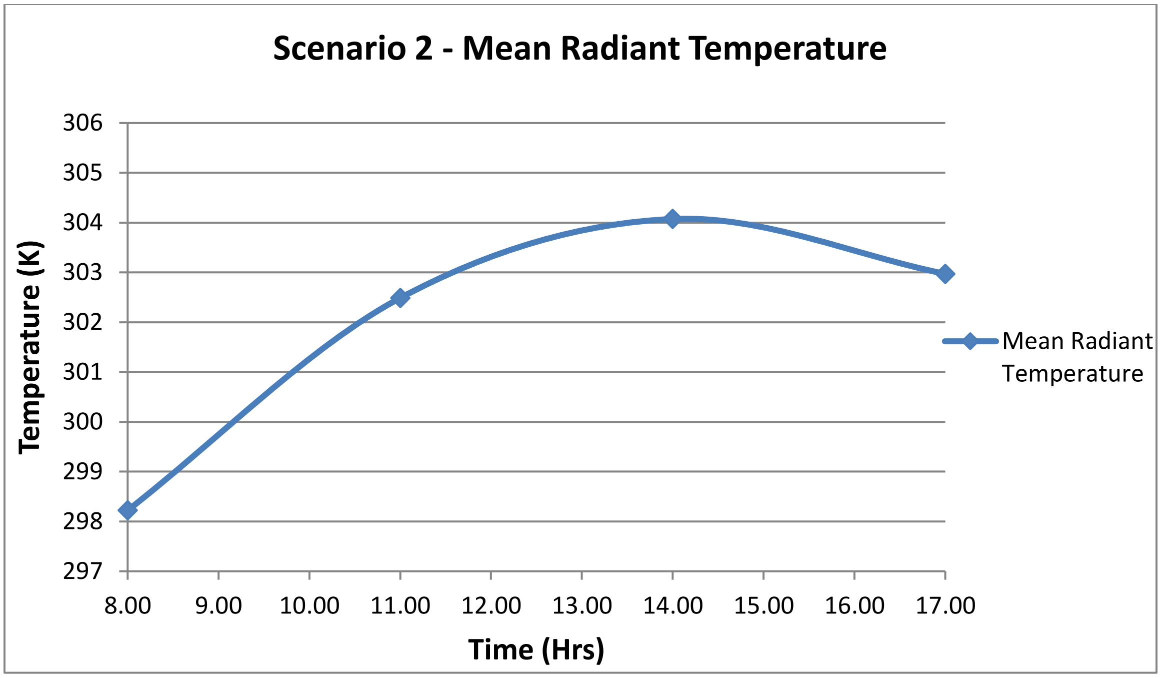


Figure 5.4 - Mean Radiant Temperature Distribution for Scenario 2, (Author, 2015)

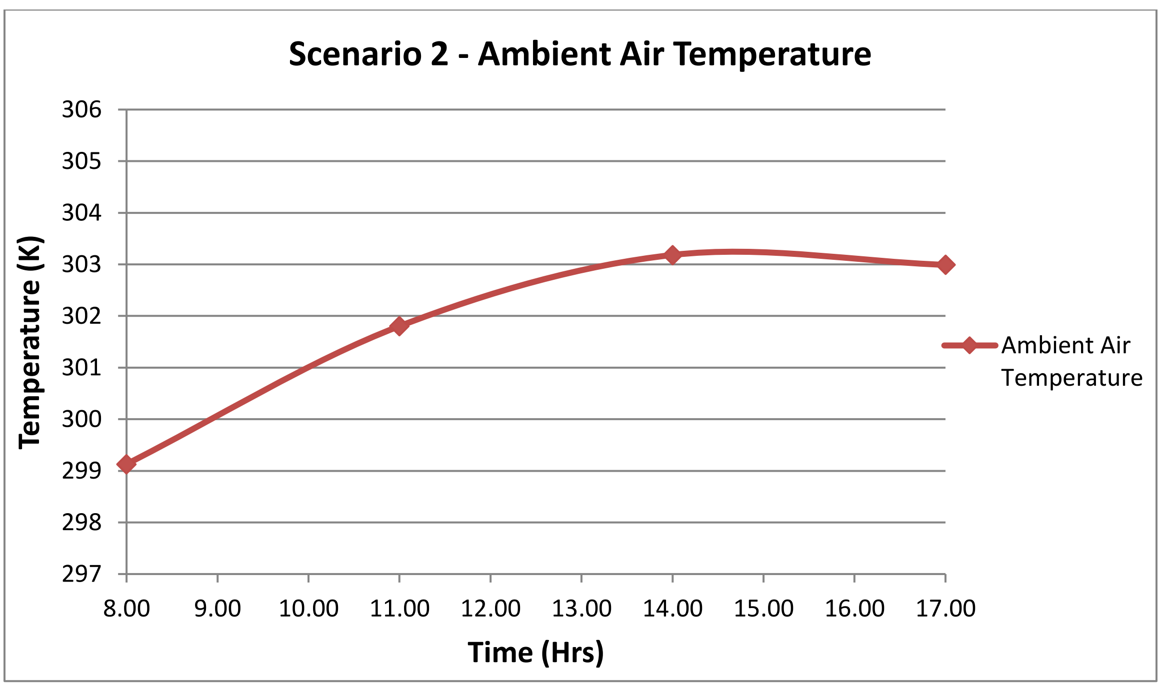


Figure 5.5 - Ambient Air Temperature Distribution for Scenario 2, (Author, 2015)

This scenario showed an improvement compared to the main model due to the replacement of asphalt pavement to concrete pavement. Figure 5.6 shows the difference between the average, maximum and minimum for the selected parameters at the four specified intervals. The analysis returned a difference of 0.16 K between the averages of the mean radiant temperature and the ambient air temperature. Subsequently, the analysis of the maximum temperatures of the two parameters yielded a difference of 0.89 K, while the analysis of the minimum temperatures for the two parameters generated a difference of 0.91K.

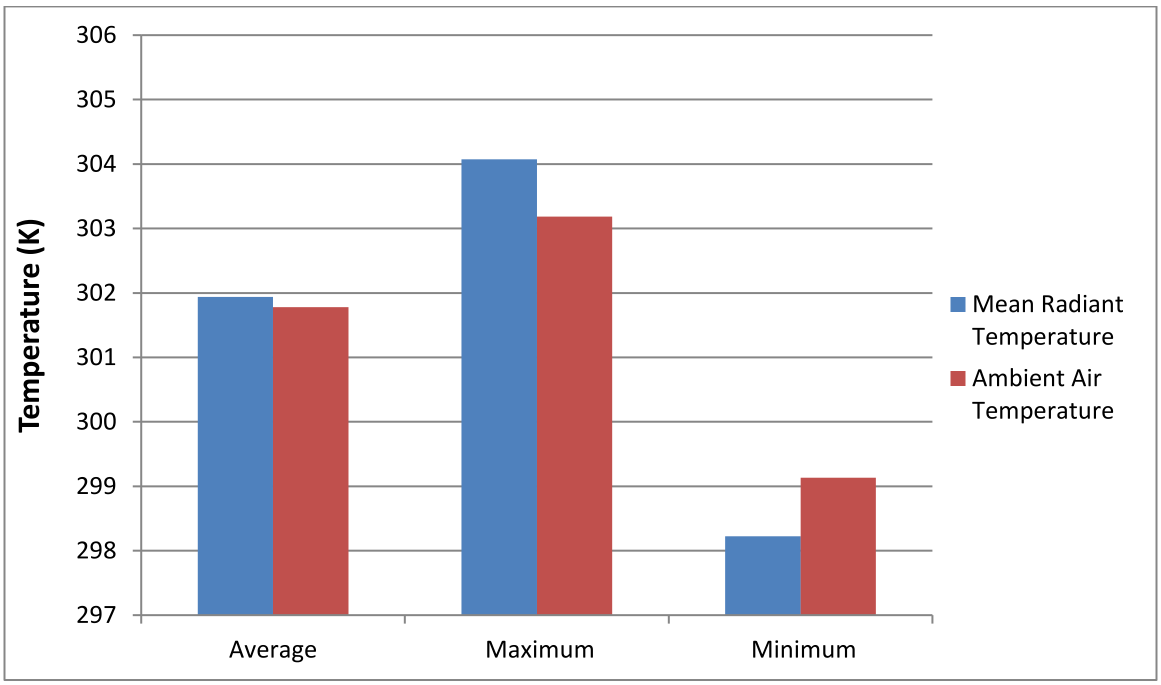


Figure 5.6 – Comparison between the Mean Radiant Temperature and Ambient Air Temperature for Scenario 2, (Author, 2015)

5.4. Scenario 3 - The Enhanced Vegetation

Coverage of vegetated landscape plants was inserted into the three-dimensional Envi-met software at 8:00 AM, 11:00 AM, 14:00 and 17:00 hours on June 21st, 2014. This will reveal any change in possible improvement in temperature reduction when compared with the base case scenario. The inputs consist of vegetation available in the model database including shrubs and trees. In addition to the existing vegetation, the additional inserted vegetation include: dense hedge (H) and very dense tree with leafless base (T2). The selection of these vegetation profiles was based on the availability and similarity of local plants with these types. Application of traditional grass in the UAE landscape is not included to the vegetation since it has the least cooling effects compared to other forms of greenery in urban parks. The weak performance of grass is related to its sparseness and indiscretion of undergrowth. Hence, the configuration with more shrubs and trees results in lower temperature in different seasons (Cao et al. 2010).

The selected plants are principally from the Envi-met software, however these are quite general, regulated features are programmed into the database. A thorough Leaf Area Index (LAI) assessment is not tackled for the aim of this research. However, in depth study in this area can perhaps influence the outputs of the vegetation enhancement investigation. Despite the Leaf Area Index assessment, the insertion of vegetation can probably mitigate urban temperatures from 18 – 21 °Cthan the suburban areas. The level of Urban Heat Island (UHI) effect can be decreased by the application of landscape vegetation. This way, a decrease in landscape surface temperature can aid in reducing the UHI levels in the Jumeirah Village Circle community.

The Envi-met simulation software will calculate the below parameters to specify the level of temperature reduction by the enhancement of landscape vegetation:

5.4.1. Parameter 1: Mean Radiant Temperature

An analysis of the ENVI-met simulation and the graphical representation was conducted after exerting auxiliary vegetation to the field in addition to the current plantation while the other characteristics of the site remain constant. Figure 5.7 shows the mean radiant temperatures at the selected hours at 8:00 AM, 11:00 AM, 14:00 PM and 17:00 PM.

At 8:00 AM the attained results from the graphical representation returned a Mean Radiant Temperature of 298.19 K, with a maximum of 298.62 K and a minimum of 297.80 K. The Mean Radiant Temperature obtained for the enhanced vegetation scenario at 11:00 AM recorded an average of 302.47 K with a maximum of 303.22 K and a minimum of 301.91 K. According to the same figure, the Mean Radiant Temperature at 14:00 resulted is 304.05 K with a maximum of 304.86 K and a minimum of 303.36 K. Also, the Mean Radiant Temperature at 17:00 was calculated to be 302.86K with a maximum of 303.56 K and a minimum 302.23 K.

5.4.2. Parameter 2: Ambient Air Temperature

The results interpreted for the Ambient Air Temperature for the enhanced vegetation scenario at 8:00 AM returned an average value of 299.11 K as shown in Figure 5.8 with a maximum of 299.16 K and a minimum of 299.05 K. This parameter at 11:00 AM has an average of 301.80 K, with a maximum of 301.88 K and a minimum of 301.74 K.

At 14:00, the figure shows an average Radiant Temperature of 303.16 K, with a maximum of 303.26 K and a minimum of 303.11 K. While at 17:00 the value was calculated to be 302.92 K with a negligible difference between the maximum and minimum Ambient Air Temperature.

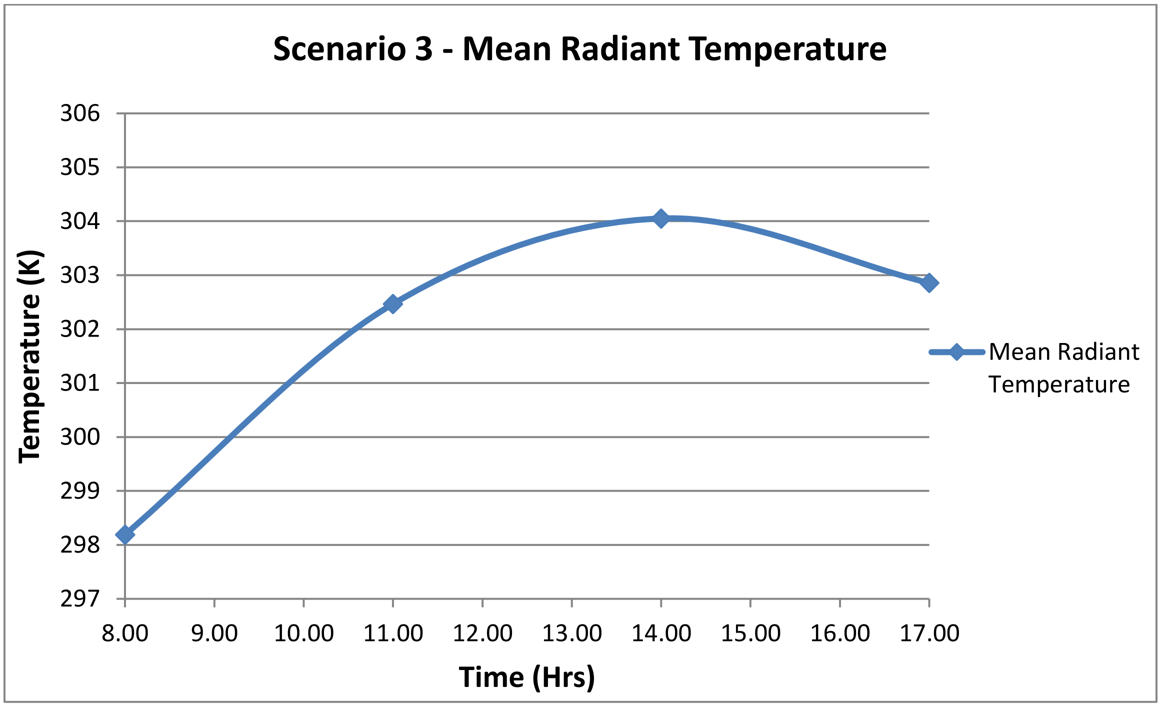


Figure 5.7 - Mean Radiant Temperature Distribution for Scenario 3, (Author, 2015)

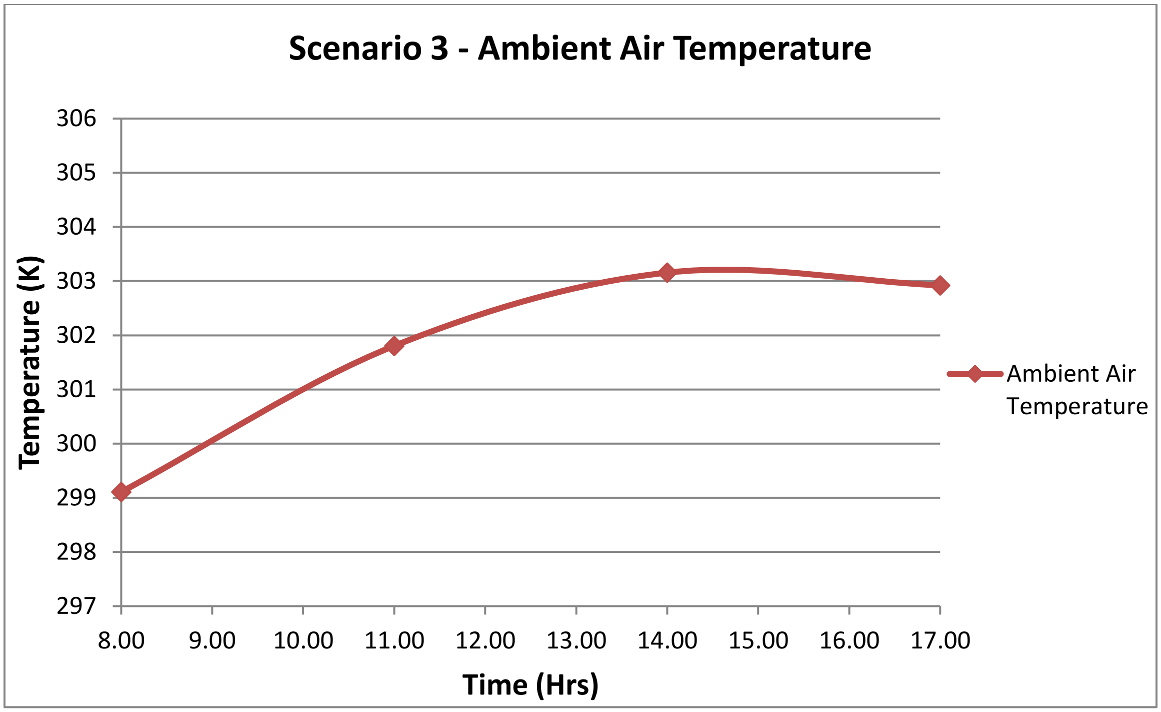


Figure 5.8 – Ambient Air Temperature Distribution for Scenario 3, (Author, 2015)

Similarly to the concrete pavement scenario, the enhancement of the landscape through the insertion of dense hedge and very dense tree with leafless base to the existing condition showed a reduction in the selected parameters value compared to the main model. The differences between the average, maximum, and minimum for the selected parameters are shown in Figure 5.9. The difference in the average of the two parameters returned a value of 0.14 K, with the maximums and minimums obtaining differences of 0.89 K and 0.92 K respectively.

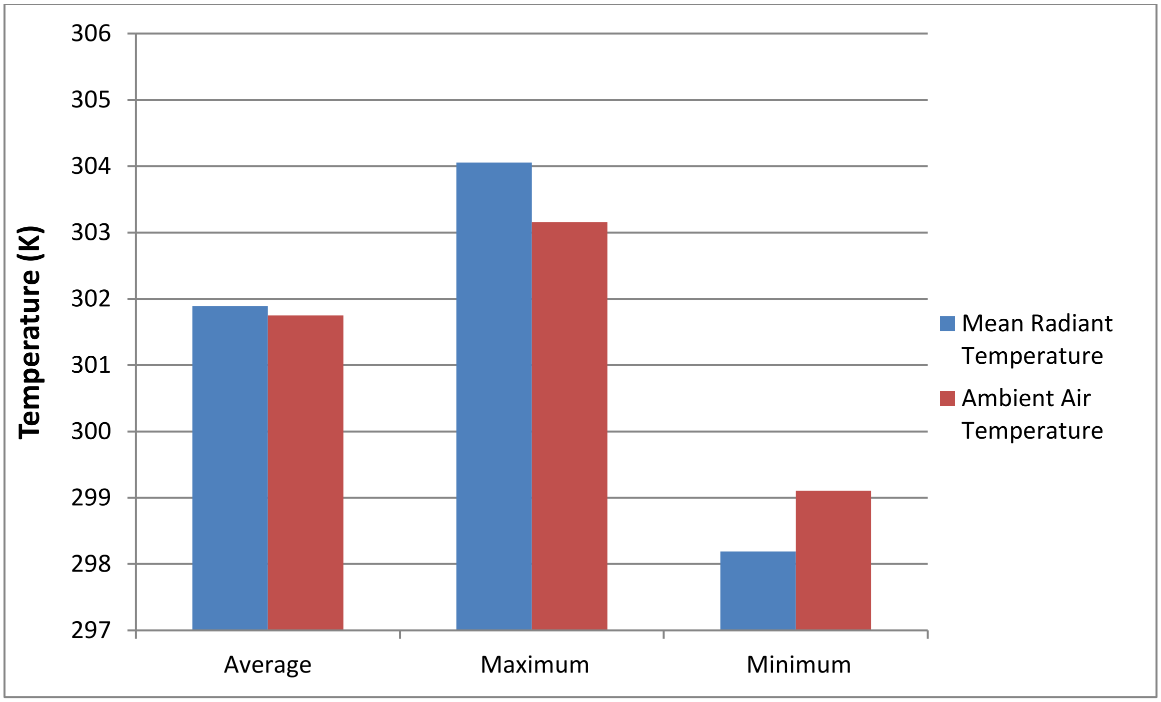


Figure 5.9 – Comparison between the Mean Radiant Temperature and Ambient Air Temperature for Scenario 3, (Author, 2015)

5.5. Scenario 4 - The Application of Water Bodies

In the fourth proposed scenario, the application of urban water bodies was integrated into the three-dimensional Envi-met software at 8:00 AM, 11:00 AM, 14:00 and 17:00 hours on June 21st, 2014. The water feature insertions were applied in the form of shallow water features e.g. residential swimming pools and or water ponds. It should be considered that the software does not allow for detailed incorporation of wet profiles. This is while the existing condition of the site suffers from the absence of any kind of water feature surface. Consequently, these surfaces were assigned as water (w) in the Envi-met model area input file. Similar to the previous scenarios, the performance of the following two parameters was investigated for this scenario.

5.5.1. Parameter 1: Mean Radiant Temperature

An analysis of the graphical representation returned a Mean Radiant Temperature of 298.52 K at 8:00 AM, with a maximum of 298.94 K and a minimum of 298.16 K. Subsequently, this parameter at 11:00 AM was obtained from the graphical representation for the water bodies' scenario shown in Figure 5.10. The extracted average value is 302.90 K, with a maximum value of 303.57 K and a minimum value of 302.51 K. The Mean Radiant Temperature at 14:00 for this scenario yielded an average of 304.75 K, with a maximum of 305.46 K and a minimum of 304.36 K. The Mean Radiant Temperature at 17:00 was calculated to be 303.90 Kwith a maximum of 304.48 K and a minimum of 303.45 K.

5.5.2. Parameter 2: Ambient Air Temperature

The results of ENVI-met simulation extracted for the Ambient Air Temperature shown in Figure 5.11 for the water bodies' scenario at 8:00 AM revealed an average value of 299.27 K with a maximum value of 299.29 K and a minimum of 299.24 K. At 11:00 AM, the average Ambient Air Temperature is 302.09 K, with a maximum value of 302.18 K and a minimum value of 302.06 K. At 14:00, the figure shows an average ambient Temperature of 303.67 K, with a maximum value of 303.77 K and a minimum of 303.64 K. Finally at 17:00, the average ambient temperature was calculated to be 303.67 K with a difference of 0.04 K between the maximum and minimum values.

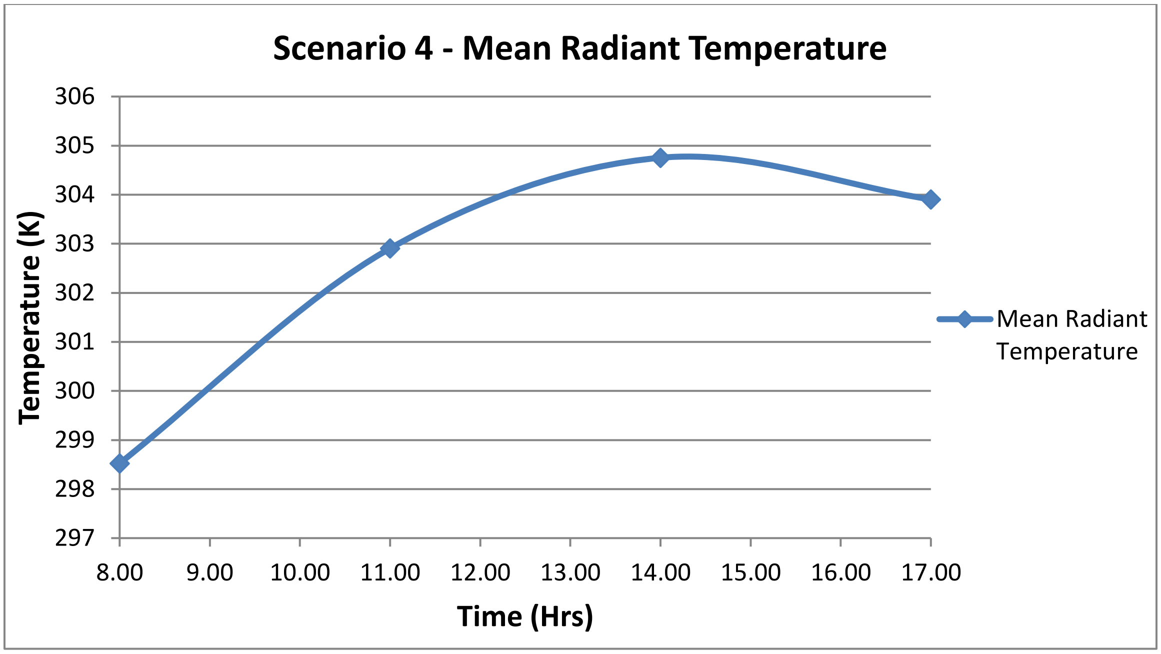


Figure 5.10 - Mean Radiant Temperature Distribution for Scenario 4, (Author, 2015)

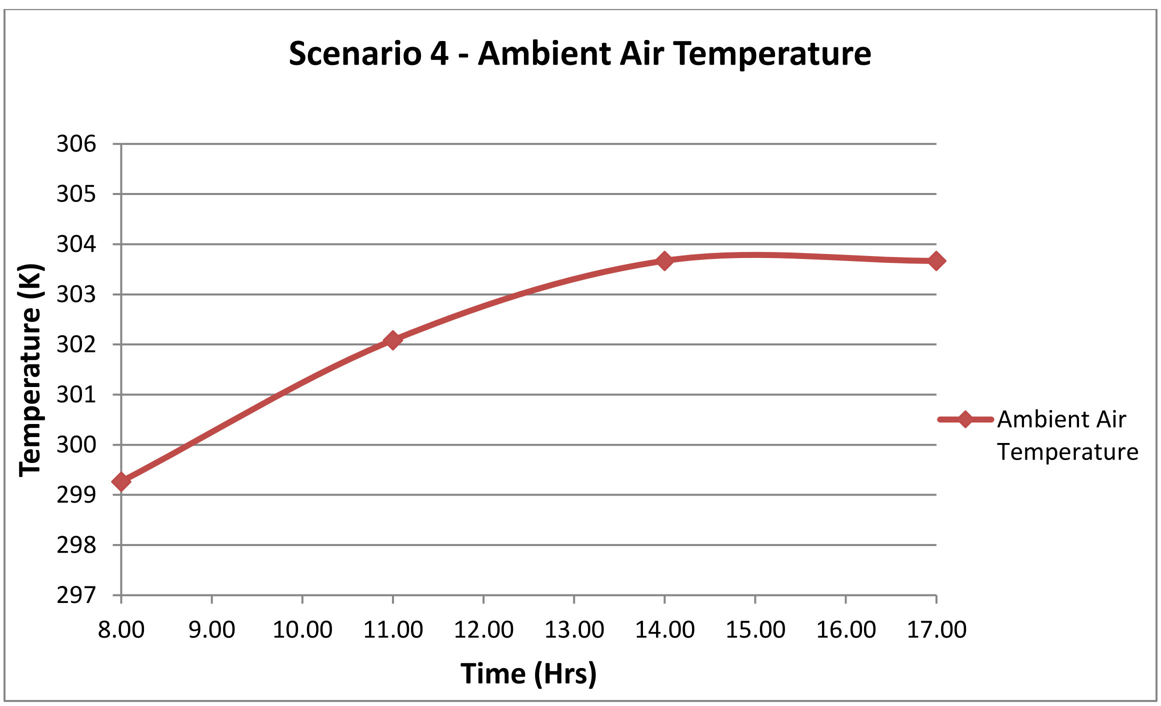


Figure 5.11– Ambient Air Temperature Distribution for Scenario 4, (Author, 2015)

In general, the addition of water bodies showed an enhancement in the Mean Radiant and Ambient Air Temperatures at 11:00 AM where the heat emissivity is at the highest point during the day since the main model lacked the existence of any type of water bodies. The differences between the average, maximum, and minimum for the selected parameters are shown in Figure 5.12. The difference in the average of the two parameters returned a value of 0.35 K, with the maximums and minimums obtaining differences of 1.08 K and 0.75 K respectively.

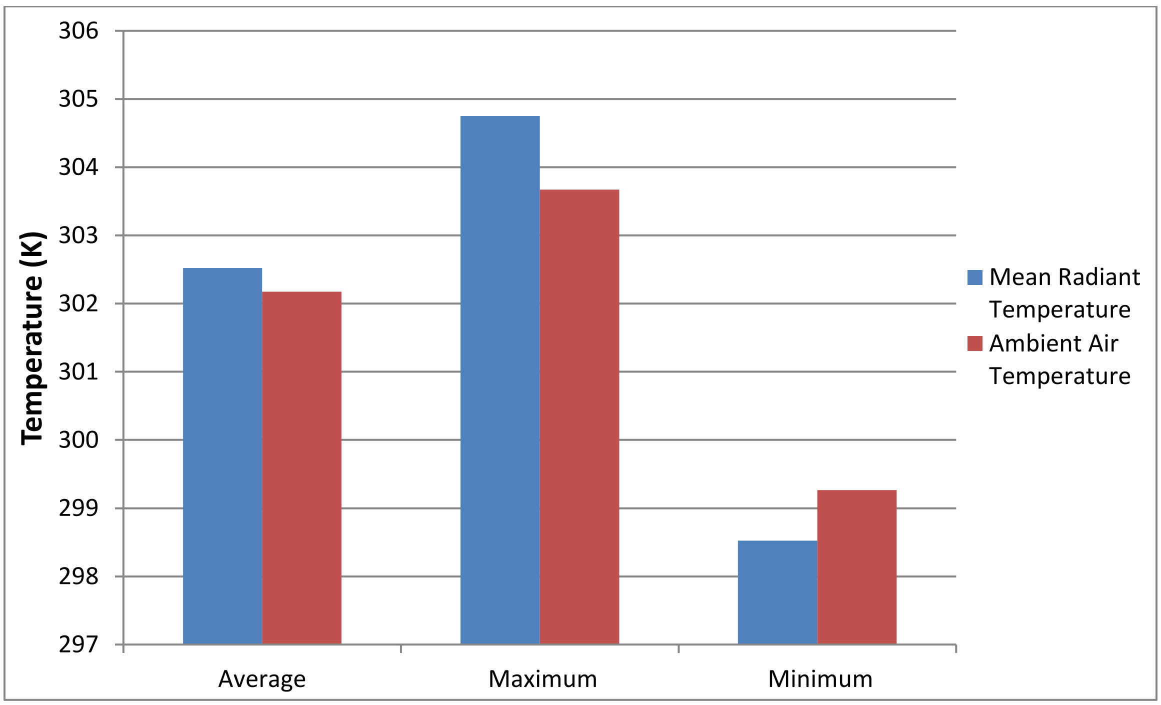


Figure 5.12– Comparison between the Mean Radiant Temperature and Ambient Air Temperature for Scenario 4, (Author, 2015)

5.6. Scenario 5 - The Bioclimatic (Combined)

In this scenario, the existing condition of the site was manipulated by combining the three alterations that were carried out in scenario 2, 3 and 4. Therefore, paved concrete road (p) profile was replaced with the existing asphalt material at the site. It is important to mention that this step was done with the same procedure in the second scenario and the concrete pavement integration was applied for the same areas. Next, like in the third scenario, rather than the vegetation available in the existing scenario additional vegetation profiles were inserted including dense hedge (H) and very dense tree with leafless base (T2). This was done precisely similar to the vegetation insertion in scenario three and the exact vegetation profiles were incorporated. Lastly, equivalent changes in the fourth scenario were carried out and the application of water features was done in the same manner.

Since in this scenario all three previous microclimatic enhanced scenarios are combined together, it is expected to achieve more improved results in terms of temperature reduction from it. Hence, there is a possibility for this scenario to be recognized as the best case scenario for the current research. The results of the simulation will be presented below to observe the performance of the combined scenario and later these results will be compared to the results obtained from the previous scenarios.

5.6.1. Parameter 1: Mean Radiant Temperature

The ENVI-met simulation confirmed that at 8:00 AM the Mean Radiant Temperature was measured with an average value of 298.17K as shown in Figure 5.13, with a minimum of 297.80 K and a maximum of 298.55K. Then, at 11:00 AM the value was calculated to be 302.41K with a minimum of 301.90K and a maximum of 302.89K.

The model recorded the average Mean Radiant Temperature at 14:00 to be 304.00K while the minimum is 303.35 K and the maximum is 304.55 K. Lastly, at 17:00 the simulation calculations revealed an average of 302.85K with a minimum of 302.23 K and a maximum of 303.43 K.

5.6.2. Parameter 2: Ambient Air Temperature

Figure 5.14illustrate the obtained values from the model for the Ambient Air Temperature from 6:00 AM till 6:00 PM. According to the figure, this parameter at 8:00 AM is measured to be 299.11 K with a minimum and maximum of 299.05 K and 299.16 K respectively. The average Ambient Air Temperature at 11:00 AM increases up to 301.78 K followed by the increased minimum and maximum values at 301.74 K and 301.86 K respectively. At 14:00 the average Ambient Air Temperature shows a significant increase at 303.15 K. Similarly for the minimum and maximum, the values increase up to 303.24 K and 303.11 K. Finally, a slight decrease occurs in the average of theAmbient Air Temperature at 17:00 at 302.92 K. This is followed by a decrease in the minimum value to302.91 K and the maximum value to302.94 K.

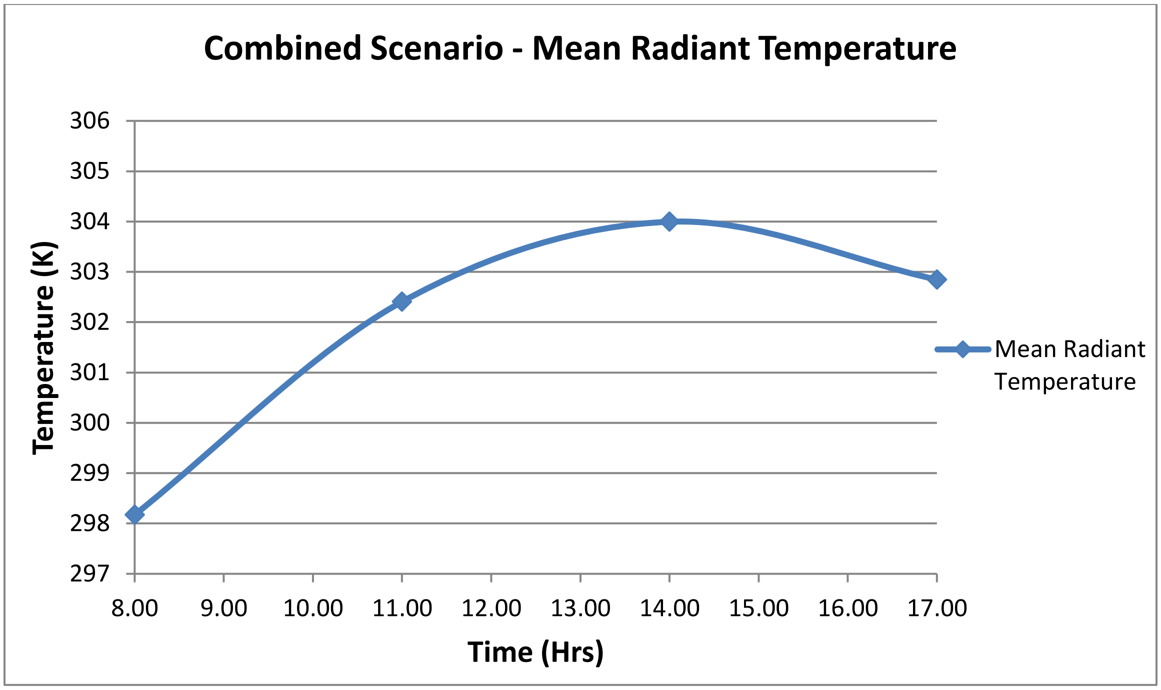


Figure 5.13 – Mean Radiant Temperature Distribution for Scenario 5, (Author, 2015)

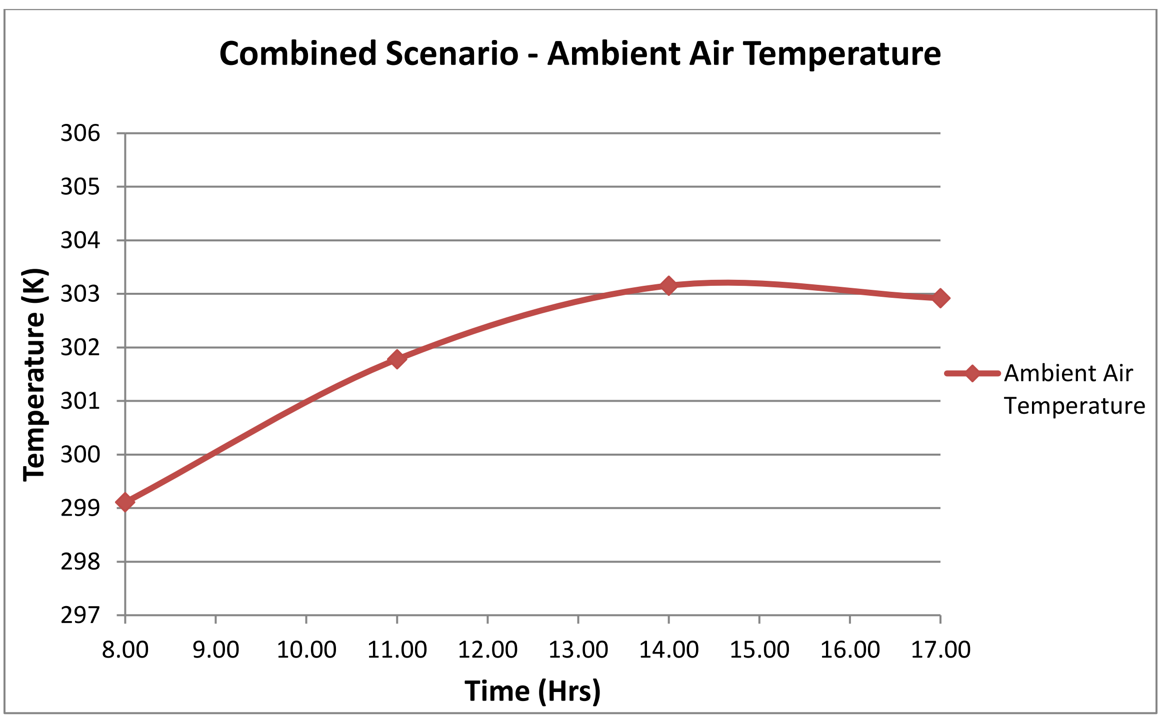


Figure 5.14– Ambient Air Temperature Distribution for Scenario 5, (Author, 2015)

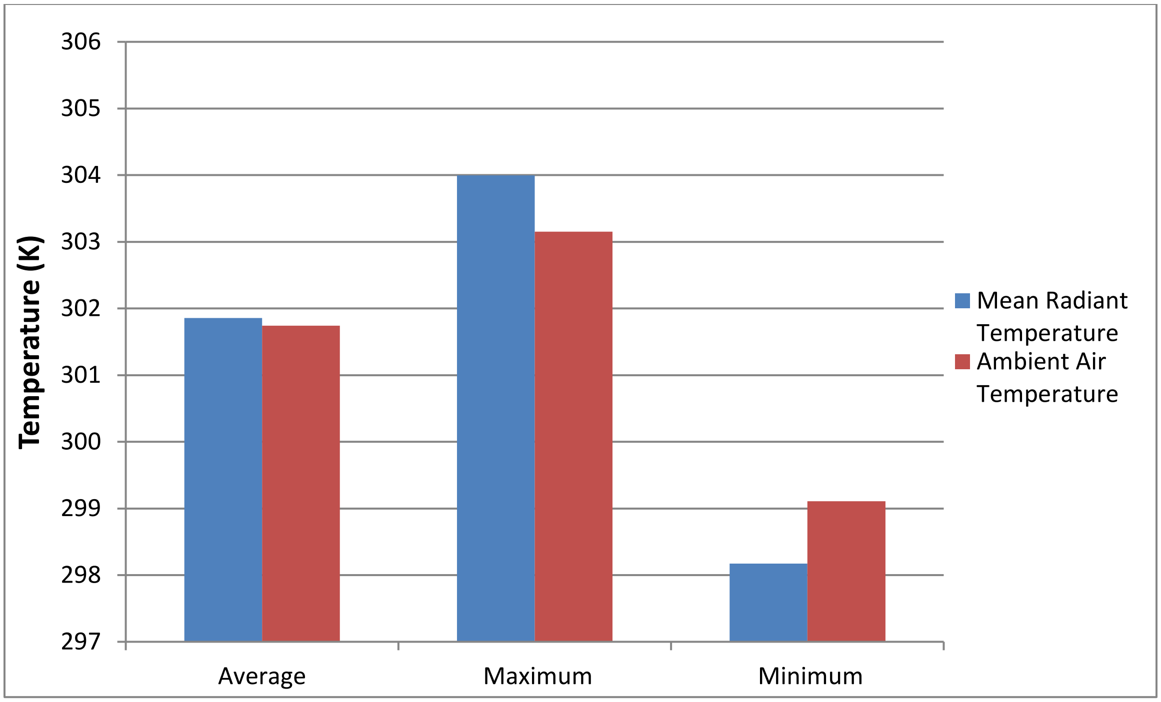


Figure 5.15– Comparison between the Mean Radiant Temperature and Ambient Air Temperature for Scenario 5, (Author, 2015)

5.7. Comparative Analysis

Evaluation of all the five scenarios will be presented comparing the temperature results attempting to inspect the actual impact a bioclimatic approach could have on the microclimate of urban residential areas. In the current research, the purpose of the improved scenario is to achieve the lowest temperature values in summer which meets the thermal comfort levels during hot and dry summer seasons in Dubai. The five scenarios had a half day simulation consisting the part of the day when the sun appears between 6.00 AM and 6.00 PM to accomplish stability between the temperature behaviors during daytime and nighttime. For each scenario, the average values were considered to specify the balance between the minimum and maximum temperature levels.

As expected, the main model scenario shown in Table 5.1recorded the highest average values for both temperature parameters with an average Mean Radiant Temperature of 302.98Kand an average Ambient Air Temperature of 302.17 K. These values were considerably improved in the second scenario due to the replacement of asphalt surfaces with cool concrete pavement. Therefore, the average value for the Mean Radiant Temperature was reduced by 1.05 K and 0.4 K for the Ambient Air Temperature. In the third scenario, the enhanced vegetation contributed in lower average temperature values compared with the main case scenario. These values were lower than the temperature results from the main model scenario with a difference of 1.09 K for the Mean Radiant Temperature and 0.43 K for the Ambient Air Temperature between the average values.

However in the water pond application scenario the average Mean Radiant Temperature was decreased with a difference of 0.46 K, the average Ambient Air Temperature remained constant at 302.17 K. Finally, the bioclimatic scenario also known as the combined scenario scored the lowest average Mean Radiant Temperature and Ambient Air Temperature during June, 21st among all the scenarios with a value of 301.86 K and 301.74K respectively as demonstrated in Table 5.5.

The order of the five scenarios disclosed a reasonable order during summer yet with a slight difference in terms of temperature values. Evidently, the combined scenario on June, 21st had the lowest minimum as well as the lowest maximum temperature values with a significant difference of 2.3 K in the Mean Radiant Temperature and 0.44 K in the Ambient Air Temperature.

The 2.3 K difference from the combined scenario proves to be a higher reduction in air temperature than the improvement of each proposed scenario individually. Therefore, the vegetation demonstrated to be the most temperature reduction parameter followed by the cool pavement material and water bodies respectively.

Table 5.1 - Average, Maximum & Minimum Temperature Values for Scenario 1, (Author, 2015)

	Mean Radiant Temperature (K)	**Ambient Air Temperature (K)**
Average	302.98	302.17
Maximum	304.76	303.67
Minimum	298.50	299.27

Table 5.2 - Average, Maximum & Minimum Temperature Values for Scenario 2, (Author, 2015)

	Mean Radiant Temperature (K)	**Ambient Air Temperature (K)**
Average	301.94	301.78
Maximum	304.07	303.18
Minimum	298.22	299.13

Table 5.3 - Average, Maximum & Minimum Temperature Values for Scenario 3, (Author, 2015)

	Mean Radiant Temperature (K)	**Ambient Air Temperature (K)**
Average	301.89	301.75
Maximum	304.05	303.16
Minimum	298.19	299.11

Table 5.4 - Average, Maximum & Minimum Temperature Values for Scenario 4, (Author, 2015)

	Mean Radiant Temperature (K)	**Ambient Air Temperature (K)**
Average	302.52	302.17
Maximum	304.75	303.67
Minimum	298.52	299.27

Table 5.5 - Average, Maximum & Minimum Temperature Values for Scenario 5, (Author, 2015)

	Mean Radiant Temperature (K)	**Ambient Air Temperature (K)**
Average	301.86	301.74
Maximum	303.96	303.15
Minimum	298.17	299.11

Chapter 6 – DISCUSSION

6.1. Observations and Discussion

Enhancement of the microclimatic conditions of outdoor spaces is the most important purpose of every bioclimatic design. Many numerical and experimental studies were conducted in order to examine the urban microclimate. Therefore, to develop urban microclimate, numerous approaches have been offered: supplementary plantation and higher albedo (Akbari et al., 2001), or water features supporting the evaporative cooling (Givoni and La Roche, 2000; Nishimura et al., 1998). The microclimate can be modified by the urban environment through certain techniques. The geographical situation and the arrangement of the metropolitan such as geometrical formation, morphology local climatology, human activities, vegetation, building and surface materials and water, contribute essential impacts on the urban microclimate.

Upon reviewing the outline of the research to create a sustainable landscape design for residential neighborhoods in Dubai by implementing the bioclimatic landscape strategies and studying the four potential scenarios, the discussion chapter shall combine the literature and the results demonstrated in the previous chapter to investigate and validate the results obtained in each scenario. The effects of the enhancements of each scenario at different intervals on the two parameters simulated at the longest summer day of the year will be discussed separately for each scenario at different intervals as specified using the visual maps. The visual maps extracted from ENVI-met using the LEONARDO software show the gradient temperature distribution within the space. The visual maps for the main model can be found in Appendix C.

The methodology applied for the quantitative values described before was signified by an average value for the entire context. Additionally, the temperature values assumed in the output files for each particular grid point in the layout model were averaged into two numbers that characterized the temperature of the entire site throughout that particular time. Also, buildings were removed and 5m around the buildings was combined in the calculations. This way of calculation was planned to be applied and assumed to be more accurate in terms of the current site arrangement bearing in mind the least possible background effect where an outdoor space is certainly not lonely in actuality. Hereafter, the values accomplished and matched were the average temperature obtained for the whole area every one hour.

Previous research studying analogous parameters applied different methods including simulation, experiments and field measurements. All previous validated investigations evaluating the same parameters showed to have a spread variety of variations among their outcome results, however they principally concurred on the same theory. The differences attained between the previous studies and between them and the present research will constantly be applicable between a study and another where every investigation has their own circumstances. For the current study, the validation is delivered by previous published research works which guarantee the validation of the results with regards to the date, scale, measurement standards and simulation length of each study. A small number of studies are pointed since more details were presented in the literature review section.

6.1.1. Effect of Concrete Pavement

The second proposed scenario tested the impact of concrete pavement instead of the existing asphalt profile for the roads in the model area. The results of the simulation revealed that due to the replacement of asphalt surfaces with cool concrete pavement the average value for the Mean Radiant Temperature was reduced by 1.05 K in comparison with the results of the main model. In addition, a 0.4 K enhancement for the Ambient Air Temperature was achieved which confirms the positive impacts of concrete pavement on the temperature. In the current paper, it was supposed that the thermal resistances among the various pavement coats are almost negligible. This is a rational hypothesis assuming the compaction and tack layer considered between the pavement coats throughout construction. However, further experimental investigations may deliver more information about the thermal resistances between the pavement coats.

The amount of greenery in hot and dry regions is in general smaller than in moderate climates, so the high importance of solid surfaces like building roofs and paved surfaces increases. Hence, the role of solid materials in the structure of the urban heat island has been the focus of many studies. Many researchers have reassessed the findings on the solar reflectance of several typical and reflective paving materials.

From the simulations it was discovered that the impact of road materials changes on temperature is quite important. The impact of cool pavement largely affects the spots that went through the simulated rise in albedo. Generally, the spatial scattering of temperature variation shows a relationship to the amount of surface alterations in the adaptable zones.

The variations in air temperature that are detected in the mainstream of the zones of the simulated area are as a result of the rise of the surface albedo which leads to a smaller amount of solar gains for the surface. Nevertheless, some areas show a minor growth in temperature perhaps due to horizontal and vertical involvement variations.

According to the main energy balance, a one-dimensional mathematical model was developed by Gui et al. (2007) to measure the surface temperatures using hourly measured air temperature, solar radiation, wind velocity and dew point temperature. The study concluded that appropriate pavement materials have the ability to lessen high surface temperatures and heat absorption causing the UHI effect, and human thermal comfort. It was also found that both emissivity and albedo correspondingly have the most positive effects on pavement minimum and maximum temperatures.

In an investigation carried out by Lin et al. (2010), four various pavement materials including concrete, asphalt, interlocking blocks and grass were located in a university campus to calculate the thermal physical parameters and albedo value of each. The field study was performed during different seasons and the albedo value for all pavement materials was calculated.

In another study conducted in the schema of a national level program for the enhancement of outdoor open spaces according to bioclimatic criteria. The proposal was evaluated in terms of enhancing the microclimate, building energy savings and pedestrians’ thermal comfort in hot summer season. Most solid pavements were substituted with permeable surfaces and natural soil and the rest pavements by cool pavement with high emissivity and high albedo. The effects of the proposed improvements on surface and air temperatures and on indices were assessed by comparing microclimate simulations of current and proposed plans using the ENVI-met software for two typical and extremely hot summer days. The results of the simulation revealed that the mean surface temperature reduction during severe conditions in both fields were around 14 ℃ and 18 ℃, while the mean air temperature reductions were 2.6 ℃ and 1.7 ℃ (Chatzidmitriou, 2012).

A study by Akbari et al. (2012), modeled the long-term impact of raising urban surface albedos applying a spatially clear universal climate model of medium density. They first conducted two series of modeling by increasing the albedo of several fields with similar topographical conditions. The outcomes of the simulations for every 1 m^2 of a surface with an albedo increase of 0.01specified a long-lasting worldwide temperature reduction effect of 10 K to 15 K.

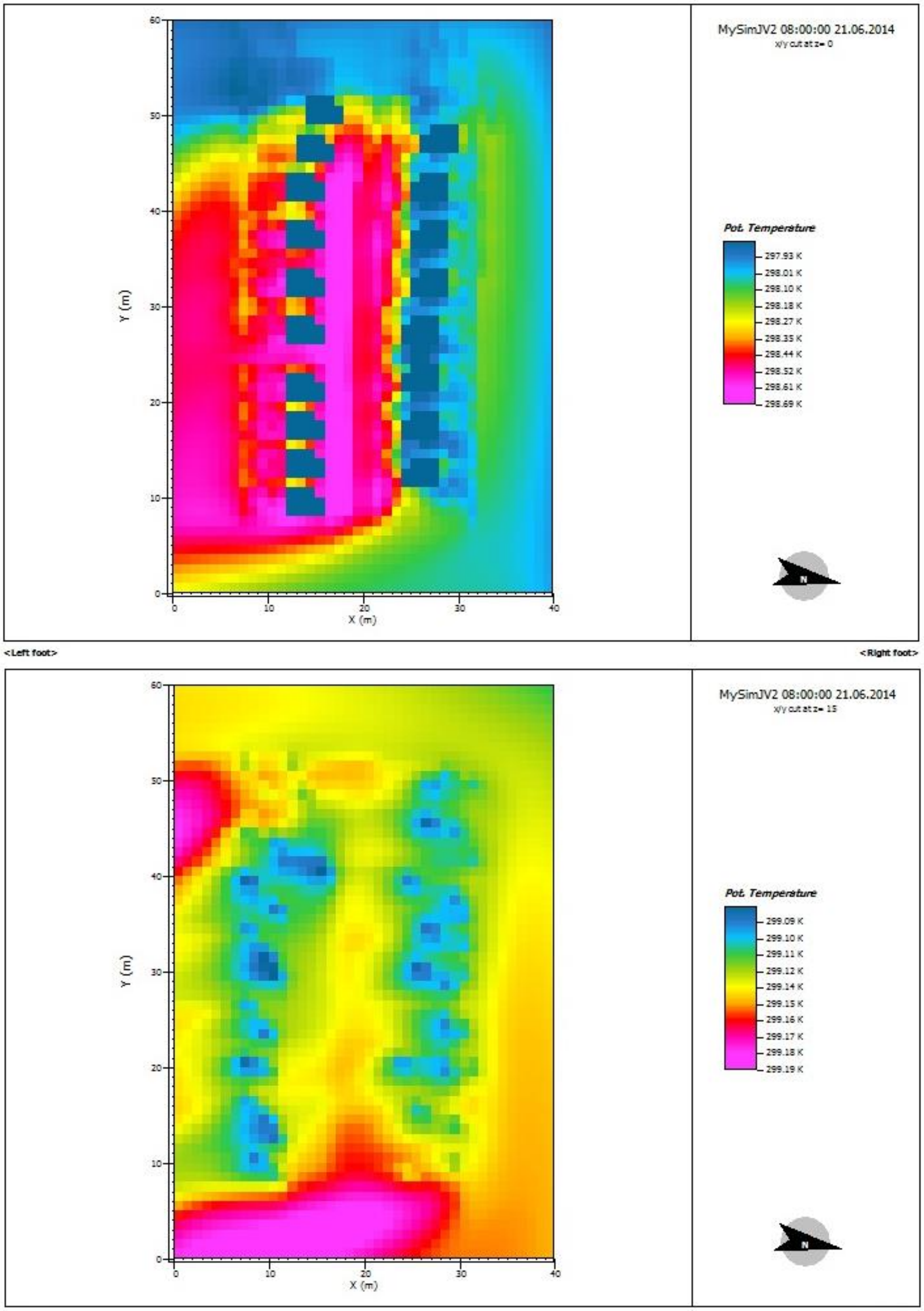
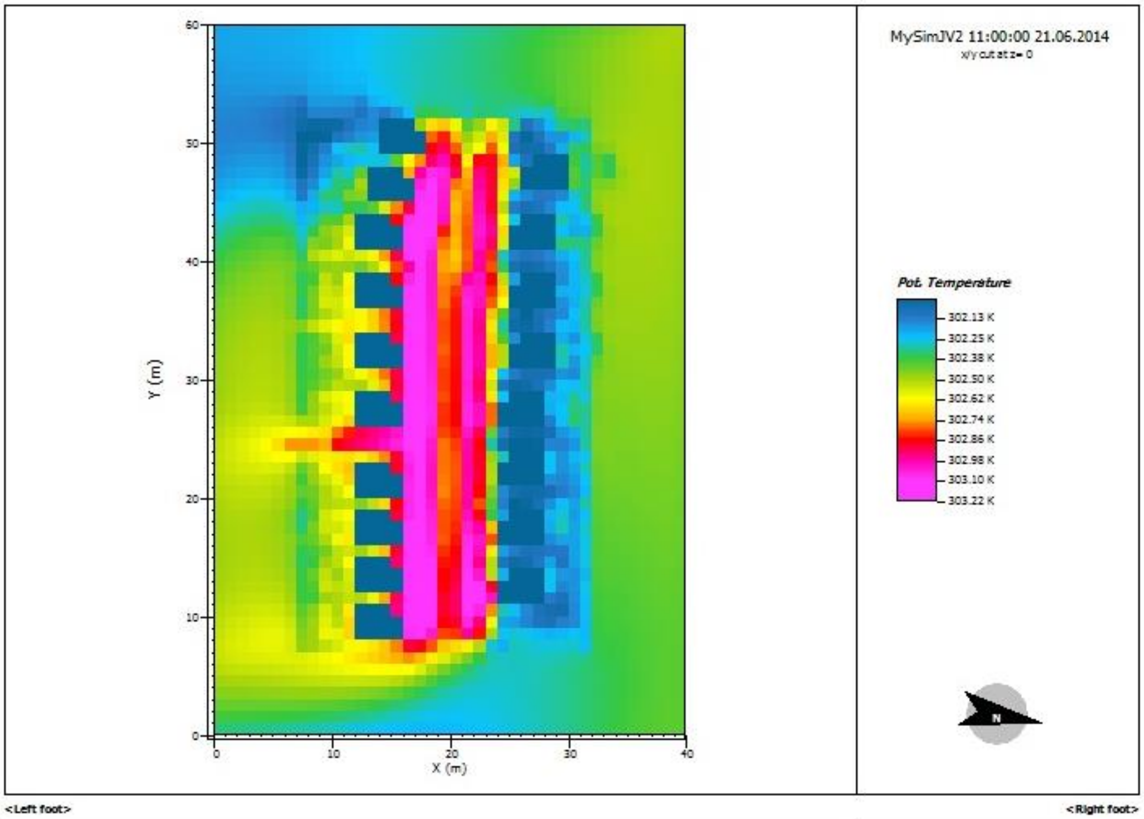


Figure 6.1 - The Mean Radiant and Ambient Air Temperatures Distribution at 8:00 for Scenario 2, (Author, 2014)



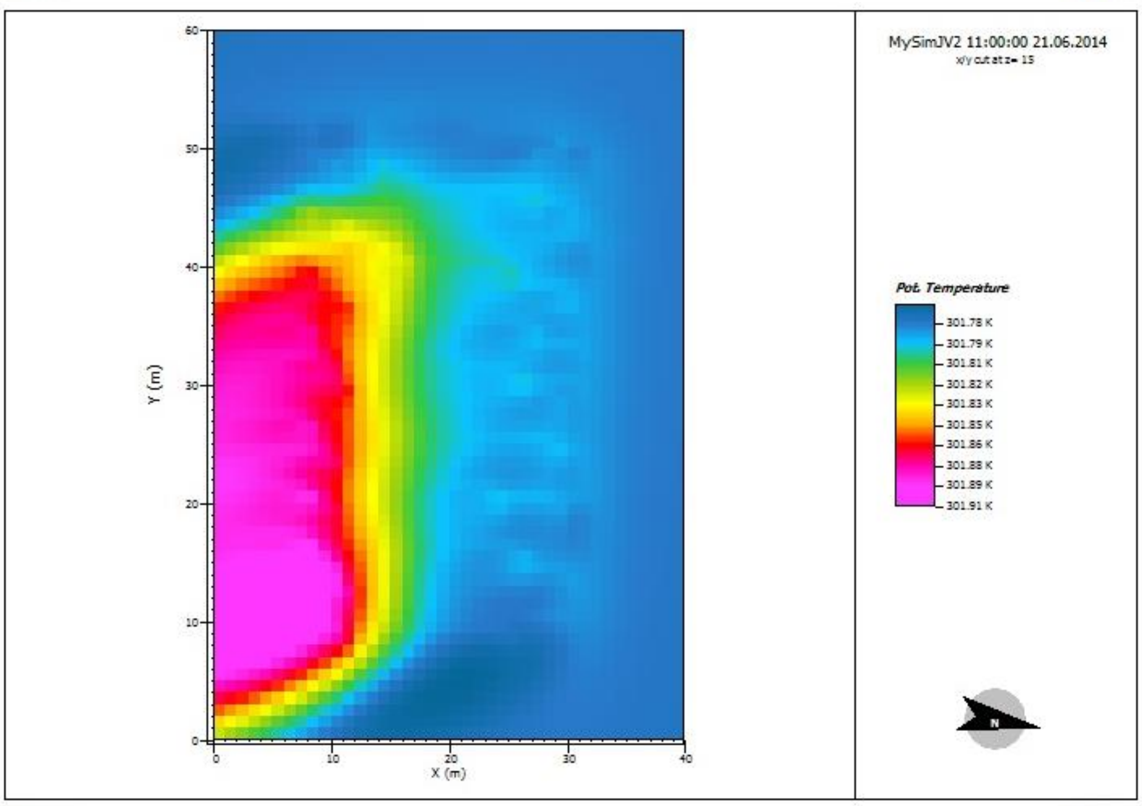


Figure 6.2 - The Mean Radiant and Ambient Air Temperatures Distribution at 11:00 for Scenario 2, (Author, 2014)

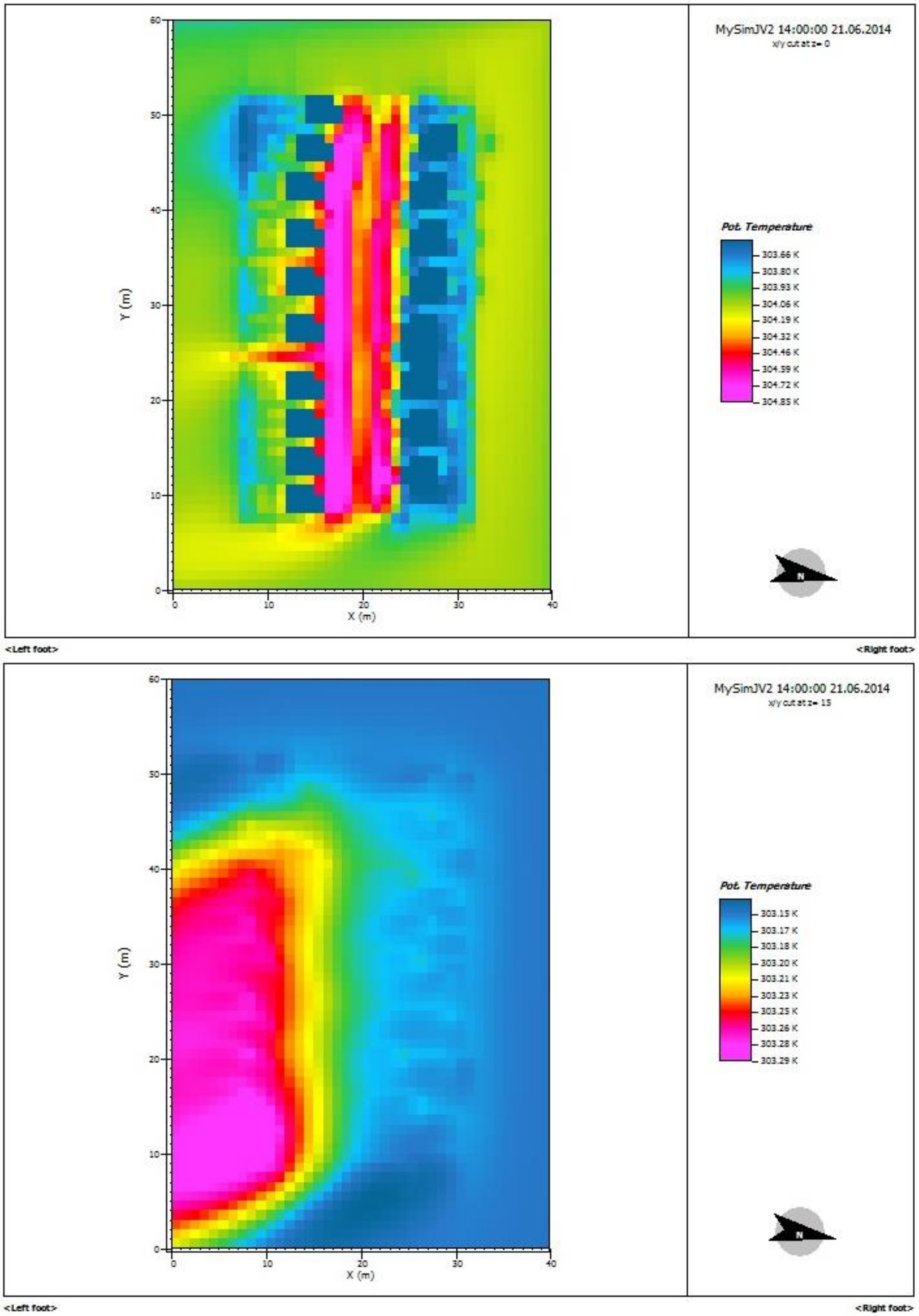


Figure 6.3 - The Mean Radiant and Ambient Air Temperatures Distribution at 14:00 for Scenario 2, (Author, 2014)

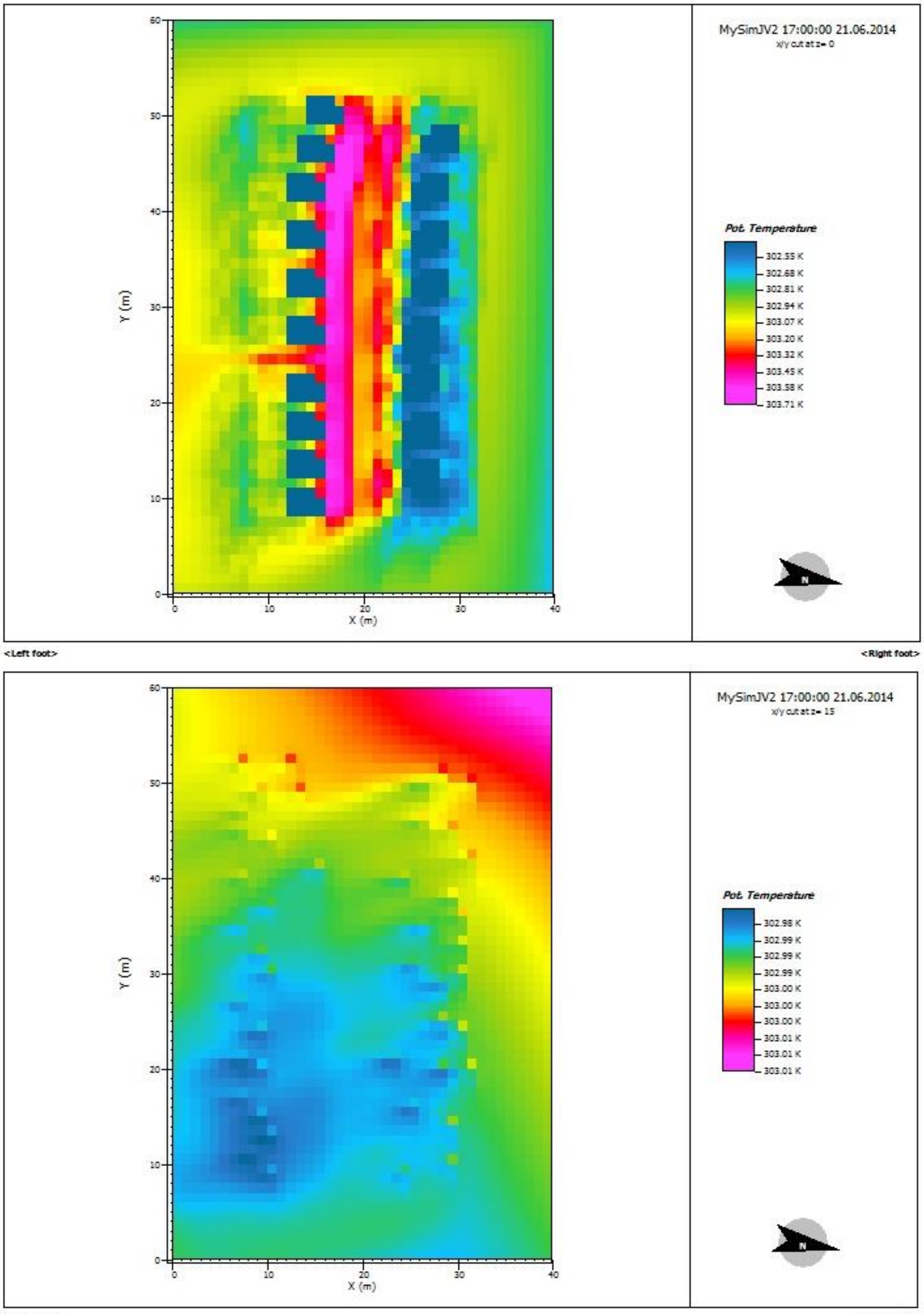


Figure 6.4 - The Mean Radiant and Ambient Air Temperatures Distribution at 17:00 for Scenario 2, (Author, 2014)

6.1.2. Effect of Vegetation

Due to the limited availability of vegetation in the main model, additional vegetation were implemented to replace the existing sandy spots of the backyards, the central boulevard and other untreated spaces. Upon implementing the vegetation in ENVI-met, the software was simulated to test the effect of vegetation on the mean radiant temperature and the ambient air temperature during the three-hour interval on the 21st of June. The study investigated the temperature reduction obtained by distributing dense hedge (H) and very dense tree with leafless base (T2), while the application of traditional grass used in UAE landscape was avoided due to its low effects compared to other forms of greenery in urban parks and also its high level of water requirement. Moreover, in the hot arid climate of Dubai, planting recommendations determines the avoidance of dense vegetation that irritates ventilation and air infiltration within the site. Therefore, the third scenario does not include thick distribution of trees and large gaps between them were implemented.

In the current paper vegetation seemed to be the most temperature reducing parameter of the tested variables in which complies with the earlier findings. In fact, the results of the ENVI-met modeling for JVC community show that vegetation modifications in scenario three contributed in lower average temperature values compared with the main case scenario. This value was lower than the temperature result from the main model scenario with a 0.43 K difference in the Ambient Air Temperature which is the highest difference among all other scenarios.

The ENVI-met simulation showed significant difference obtained between the main model and the vegetation scenario, hence the vegetation proved to be essential in terms of temperature reduction with an overall improvement of 1.09 K in the average Mean Radiant Temperature, and a minimal difference of 0.43 K in the Ambient Air Temperature throughout the peak thermal stress period. The maximum Ambient Air Temperature difference was greater than the average difference which approves that the influence of vegetation increases through the hottest period of the day. Other parameters such as the wind direction, the building materials and shading from the buildings could also affect the temperatures but have not been covered for the current paper.

As mentioned earlier, it is illustrated that all earlier case studies have concluded that vegetation have a considerable impact on the air temperature. Although the value of reduction in temperature was different yet all were within the same range.

The vegetation integrates two factors in charge for the lowering temperature effect which are the shade delivered by plants and evapotranspiration. The shade is argued earlier to lessen the amount of heat captivated therefore emitted by the exteriors in which decreases the surface temperatures. Vegetation principally has two other benefits, first is set upon the soil near a plant bearing in mind the irrigation procedure contributing to evaporative cooling and then is the characteristic of the plants natural life cycle called transpiration. Plants converts the energy in the air into nutrition and the water passage inside the leaves and trunk is similarly evaporated to air supplying a cooling effect. Grass combines the second mechanism which is the evaporative cooling effect, while since trees offer shade beside with the evaporative cooling effect they showed to be more operative than grass in the temperature reduction.

Experimental data demonstrate that the temperature reducing effect of vegetation, due to shared influence of evapotranspiration and shade, can lead to an ambient temperature decrease by 1–4.7 K (Upmanis, 1998; Ca et al., 1998; Barradas, 1998; Shashua-Bar and Hoffman, 2000). Bar et al (2009) used an experimental method to test the impact of vegetation on air temperature. The improvement vegetation had on a similar size and scale of an outdoor space through six different landscape strategies was found to be 2K in which the current cooling effect value was 1.1 K. The duration and date of the test was not mentioned.

The impact of plantation in enhancing the air temperature was assured in many studies (Masmoudi and Mazouz; 2004, Robitu et al. 2006, Hoffman and Bar; 2000, Bar et al. 2009) despite the variation of results. In spite of the different strategies and variation between each case study, all studies confirm the effect of vegetation on the mean radiant and ambient air temperatures. Also, Robitu et al. (2006) stated that vegetation improved the levels of thermal comfort due to its capability not just to improve the air temperature but air velocity, humidity and a lot of other outdoor parameters as well.

Fortunately, Wong et al. (2007) used the same tool as the current study which is ENVI-met supported the results using field measurement yet the scale of application was much larger than the current study. The field measurement supported Wong's results revealed that dense vegetation on a large scale enhanced the air temperature by 3 K. the results seems to be supporting the current findings since the scale used in this study is much bigger in which definitely has a greater cooling effect.

According to Hoffman and Bar (2000),the temperature of the cooling effect of greenery was averaged at 2.8 K depending on the shading coverage and the background effect of the site. Masmoudi and Mazouz (2004) mentioned the difference between an empty space and that of three central bands of trees was 1.7 K. The difference is similar to the value attained with respect to the size and date of simulation.

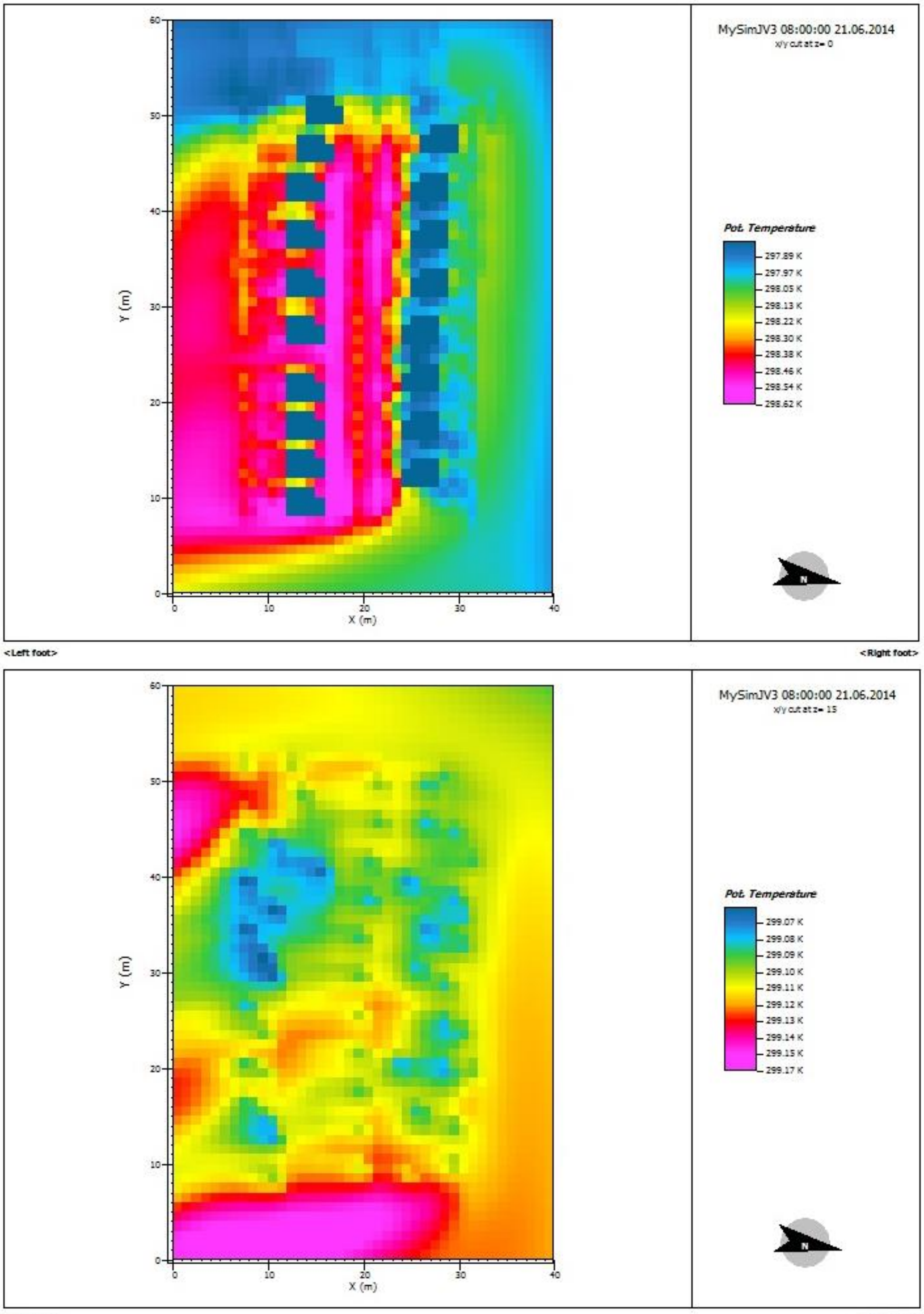


Figure 6.5 - The Mean Radiant and Ambient Air Temperatures Distribution at 8:00 for Scenario 3, (Author, 2014)

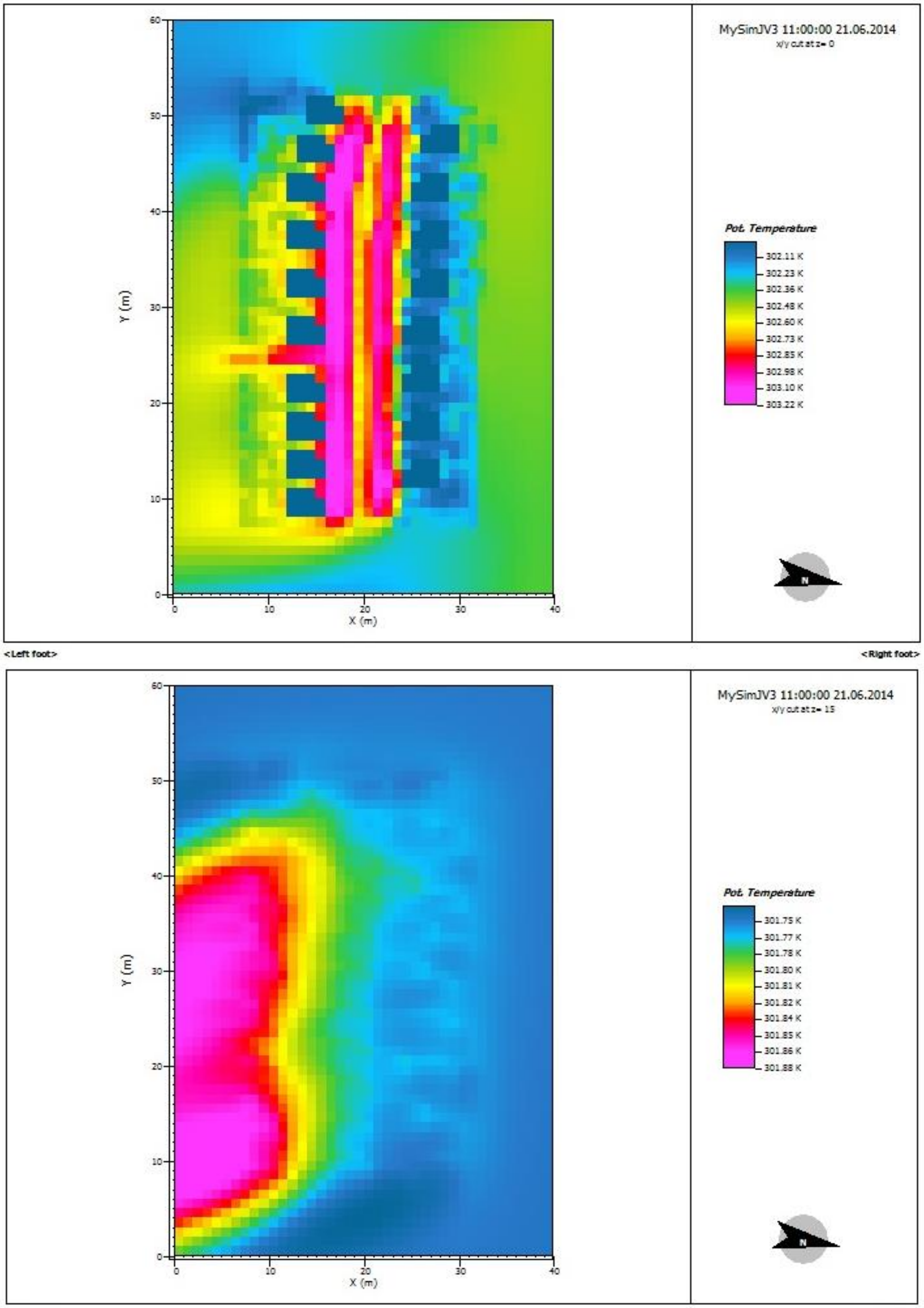


Figure 6.6 - The Mean Radiant and Ambient Air Temperatures Distribution at 11:00 for Scenario 3, (Author, 2014)

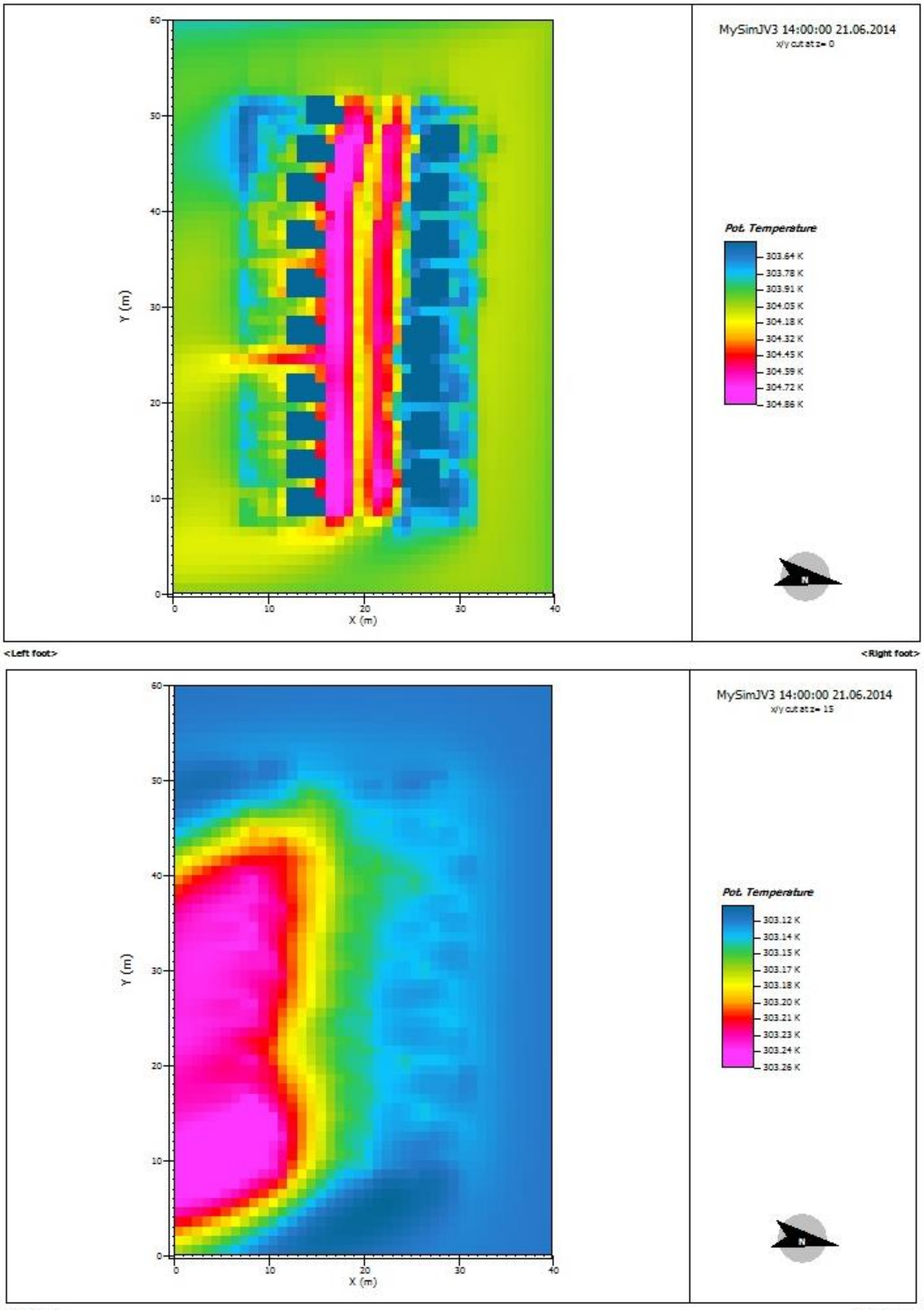


Figure 6.7 - The Mean Radiant and Ambient Air Temperatures Distribution at 14:00 for Scenario 3, (Author, 2014)

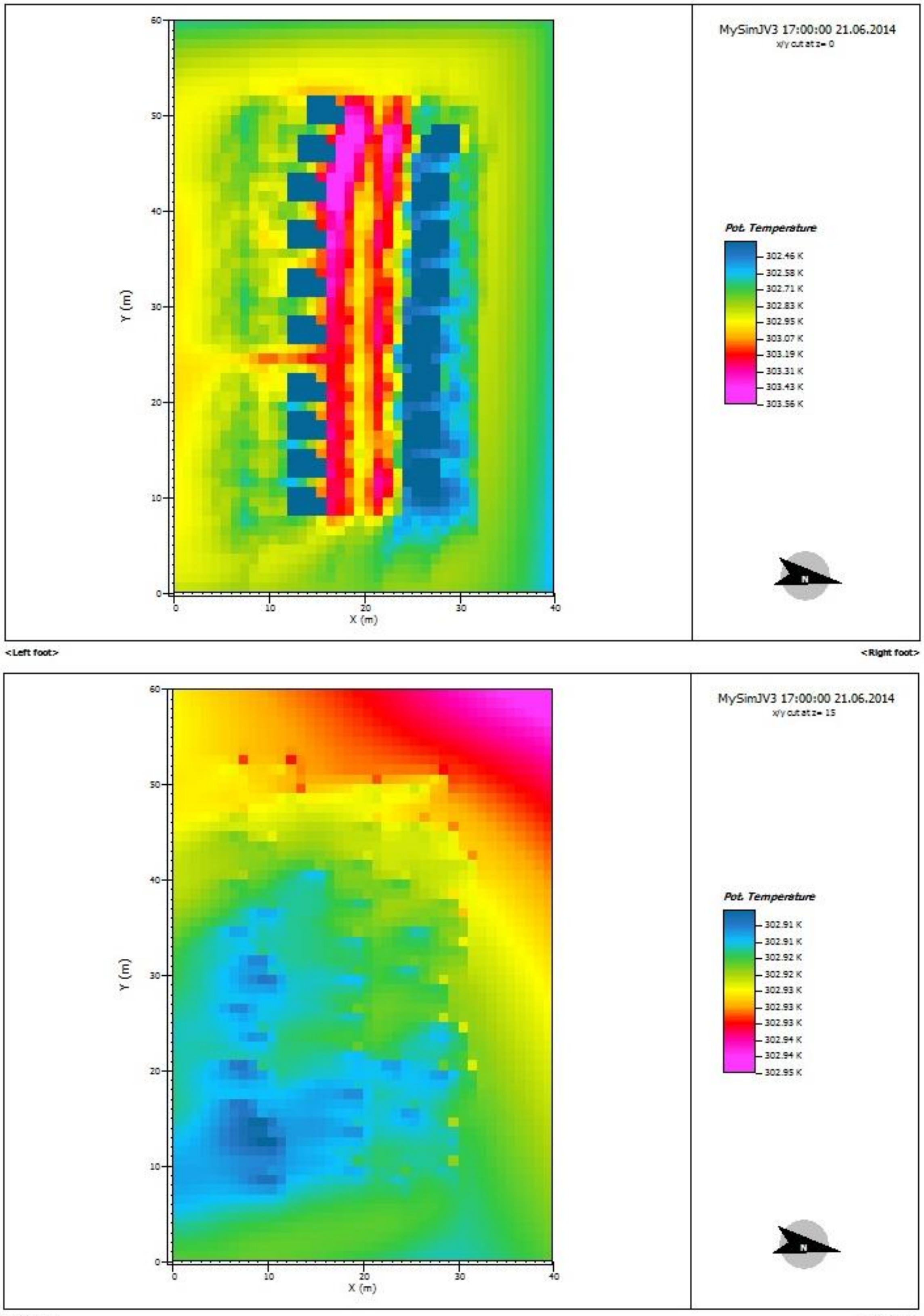


Figure 6.8 - The Mean Radiant and Ambient Air Temperatures Distribution at 17:00 for Scenario 3, (Author, 2014)

6.1.3. Effect of Waterbodies

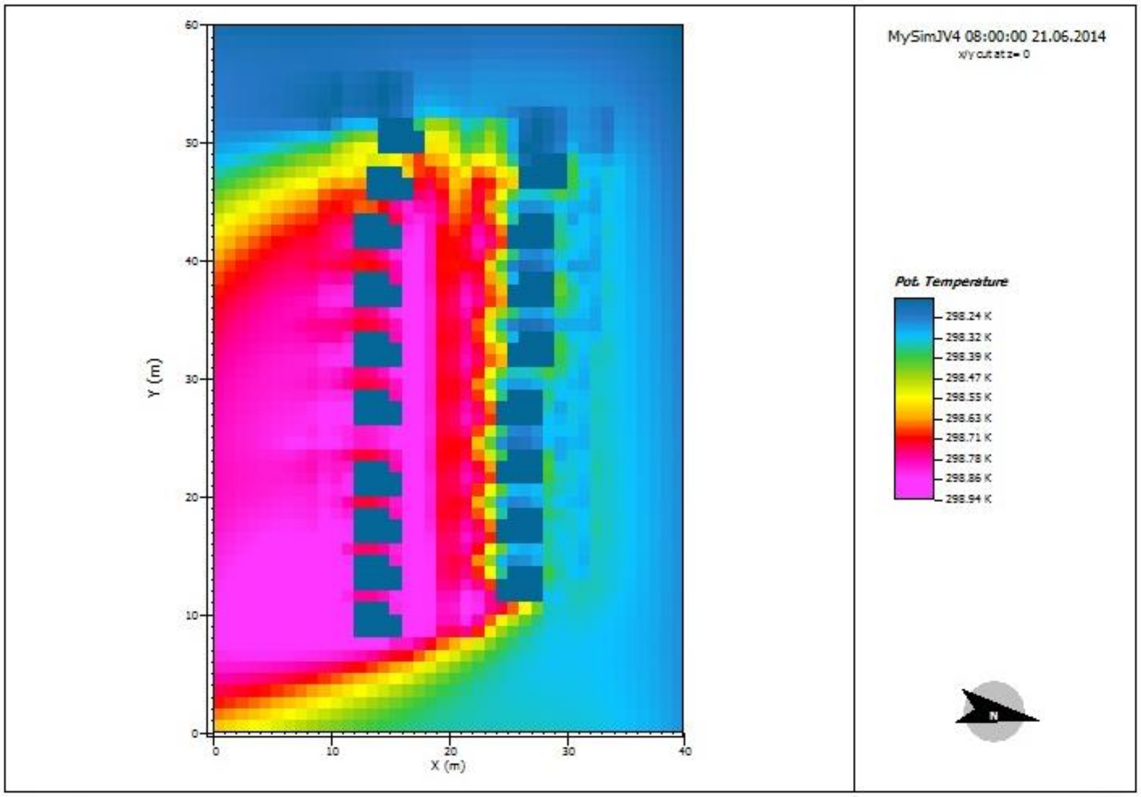
The existence of water ponds enhances the urban microclimate during summer season by cooling the air through evaporation which is always linked to the heat exchange between water and the air. A simulation study has been performed for a typical hot clear sky summer day, June the 21th, for Jumeirah Village Circle community in Dubai to prove this reasoning. The investigation of the effect of water bodies on microclimate was carried out for the fourth scenario in which shallow water features were added to the main model in the form of private pools and public ponds in different locations of the field. Although, it was observed that the Mean Radiant Temperature differed from the existing case by 0.46 K; the ambient air temperature value remained constant at 302.17 K. This can be due to the decrease and variation in the airflow.

Many studies revealed that evaporative cooling is debatably among the most effective methods of passive cooling for urban spaces in hot arid environments (Givoni, 1991; Ken-Ichi, 1991). In an early study by Nishimura et al. (1998) suggested unique water features such as waterfall and spray fountain to generate comfy urban microclimate. The air temperature calculations on the sheltered corner underlined a decrease by almost 3 K of the temperature in the water vaporization phase and that the impact of the water feature from 14 PM till 15 PM can be sensed up to about 35 m of the water feature.

Later, Givoni and La Roche (2000) investigated the performance of an indirect evaporative cooling system with an outdoor pond which is suitable for climates with high relative humidity such as Dubai. The study was experimented in the summer of 1999 at the University of California at Los Angeles using a 6.88 m^3 pond and a 4.46 m^3 test cell.

The test cell wall was made of fiberglass from the inside and plywood from the outside, while the roof was made of concrete with tubing for cooling. The aim of the experiment is to determine the applicability of the evaporative cooling systems in different climates. The system was compared with the outdoor temperature. The results showed that the maximum temperature including the water pond decreased by 3.9 K compared to the maximum outside dry bulb temperature. The authors concluded that to ensure a passive cooling of a building, the indirect cooling systems are suitable to combine with thermal mass to achieve the desired outcome.

Also, in a parallel study done by Gonzalez and Costache (2011), the cooling performance of wet and dry roof ponds in University of Nevada, Las Vegas were evaluated through experimental approach. The set up involved two duplicate test cells each with a 6 inch deep roof pond and removable surface. The two cells were different in having dry and wet roof ponds. During the astronomic summer (June 21st till September 21st), the indoor and outdoor bioclimatic results were tentatively investigated. The outcomes showed that a dry roof pond has the capability to maintain the maximum indoor temperature almost 12 °F lower than the maximum outdoor temperature. It was also revealed that by reducing the maximum indoor temperature an extra 8 °F, a wet roof pond is capable to improve the performance of the dry roof pond.



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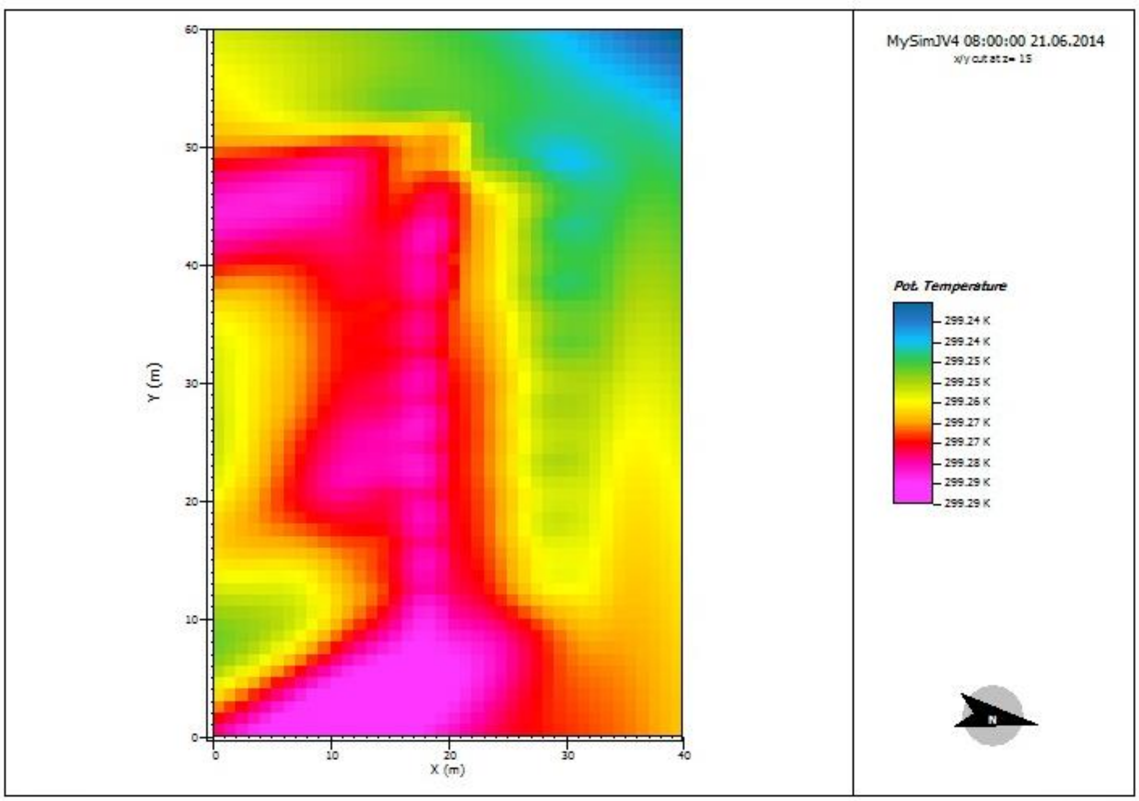

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Figure 6.9 - The Mean Radiant and Ambient Air Temperatures Distribution at 8:00 for Scenario 4, (Author, 2014)

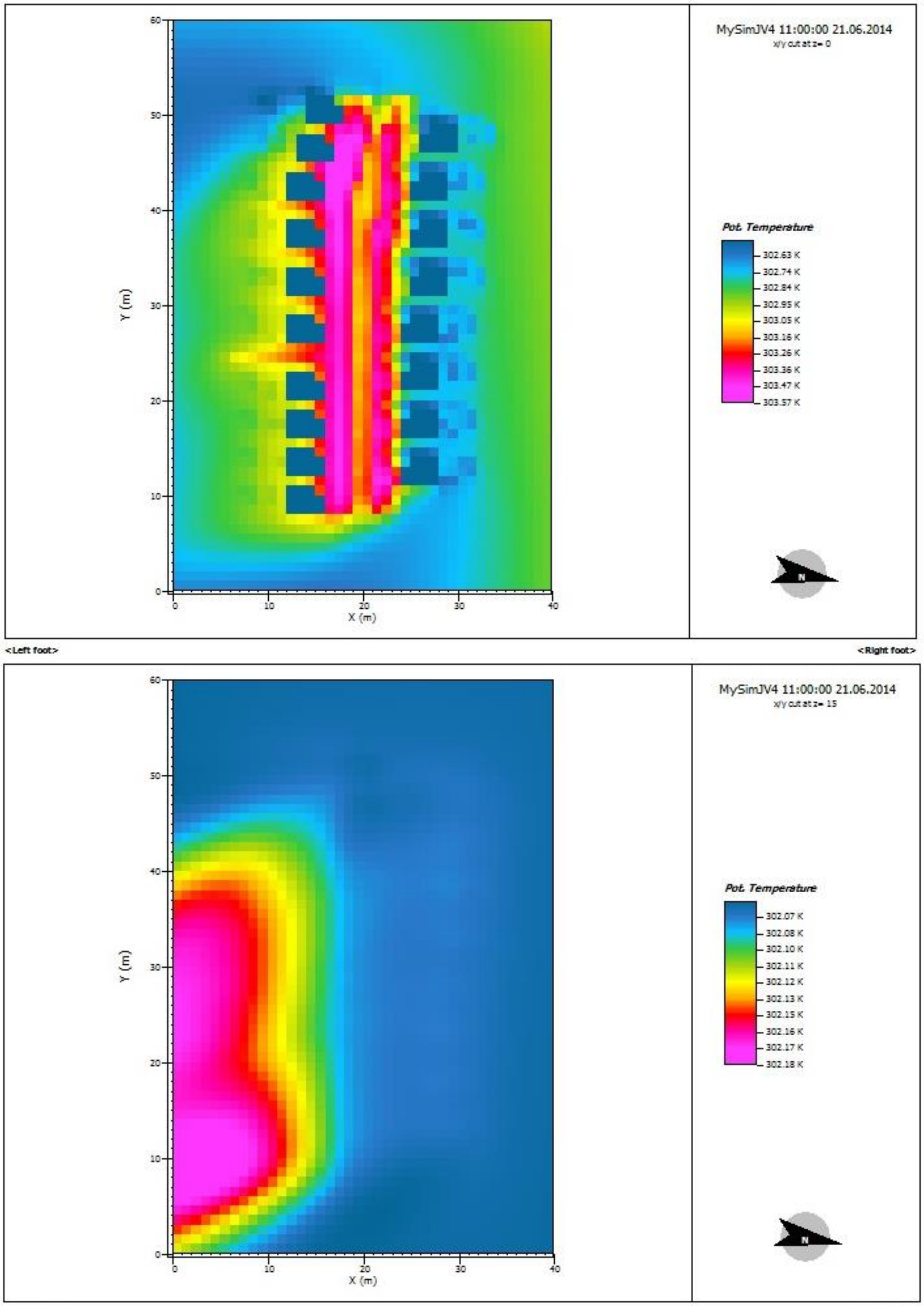


Figure 6.10 - The Mean Radiant and Ambient Air Temperatures Distribution at 11:00 for Scenario 4, (Author, 2014)

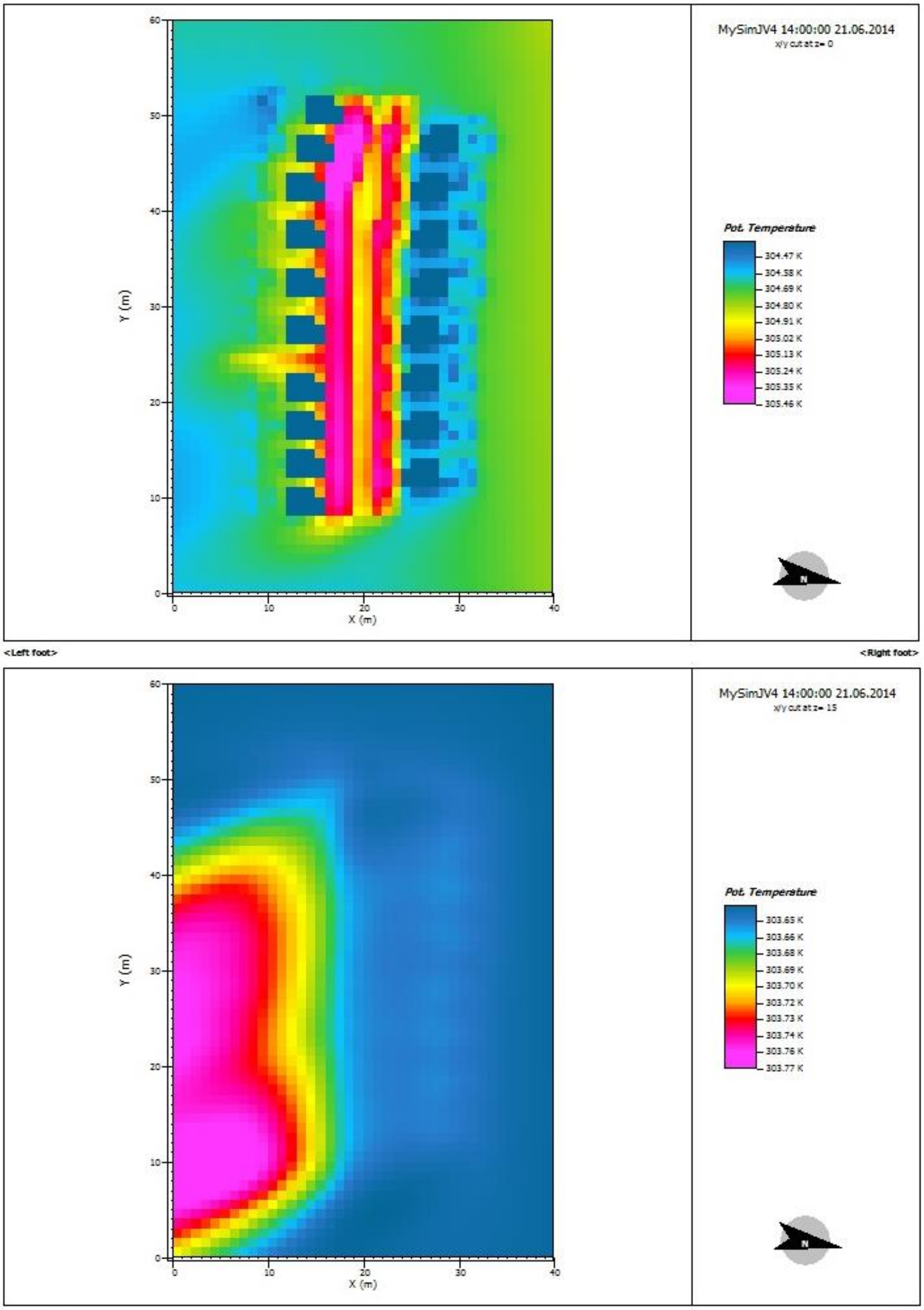


Figure 6.11 - The Mean Radiant and Ambient Air Temperatures Distribution at 14:00 for Scenario 4, (Author, 2014)

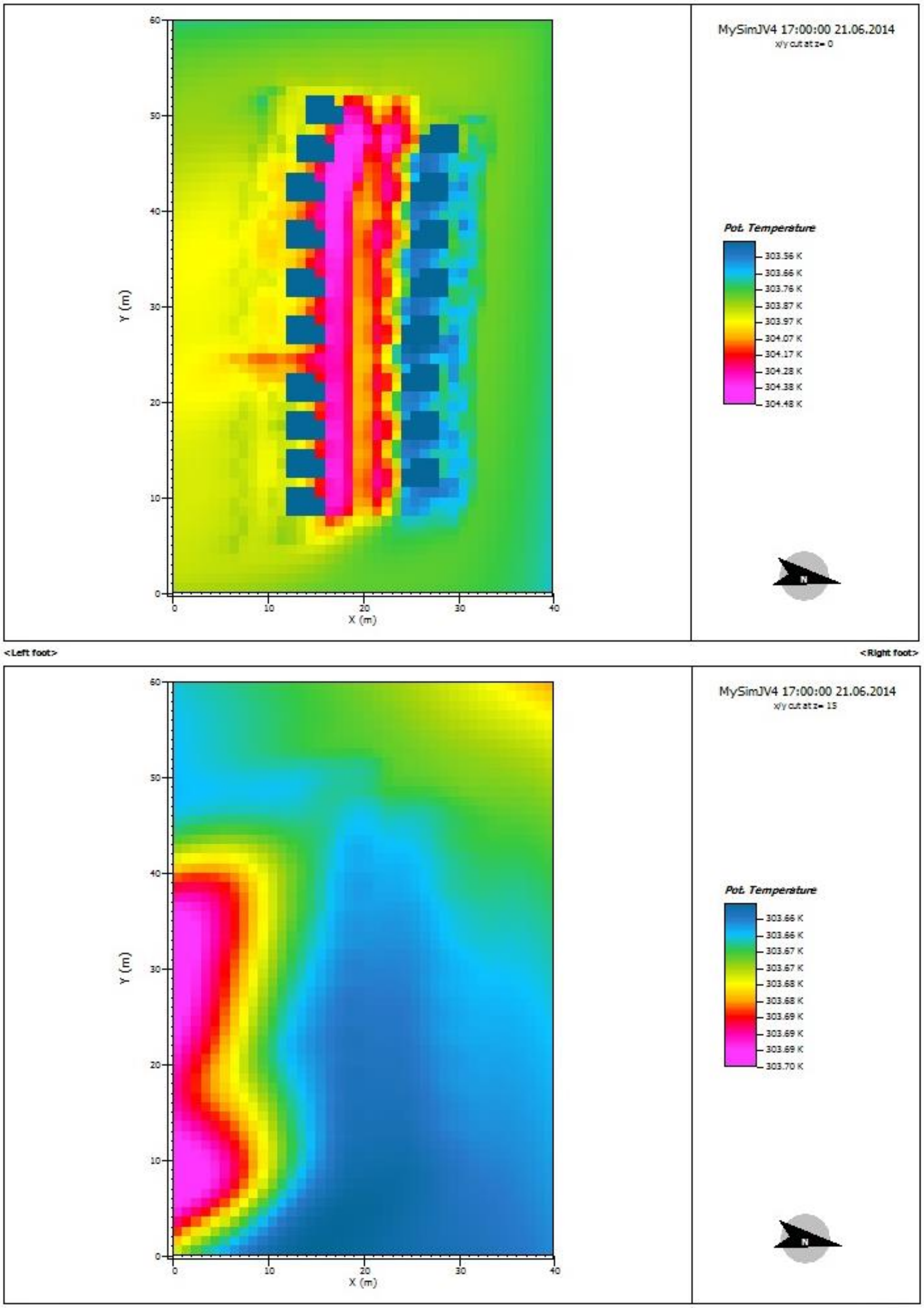


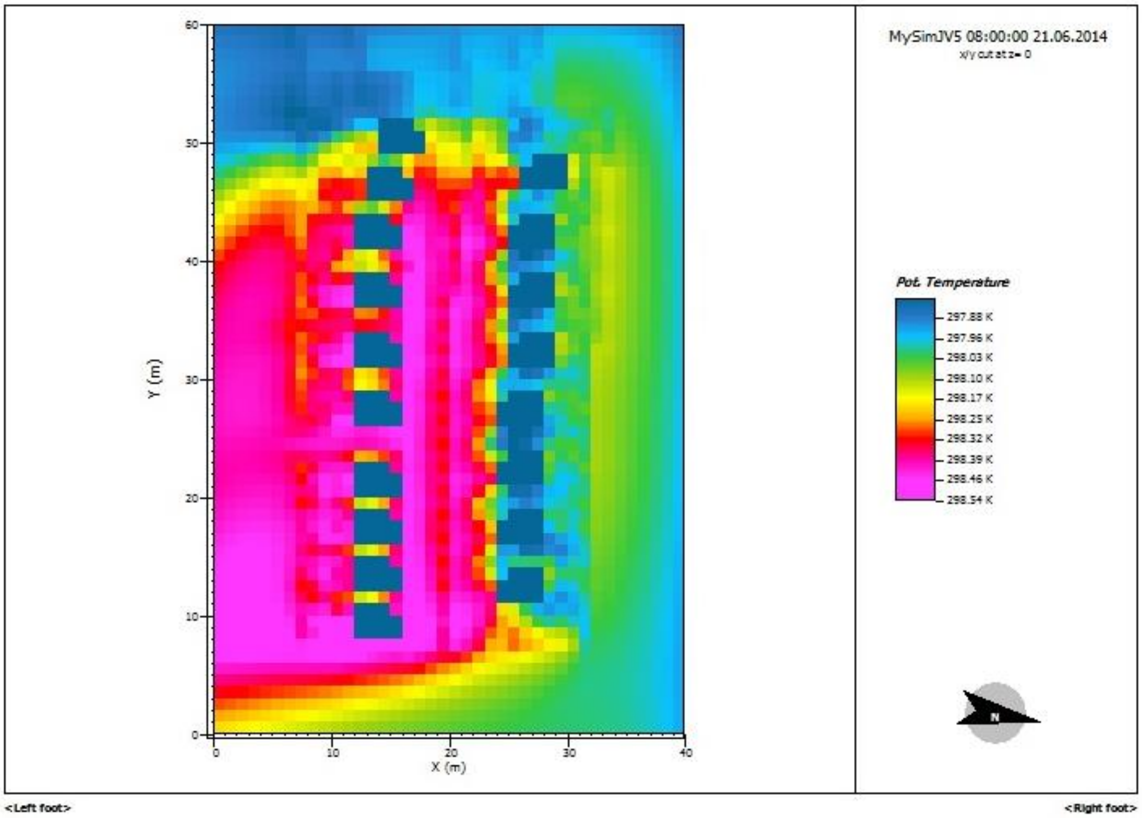
Figure 6.12 - The Mean Radiant and Ambient Air Temperatures Distribution at 17:00 for Scenario 4, (Author, 2014)

6.2. Summary of Section

By observing the visual thermal maps spreading specified by the five scenarios in the summer, it was obvious that temperature differences in the visual maps are more extensive than the obtained quantitative values.

Expectedly, the existing scenario recorded the highest minimum and maximum Mean Radiant Temperature and Ambient Air Temperature, accordingly defined as the worst case scenario. The simulation results of the three other scenarios also make sense. In a logical sequence, the enhanced vegetation scenario recorded the second best performance after the combined scenario. The vegetation insertions in this scenario revealed to enhance the Mean Radiant Temperature by 1.09 K and the Ambient Air Temperature by 0.43 Kin comparison with the same values in the existing scenario. This is reasonable due to the shading effects that vegetation provides to the urban surfaces. Next, the cool pavement scenario contributed in Mean Radiant Temperature reduction with a value of 1.05 K and reduction in Ambient Air Temperature with a value of 0.43 K. The results confirm the important role of light pavement materials with high albedo. At last, the application of water bodies revealed a slight reduction in Mean Radiant Temperature by 0.46 K with no changes in the Ambient Air Temperature.

Therefore, the vegetation demonstrated to be the most temperature reduction parameter followed by the cool pavement material and water bodies respectively. The 2.3 K difference from the combined scenario proves to be a higher reduction in air temperature than the improvement of each proposed scenario individually. The results of the five scenarios compared to each other revealed that the integration of the bioclimatic criteria recommended, enhanced the Ambient Air Temperature by 0.44 K. However this value is supposed to be comparatively minimal but a progress is proved which needed extra clarifications to validate such value. This highlights the capability of the fifth scenario to generate the lowest temperature values in the current investigation as predicted. The combined scenario is therefore assigned to be the best case scenario for this study. The best independent values were chosen based on the average air temperatures rather than the minimum and maximum values.



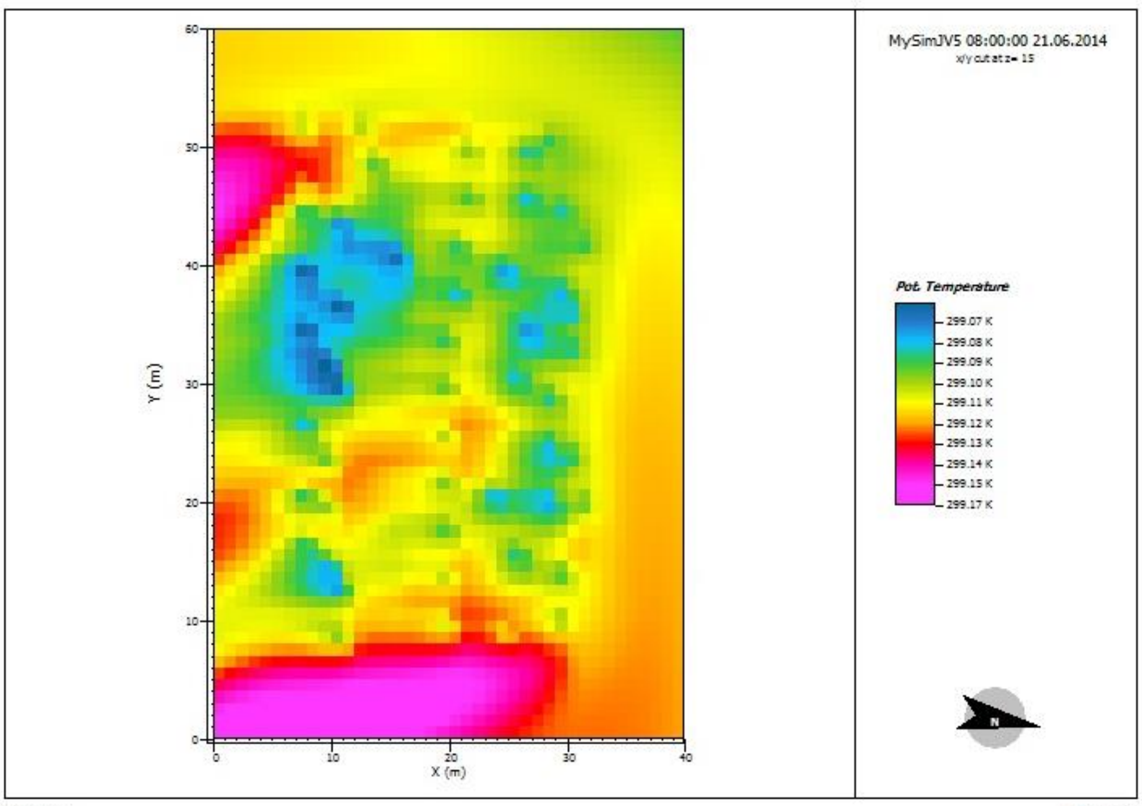


Figure 6.13 - The Mean Radiant and Ambient Air Temperatures Distribution at 8:00 for Scenario 5, (Author, 2014)

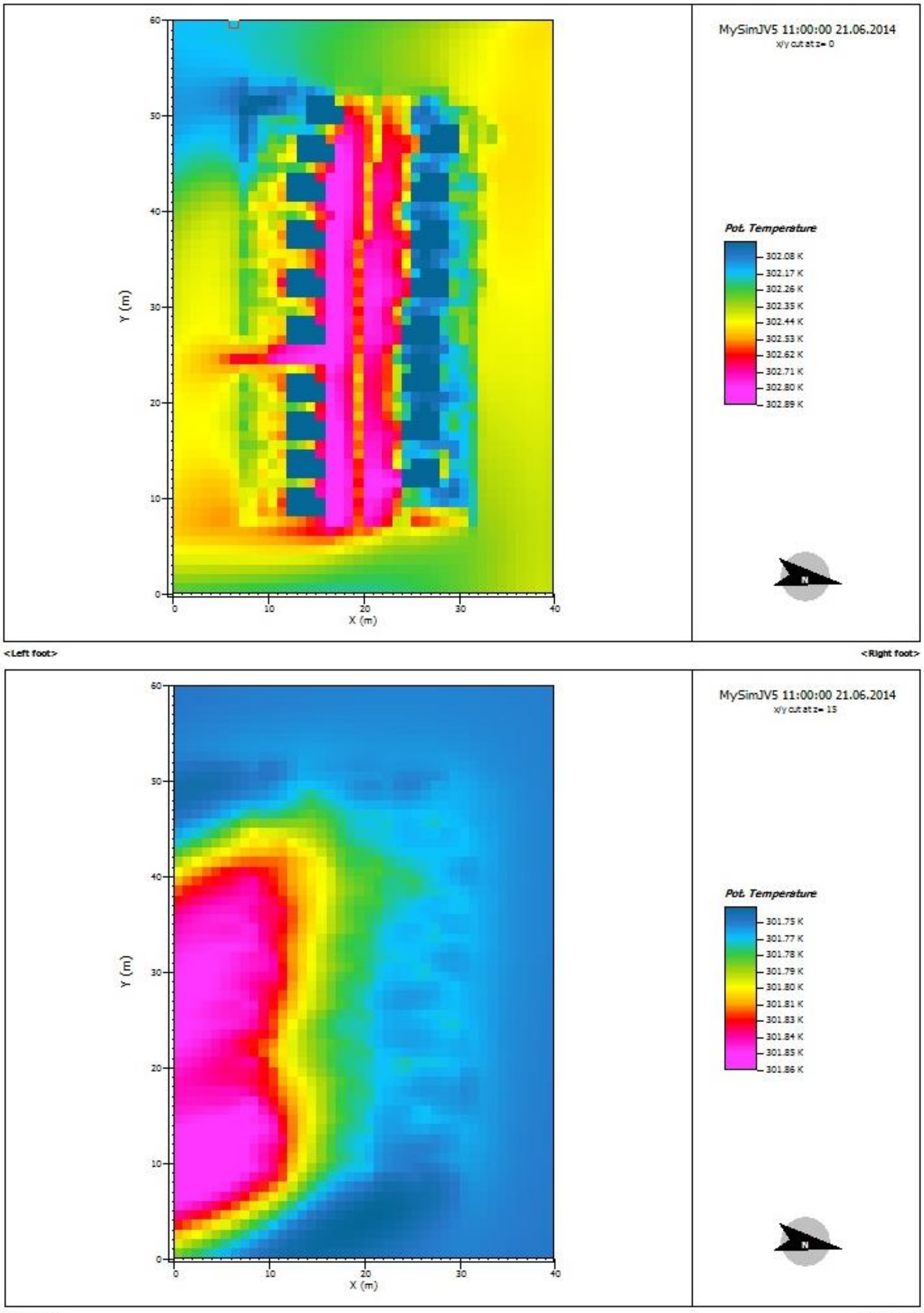


Figure 6.14 - The Mean Radiant and Ambient Air Temperatures Distribution at 11:00 for Scenario 5, (Author, 2014)

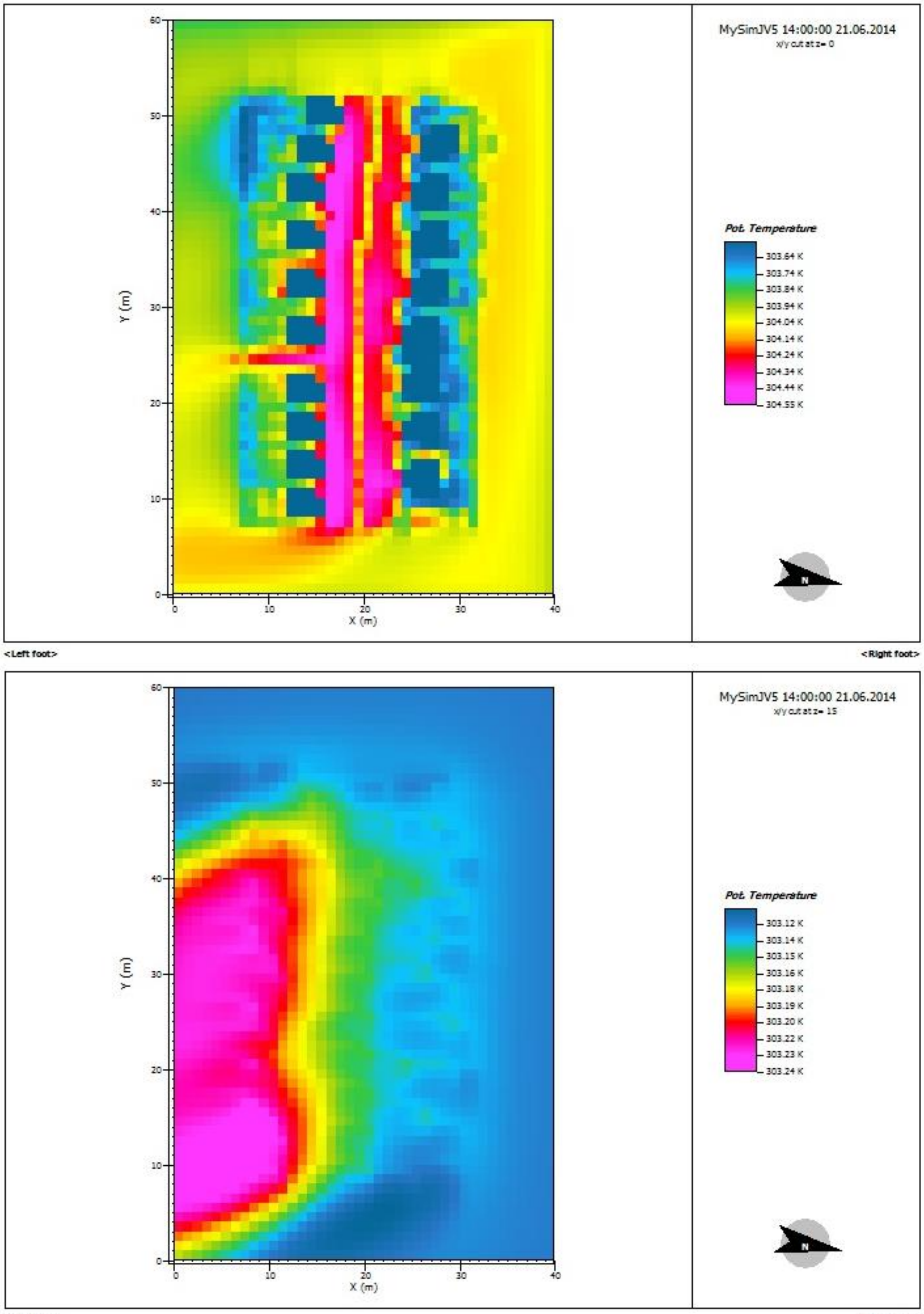


Figure 6.15 - The Mean Radiant and Ambient Air Temperatures Distribution at 14:00 for Scenario 5, (Author, 2014)

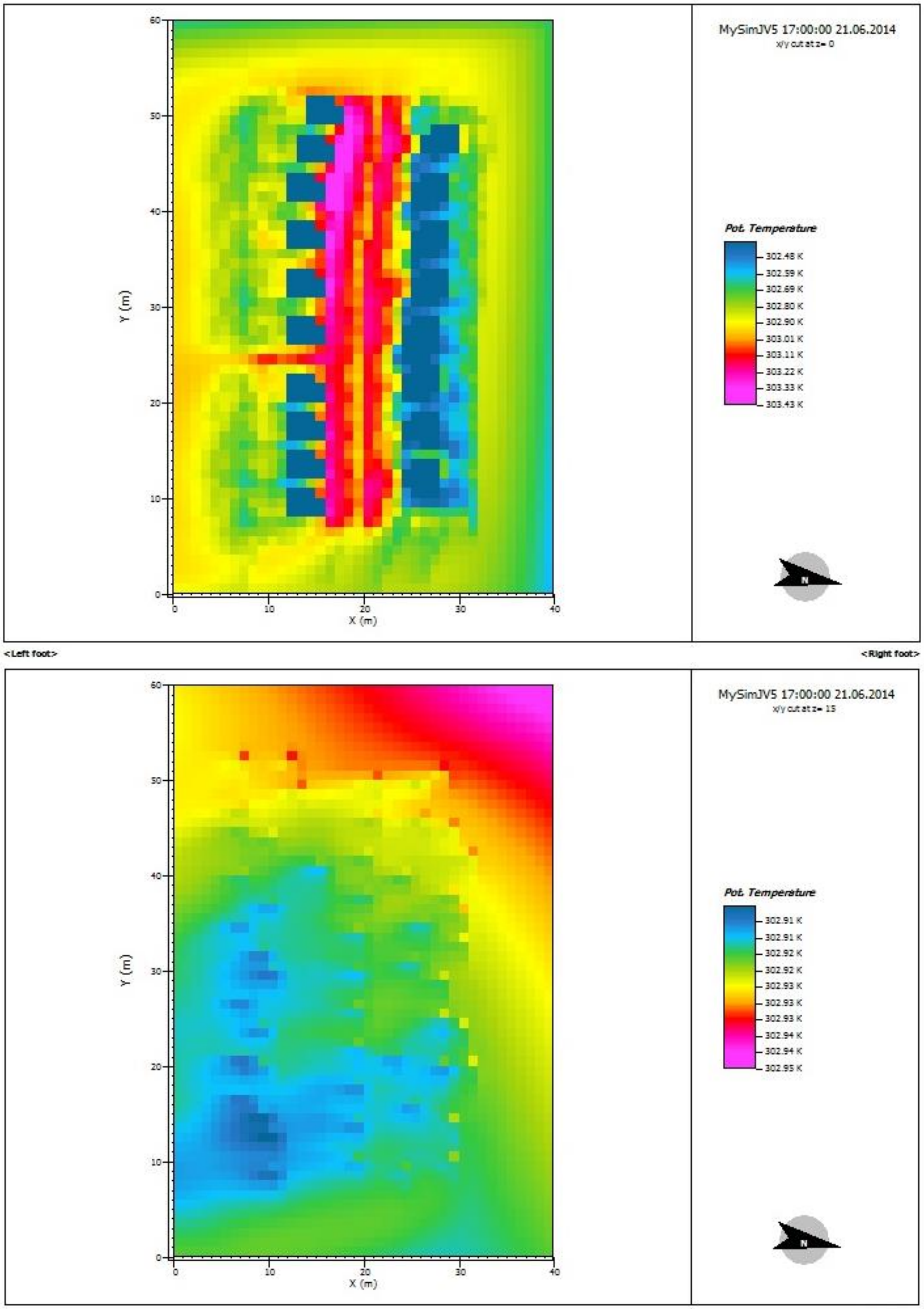


Figure 6.16 - The Mean Radiant and Ambient Air Temperatures Distribution at 17:00 for Scenario 5, (Author, 2014)

Chapter 7 – CONCLUSION & RECOMMENDATIONS

Conclusion

The availability of pleasant outdoor spaces plays a significant role in the presence of sustainable urban environments. The demands to accomplish comfortable open spaces during hot season of the year in Dubai assisted in conducting the present study and delivering a series of outdoor climatic strategies that boost the air temperature.

This paper, comprehensively investigated the effects of selected bioclimatic factors on the air temperature in order to improve residential outdoor spaces in Dubai as its main study through objectives demonstrated in chapter 2. The first objective aimed at determining the influence of bioclimatic factors on outdoor thermal performance. To fulfill the second objective, an optimum landscape scenario for the selected case study was presented to perform a comparative study assisting in analyzing the amount of progress accomplished in reducing the surface and ambient air temperature by each parameter and recognizing the performance of the parameters. The third objective focused on illustrating a successful proposal to promote appropriate land use design including pavement materials, vegetation and water bodies. This objective was followed by assessing the benefits of bioclimatic landscaping and establishing a series of recommendations embracing benefits of ecological landscape design for the professionals in the region.

Therefore, in addition to the existing condition of the site four scenarios were proposed and examined to select the most useful ones in terms of passive cooling. The longest summer day (21st of June) was the target of the variables including cool pavement, vegetation and water bodies. The five scenarios had a half day simulation consisting the part of the day when the sun appears between 6.00 AM and 6.00 PM to accomplish stability between the temperature behaviors during daytime and nighttime. The experimental outcomes of the simulations performed, displayed the behaviors of Ambient Air Temperature and Mean Radiant Temperature phenomena which were extracted and justified from ENVI-met.

Obviously, the main model scenario recorded the highest average values for both temperature parameters. These values were considerably improved in the second scenario due to the replacement of asphalt surfaces with cool concrete pavement. Therefore, the average value for the Mean Radiant Temperature was reduced by 1.05 K and 0.4 K for the Ambient Air Temperature. In the third scenario, the enhanced vegetation contributed in lower average temperature values compared with the main case scenario. However, in the water pond application scenario, the average Mean Radiant Temperature was decreased by a difference of 0.46 K, the average Ambient Air Temperature remained constant at 302.17 K. Finally, the bioclimatic scenario also known as the combined scenario scored the lowest average Mean Radiant Temperature and Ambient Air Temperature during June, 21st among all the scenarios with a value of 301.86 K and 301.74 K respectively.

Generally, the simulation results of the three other scenarios also make sense. In a logical sequence, the enhanced vegetation scenario recorded the second best performance after the combined scenario. Therefore, the vegetation demonstrated to be the most temperature reduction parameter followed by the cool pavement material and water bodies respectively. The 2.3 K difference from the combined scenario proves to be a higher reduction in air temperature than the improvement of each proposed scenario individually. The results of the five scenarios compared to each other revealed that the integration of the bioclimatic criteria recommended, enhanced the Ambient Air Temperature by 0.44 K. However, this value is supposed to be comparatively minimal but a progress is proved which needed extra clarifications to validate such value. This highlights the capability of the bio-climatically enhanced scenario to generate the lowest temperature values in the current investigation as predicted.

In general, the application of innovative mitigation practices extremely contributes to reduce temperatures and promote comfort in outdoor urban areas. However, it was derived that in very hot arid environments like Dubai, obtaining the thermal comfort levels of temperature during summer showed to be unfeasible yet a slight enhancement is attainable.

Cool materials offering a high emissivity and solar reflectivity have been recommended as an operative moderation method when used in buildings and outdoor environments. While wide range of experimental information is accessible to analyze the performance of cool materials in secluded buildings, inadequate data are obtainable regarding the reducing ability of reflective surfaces when used in outdoor urban spaces. The results show that vegetation, water bodies and cool pavements should be considered as actual means for the enhancement of microclimatic conditions in outdoors in hot dry regions.

Recommendations

A direction for future recommendations to add to the existing knowledge is performed by conducting this study. The findings delivered earlier depended on particular principles narrowed down by the existing resources and assets. The restricted testing instruments and time frame largely controlled many conditions in the creation of the study environment of the investigation of variables. Some of the findings argued before initiated several questions that require corrective movements. Few of the parameters considered for the current study such as vegetation were too extensive which needed extra research, however was not possible and thus will be declared in the following recommendations for future studies:

- The methodology of this study has not been combined with field measurements to validate the results obtained through ENVI-met simulations. Therefore it recommended conducting future research which includes field measurements.
- This study has only considered the summer condition since it is the harshest than the other seasons. Therefore this study can be further investigated to include the field measurements during different seasons to better understand the intertwined and intricate relationships and interactions of the landscaped opens spaces with the environment.
- Using this study as a basis, further research can be done to identify the other factors that can influence the temperature like the shading from the building during the different times of the day, as is seen in the results where no change in temperature occurred even with the addition of plants.
- Examination of the independent parameters within winter season needs to be performed.
- Evaluation of greater scopes of areas for the similar parameters to recognize the threshold for the proficiency of the bioclimatic ideologies according to the scope

- Integrating the probability of using air flow and wind speed features with appropriate design in parallel with the examined parameters.
- Generating more software which are easy to perform for outdoor study with extensive archives and resources is required where combination of the independent variables like creating arcades or shading elements, fronts projections and their impact on the outdoor climate.
- The independent parameters including cool pavement, vegetation and water bodies were investigated within 12 hours in June remarking the diurnal patterns in which nighttime configurations needs to be examined to confirm the coolest parameters designated.
- Assessment of ENVI-met findings with field measurements studies to remove the issue of justification in the earlier research works.

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Appendix A – ENVI-MET SIMULATION

ENVI-met V3.1 MySimJV5

Configuration | ENVI-met Output | ENVI-met

[Internal Default] ENVI-met

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

Computername for ENVI-met cluster: ENVInode_GHAZAL-PC

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 ******************

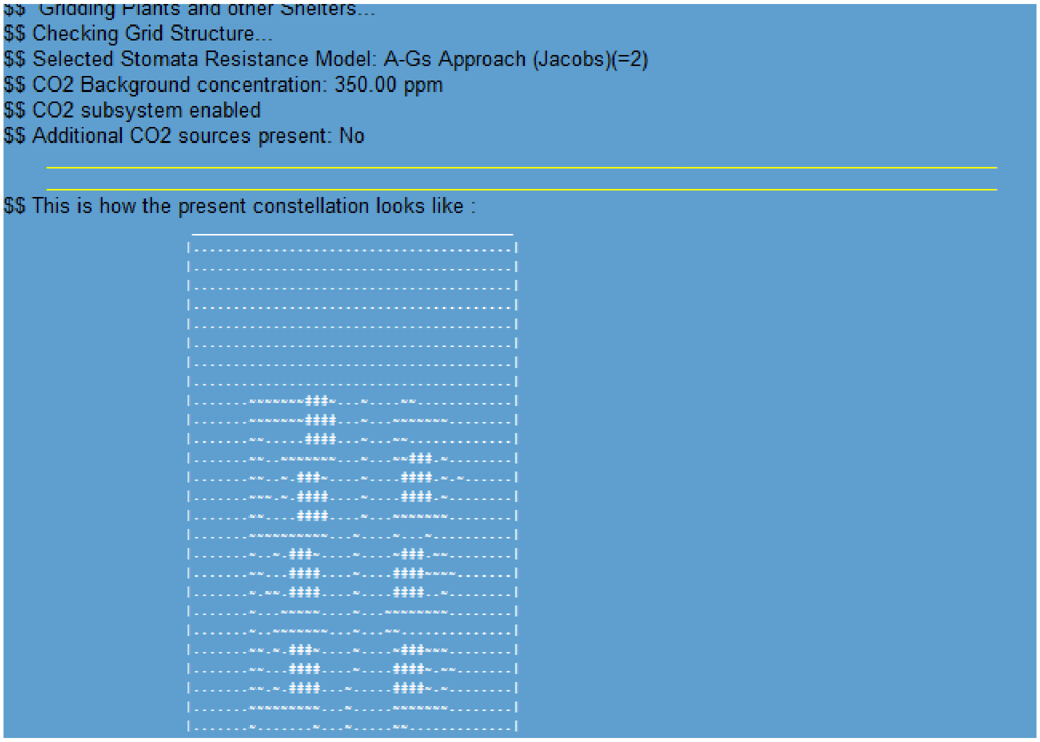
Source Modell Settings : --------------------------------
Identified Source Type: PM (Particulate Matter)
Given Name: PM10
Type of source: Particle

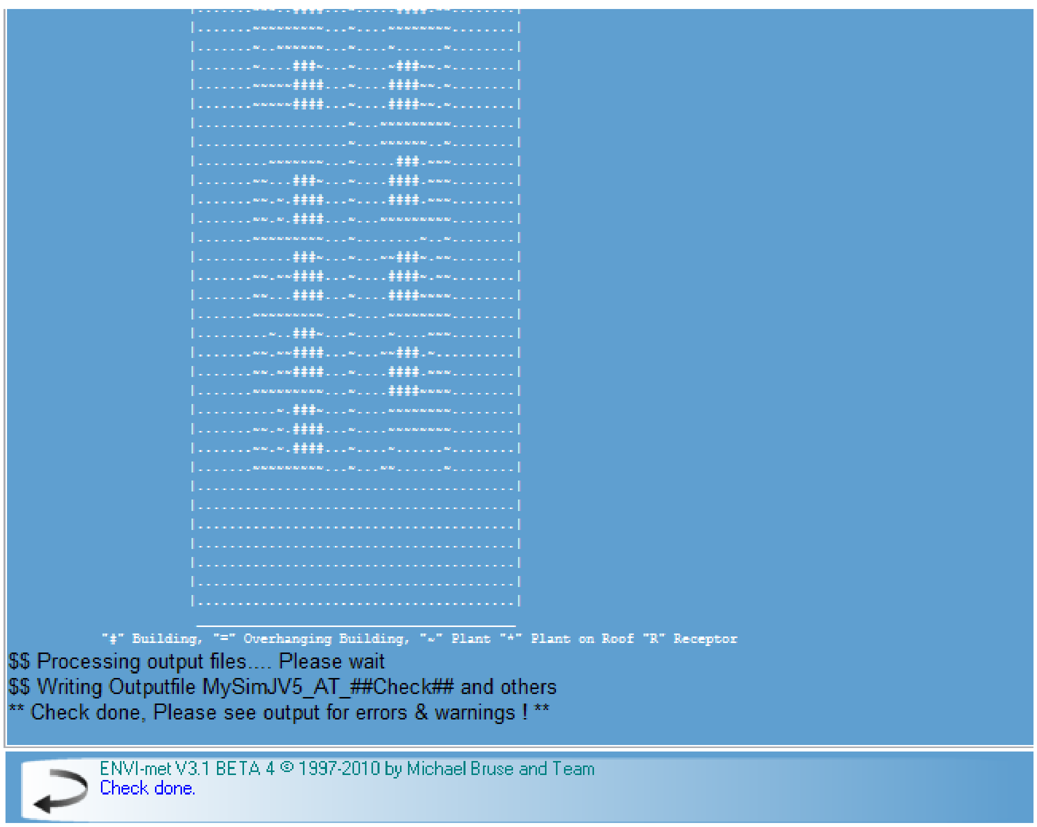
```
Particle Diameter (µm)        :10.00
Particle Density (g/cm³)      :1.00
Settling Velocity (cm/h)      :1107.50
Diffusion Coefficient (cm²/s):0.0000
Schmitt-Number                :4054944.25
Transfer resistance soils     :0.00
Mesophyll transfer resistance:0.00
```

$$ Reading Global Plant Database sys.basedata\plants.dat...
$$ ********************** 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
$$ Creating chess patterns for nesting model using " I" for black and " I" for white

$$ Grid Information:

$$    dxy(Main)=3.00 m  Nesting:3 grids. dxy(Nest)=12.00,9.00,6.00 m
$$    dz=1.00 (non-equidistant with telecoping factor=  0%)
$$ Top of 3D Model is at 19.50 m height
$$ Highest object in model area is 6.00 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:\ENVImet31\input\NewAreaJV5.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:\ENVImet31\input\NewAreaJV5.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
```


$$ Gridding Plants and other Shelters...
$$ 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 :


"#" Building, "=" Overhanging Building, "~" Plant "*" Plant on Roof "R" Receptor
$$ Processing output files.... Please wait
$$ Writing Outputfile MySimJV5_AT_##Check## and others
** Check done, Please see output for errors & warnings ! **
ENVI-met V3.1 BETA 4 © 1997-2010 by Michael Bruse and Team
Check done.

Appendix B **– EXTRACTED RAW RESULTS FROM ENVI-MET**

B.1 – Extracted Raw Results from Envi-met for Main Model at 8:00 (Mean Radiant Temperature)

x(m)	y(m)	Pot. Temperature (K)	Filtered Results
49.5	31.5	298.9192	298.9192
25.5	28.5	298.9212	298.9212
49.5	28.5	298.9225	298.9225
52.5	37.5	298.9229	298.9229
25.5	25.5	298.9235	298.9235
49.5	34.5	298.9249	298.9249
37.5	22.5	298.9261	298.9261
28.5	28.5	298.9267	298.9267
34.5	28.5	298.9275	298.9275
28.5	25.5	298.9291	298.9291
52.5	34.5	298.931	298.931
31.5	25.5	298.9345	298.9345
52.5	28.5	298.937	298.937
52.5	31.5	298.9384	298.9384
34.5	25.5	298.9402	298.9402
		Average	298.9283133
		Maximum	298.9402
		Minimum	298.9192

B.2 – Extracted Raw Results from Envi-met for Main Model at 11:00 (Ambient Air Temperature)

x(m)	y(m)	Pot. Temperature (K)	Filtered Results
100.5	0 142.5	0 302.0676	302.0676
100.5	0 139.5	0 302.0676	302.0676
100.5	0 136.5	0 302.0677	302.0677
100.5	0 106.5	0 302.0680	302.068
100.5	0 103.5	0 302.0680	302.068
100.5	0 133.5	0 302.0681	302.0681
100.5	0 100.5	0 302.0681	302.0681
100.5	0 109.5	0 302.0682	302.0682
100.5	0 121.5	0 302.0683	302.0683
100.5	0 118.5	0 302.0683	302.0683
100.5	0 130.5	0 302.0684	302.0684
100.5	0 124.5	0 302.0684	302.0684
100.5	0 115.5	0 302.0685	302.0685
100.5	0 112.5	0 302.0685	302.0685
100.5	0 127.5	0 302.0686	302.0686
		Average	302.867561
		Maximum	302.184
		Minimum	302.0591

B.3 – Final Raw Results Extracted for Main Model Scenario

	A	B
1	Time	Mean Radiant Temperature (K)
2	8.00	298.4997231
3	11.00	304.761532
4	14.00	304.761532
5	17.00	303.8989626
6	Average	302.9804375
7	Maximum	304.761532
8	Minimum	298.4997231
9		
10		
11		
12		
13		
14		
15		
16		
17	Time	Ambient Air Temperature
18	8.00	299.2672265
19	11.00	302.0867561
20	14.00	303.6699946
21	17.00	303.6669591
22	Average	302.1727341
23	Maximum	303.6699946
24	Minimum	299.2672265

B.4 – Extracted Raw Results from Envi-met for Scenario 2 at 11:00 (Mean Radiant Temperature)

x(m)	y(m)	Pot. Temperature (K)	Filtered Results
109.5	0 133.5	0 302.4991	302.4991
115.5	0 178.5	0 302.4993	302.4993
109.5	0 148.5	0 302.4994	302.4994
106.5	0 145.5	0 302.4995	302.4995
112.5	0 145.5	0 302.4997	302.4997
112.5	0 139.5	0 302.4998	302.4998
118.5	0 175.5	0 302.5001	302.5001
112.5	0 142.5	0 302.5001	302.5001
115.5	0 172.5	0 302.5002	302.5002
109.5	0 136.5	0 302.5004	302.5004
109.5	0 145.5	0 302.5011	302.5011
109.5	0 139.5	0 302.5011	302.5011
109.5	0 142.5	0 302.5014	302.5014
118.5	0 178.5	0 302.5023	302.5023
115.5	0 175.5	0 302.5026	302.5026
		Average	302.4866835
		Maximum	303.2196
		Minimum	301.9199

B.5 – Final Raw Results Extracted for Scenario 2

	A	B
1	Time	Mean Radiant Temperature
2	8.00	298.2227795
3	11.00	302.4866835
4	14.00	304.0723921
5	17.00	302.9709418
6	Average	301.9381992
7	Maximum	304.0723921
8	Minimum	298.2227795
9		
10		
11		
12		
13		
14		
15		
16	Time	Ambient Air Temperature
17	8.00	299.1306584
18	11.00	301.8040332
19	14.00	303.1829
20	17.00	302.9911742
21	Average	301.7771915
22	Maximum	303.1829
23	Minimum	299.1306584

B.6 – Extracted Raw Results from Envi-met for Scenario 3 at 17:00 (Mean Radiant Temperature)

x(m)	y(m)	Pot. Temperature (K)	Filtered Results
100.5	0 100.5	0 302.8658	302.8658
100.5	0 163.5	0 302.8676	302.8676
100.5	0 103.5	0 302.8676	302.8676
100.5	0 157.5	0 302.8686	302.8686
100.5	0 106.5	0 302.8690	302.869
100.5	0 160.5	0 302.8694	302.8694
100.5	0 109.5	0 302.8705	302.8705
100.5	0 133.5	0 302.8713	302.8713
100.5	0 112.5	0 302.8721	302.8721
100.5	0 115.5	0 302.8755	302.8755
100.5	0 118.5	0 302.8763	302.8763
100.5	0 124.5	0 302.8776	302.8776
100.5	0 121.5	0 302.8776	302.8776
100.5	0 127.5	0 302.8788	302.8788
100.5	0 130.5	0 302.8794	302.8794
		Average	302.8561175
		Maximum	303.5555
		Minimum	302.2316

B.7 – Final Raw Results Extracted for Scenario 3

	A	B
1	Time	Surface Temp. (K) @z=0
2	8.00	298.1886371
3	11.00	302.4672423
4	14.00	304.0520567
5	17.00	302.8561175
6	Average	301.8910134
7	Maximum	304.0520567
8	Minimum	298.1886371
9		
10		
11		
12		
13		
14		
15		
16	Time	Ambient Temp. (K) @z=15
17	8.00	299.1079915
18	11.00	301.8040332
19	14.00	303.1563242
20	17.00	302.9202663
21	Average	301.7471538
22	Maximum	303.1563242
23	Minimum	299.1079915

B.8 – Extracted Raw Results from Envi-met for Scenario 4 at 14:00 (Ambient Air Temperature)

x(m)	y(m)	Pot. Temperature (K)	Filtered Results
106.5	0 175.5	0 303.6771	303.6771
112.5	0 172.5	0 303.6772	303.6772
118.5	0 169.5	0 303.6772	303.6772
103.5	0 178.5	0 303.6773	303.6773
109.5	0 175.5	0 303.6776	303.6776
115.5	0 172.5	0 303.6777	303.6777
106.5	0 178.5	0 303.6779	303.6779
112.5	0 175.5	0 303.6782	303.6782
118.5	0 172.5	0 303.6783	303.6783
109.5	0 178.5	0 303.6785	303.6785
115.5	0 175.5	0 303.6788	303.6788
112.5	0 178.5	0 303.6792	303.6792
118.5	0 175.5	0 303.6794	303.6794
115.5	0 178.5	0 303.6799	303.6799
118.5	0 178.5	0 303.6806	303.6806
		Average	303.6667992
		Maximum	303.6978
		Minimum	303.6557

B.9 – Final Raw Results Extracted for Scenario 4

	A	B
1	Time	Mean Radiant Temperature
2	8.00	298.5235918
3	11.00	302.90457
4	14.00	304.752666
5	17.00	303.9034795
6	Average	302.5210768
7	Maximum	304.752666
8	Minimum	298.5235918
9		
10		
11		
12		
13		
14		
15		
16	Time	Ambient Air Temperature
17	8.00	299.2672068
18	11.00	302.0865239
19	14.00	303.6696602
20	17.00	303.6667992
21	Average	302.1725475
22	Maximum	303.6696602
23	Minimum	299.2672068
24		

B.10 – Extracted Raw Results from Envi-met for Scenario 5 at 08:00 (Ambient Air Temperature)

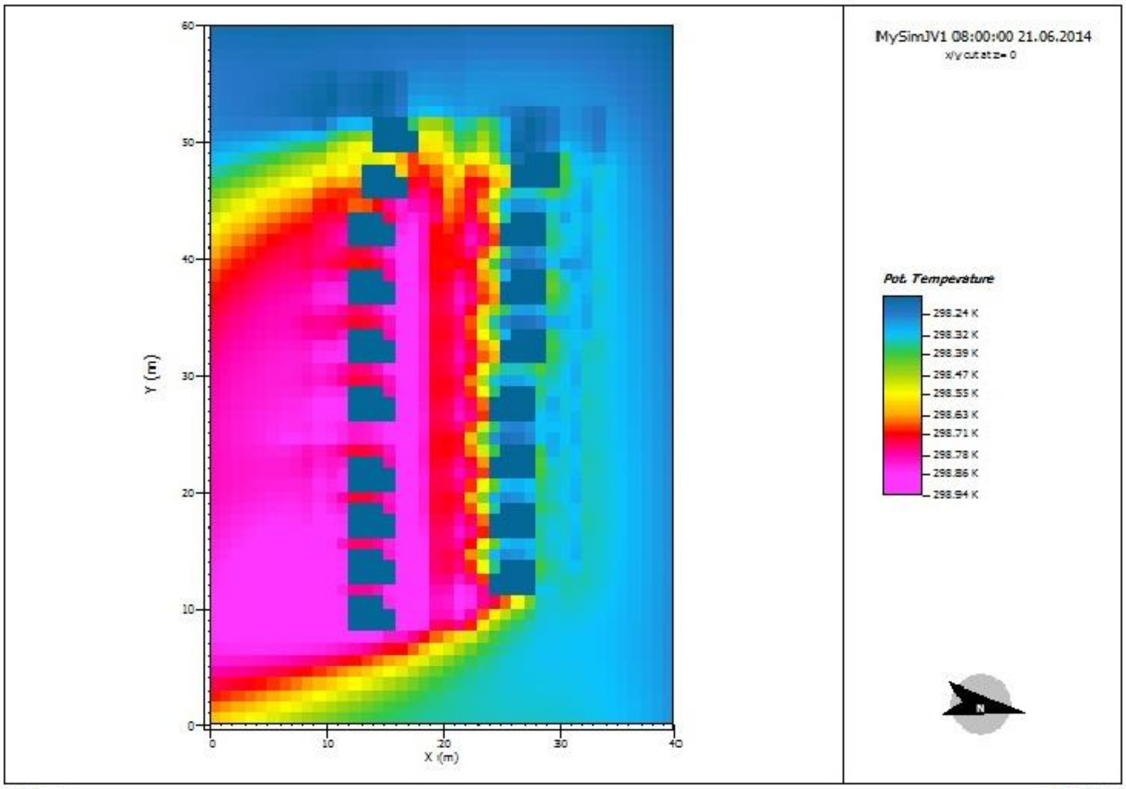
x(m)	y(m)	Pot. Temperature (K)	Filtered Results
106.5	0 100.5	0 299.1142	299.1142
118.5	0 106.5	0 299.1143	299.1143
115.5	0 109.5	0 299.1144	299.1144
112.5	0 109.5	0 299.1146	299.1146
109.5	0 106.5	0 299.1146	299.1146
118.5	0 103.5	0 299.1147	299.1147
115.5	0 106.5	0 299.1149	299.1149
112.5	0 106.5	0 299.1150	299.115
109.5	0 103.5	0 299.1151	299.1151
118.5	0 100.5	0 299.1152	299.1152
115.5	0 103.5	0 299.1153	299.1153
112.5	0 103.5	0 299.1154	299.1154
109.5	0 100.5	0 299.1154	299.1154
115.5	0 100.5	0 299.1157	299.1157
112.5	0 100.5	0 299.1159	299.1159
		Average	299.107855
		Maximum	299.1616
		Minimum	299.054

B.11 – Final Raw Results Extracted for Scenario 5

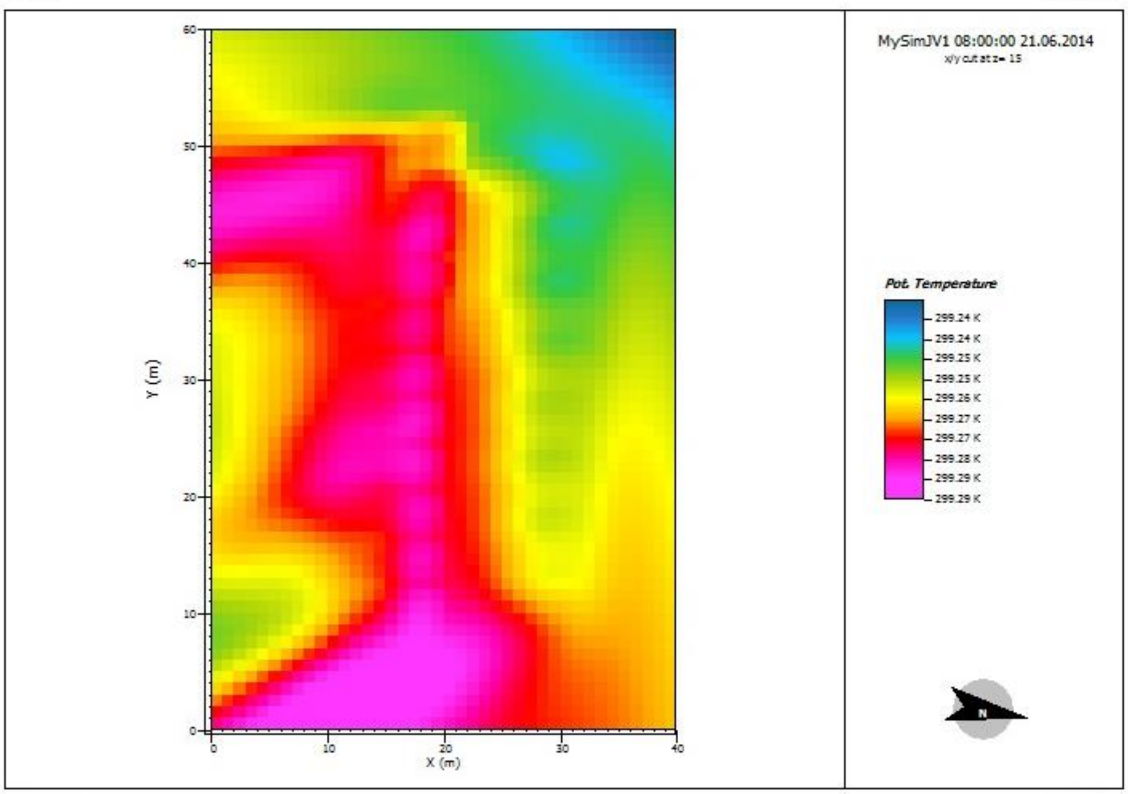
	A	B
1	Time	Mean Radiant Temperature
2	8.00	298.1723543
3	11.00	302.4066509
4	14.00	303.9958207
5	17.00	302.8468607
6	Average	301.8554216
7	Maximum	303.9958207
8	Minimum	298.1723543
9		
10		
11		
12		
13		
14		
15		
16	Time	Ambient Air Temperature
17	8.00	299.107855
18	11.00	301.7779242
19	14.00	303.153425
20	17.00	302.9201131
21	Average	301.7398294
22	Maximum	303.153425
23	Minimum	299.107855

Appendix C – THE MAIN MODEL VISUAL MAPS

C.1 - Mean Radiant and Ambient Air Temperatures Distribution at 8:00 for Scenario 1, (Author, 2014)

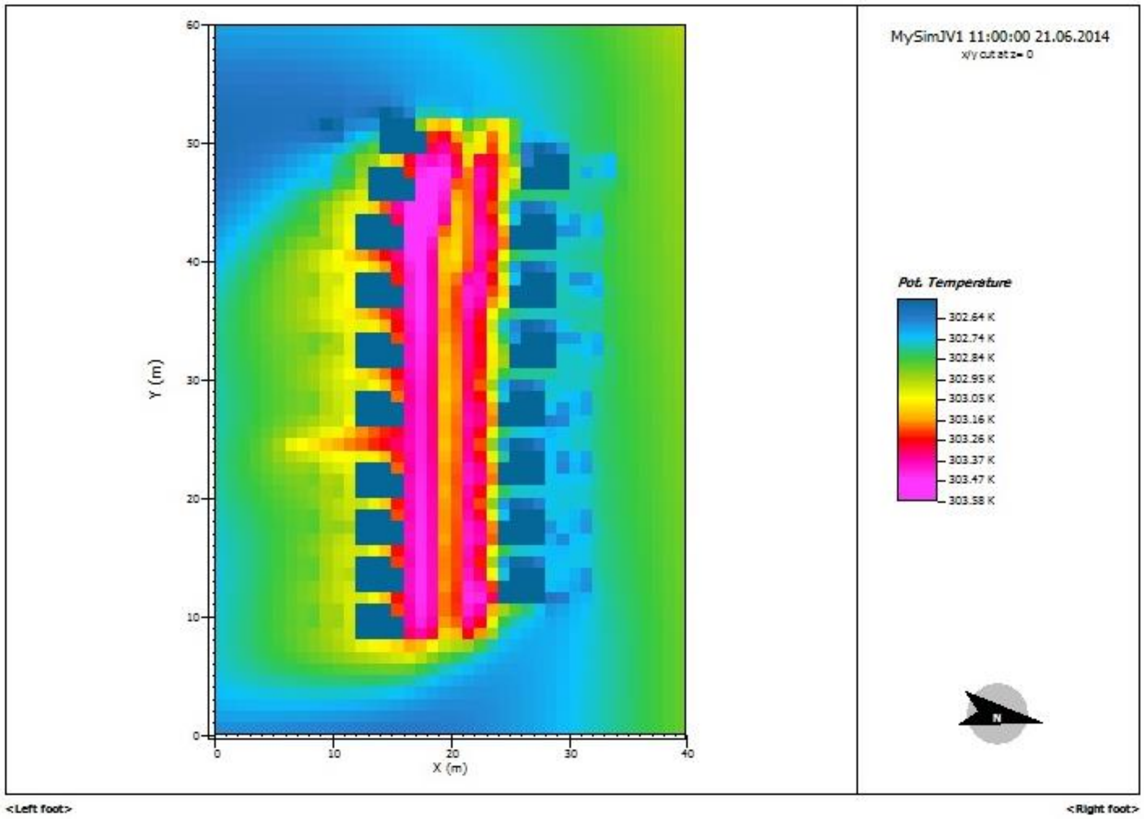


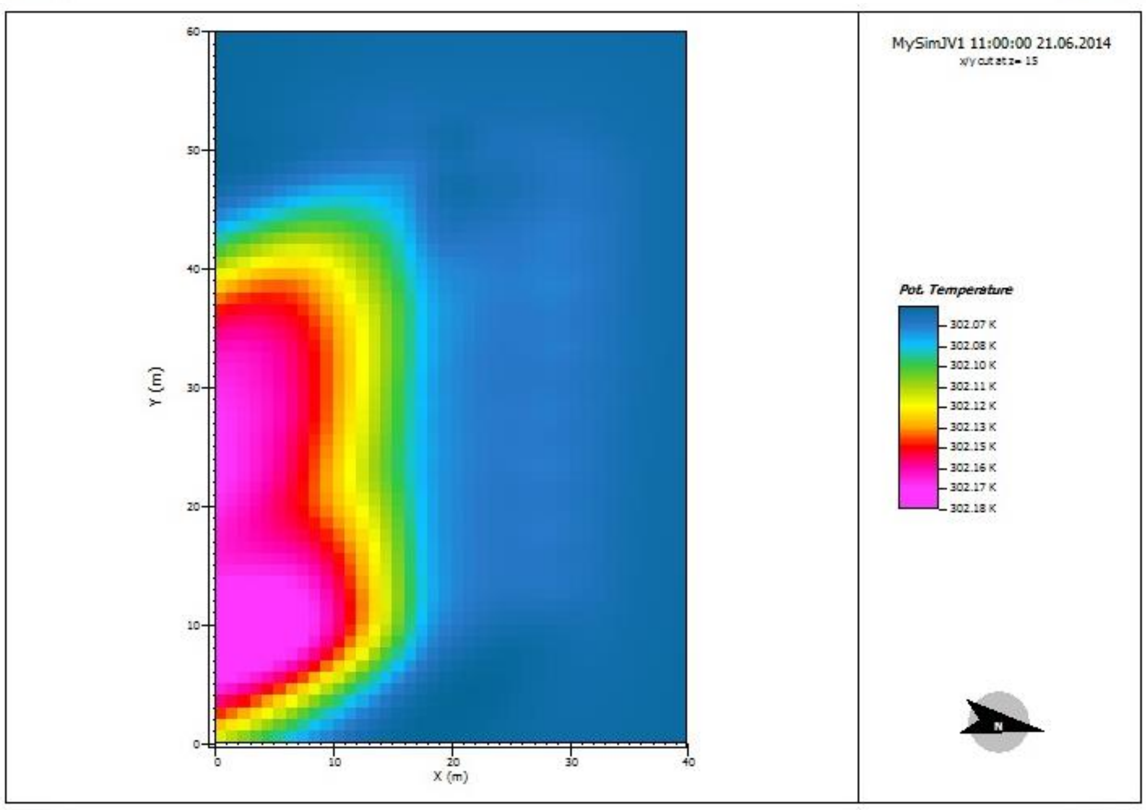
<Left foot> <Right foot>



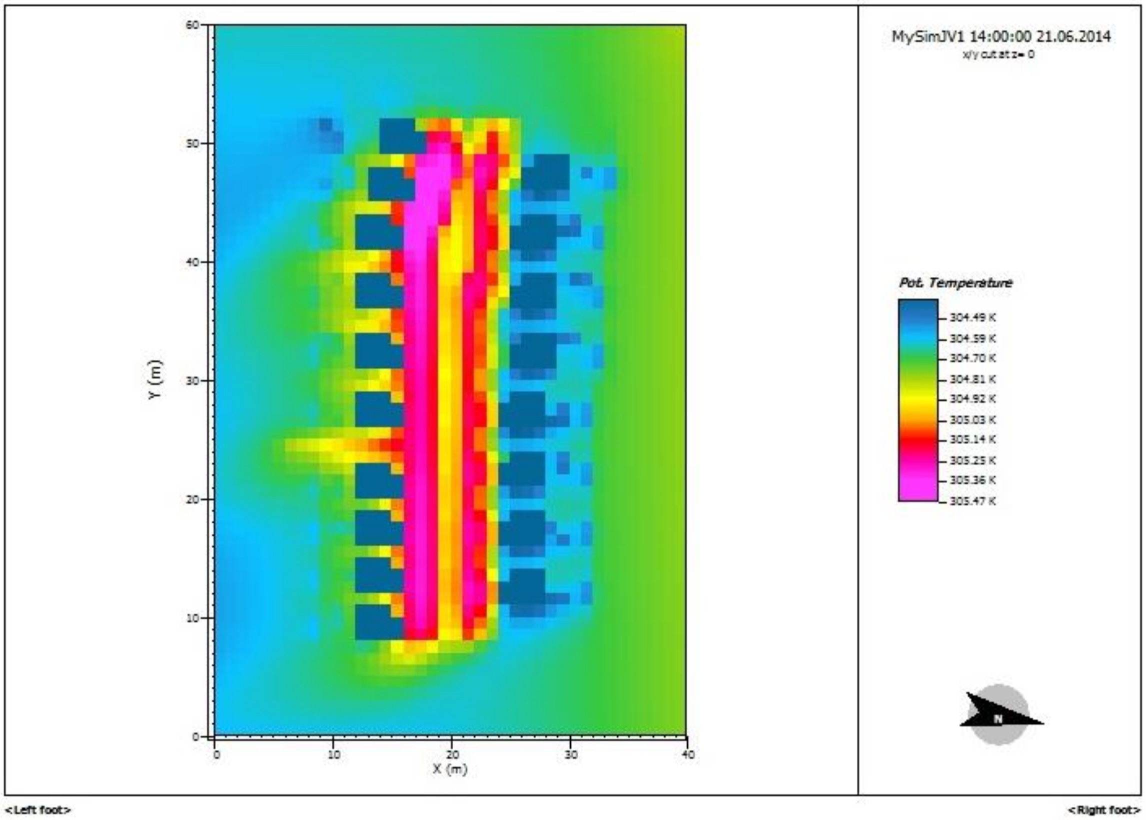
<Left foot> <Right foot>

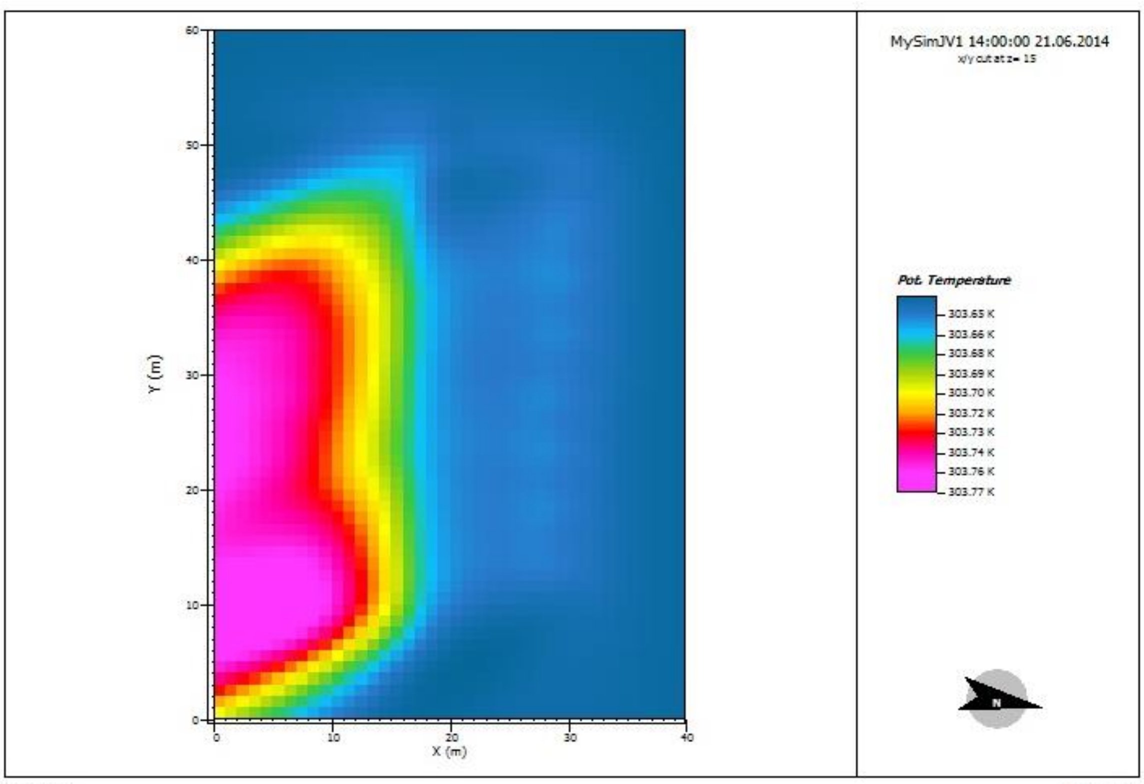
C.2 - Mean Radiant and Ambient Air Temperatures Distribution at 11:00 for Scenario 1, (Author, 2014)





C.3 - Mean Radiant and Ambient Air Temperatures Distribution at 14:00 for Scenario 1, (Author, 2014)





C.4 - Mean Radiant and Ambient Air Temperatures Distribution at 17:00 for Scenario 1, (Author, 2014)