Enhancing Thermal Comfort in Urban Communities with Urban Configurations and Green Coverage: A Case Study of Dubai Sustainable City

تحقيق الراحة الحرارية في المناطق السكنية عن طريق التكوينات الحضرية والغطاء النباتي:

دراسة حالة لمدينة دبي المستدامة - الإمارات العربية المتحدة

By

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ABSTRACT

In response to the United Nations Sustainable Development Goals and the United Arab Emirates' long-term vision for cities that provide successful and comfortable sustainable living, it is essential to study and explore strategies that enhance outdoor thermal comfort and indoor energy consumption that meets environmental, social and economic sustainability goals. The case study for this research, the Dubai Sustainable City residential cluster, which is the first development of its type and which complies with Dubai's green building code, was chosen because it contains five clusters typical in their design and content.

The software simulation analysis method was used to conduct the research, which involved using ENVI-met to build a virtual model representing the base existing case after collecting weather data from a site visit on 23 June and from records held by the National Centre of Meteorology. This model was used to evaluate the thermal behaviour of outdoor urban spaces in four phases. In the fifth phase, indoor energy was studied through simulation by using Design Builder to create a virtual model of the architectural units that were the subject of the study.

The findings indicate that the layout orientation of the master plan has a significant effect on air temperature, wind speed and wind distribution within the site. Wind speed and distribution further affect the relative humidity of outdoor areas and influence user satisfaction. Moreover, courtyard design impacts air distribution and air temperature, which is connected to predicted mean vote values, and green coverage percentage in the courtyard impacts microclimate variables, as it reduces air temperature by increasing relative humidity to a moderate level. Finally, all previous enhancements applied to the outdoor thermal comfort variable affects the indoor total energy consumption, as it reduces the energy load needed to mitigate the outdoor environment.

الـمـلـخص

استجابة لأهداف الأمم المتحدة للتنمية المستدامة ورؤية الإمارات العربية المتحدة للمدن التي توفر حياة مستدامة ومريحة كان من الضروري دراسة وبحث الاستراتيجيات التي تعزز الراحة الحرارية في الهواء الطلق واستهلاك الطاقة في الأماكن المغلقة والتي تلبي الاستدامة البيئية والاجتماعية والاقتصادية.

تم اختيار مدينة دبي المستدامة كدراسة حالة لهذا البحث، والتي تعد أول مشروع من نوعه والذي يتوافق مع قوانين المباني الخضراء في دبي مطبقة في ذلك نموذج تنافسي للبحث.

فقد تم في هذا البحث استخدام طريقة تحليل المحاكاة الحرارية للحالات الدراسة المختلفة، والتي شملت استخدام برنامج ENVI-me لبناء نموذج افتراضي يمثل القاعدة القائمة بعد جمع بيانات الطقس من زيارة الموقع في 23 حزيران / يونيه ومن السجلات التي يحتفظ بها المركز الوطني للأرصاد الجوية. وقد استخدم هذا النموذج لتقييم السلوك الحراري للمساحات الحضرية في الهواء الطلق على أربع مراحل. في المرحلة الخامسة، تمت دراسة الطاقة الداخلية من خلال المحاكاة باستخدام برنامج المحاكاة DesignBuilder لإنشاء نموذج افتراضي للوحدات المعمارية الداخلية التي كانت موضوع الدراسة.

قد تم تحليل المخرجات بناء على العوامل الحرارية الرئيسية وتشمل درجة حرارة الهواء، سرعة الرياح، الرطوبة النسبية وقيمة الراحة الحرارية على التصاميم المقترحة. بحيث انه تم التركيز على عدة محاور وتشمل المساحات بين المباني، توجيه المباني والساحات العامة ضمن النسيج العمراني و أخيرا نسبة الغطاء النباتي في الأماكن العامة.

وأشارت النتائج إلى أن التوجه التخطيطي للمباني له تأثير كبير على درجة حرارة الهواء وسرعة الرياح وتوزيع الرياح داخل الموقع. و أن سرعة الرياح والتوزيع الكتلي العمراني يؤثران أيضا على الرطوبة النسبية للمناطق في الهواء الطلق. وعلاوة على ذلك، فإن تصميم الفناء يؤثر على توزيع الهواء ودرجة حرارة الهواء، التي ترتبط بقيم البحث المتوقعة، وأيضا أشارت النتائج النهائية أن نسبة التغطية الخضراء في الفناء تؤثر على المتغيرات المناخية، لأنها تقلل من درجة حرارة الهواء عن طريق زيادة الرطوبة النسبية إلى مستوى معتدل. وأخيرا، فإن جميع التحسينات السابقة المطبقة

على متغير الراحة الحرارية في الهواء الطلق تؤثر على إجمالي استهلاك الطاقة في الأماكن المغلقة، حيث أنه يقلل من حمل الطاقة اللازم للتخفيف من البيئة الخارجية.

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Author

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LIST OF ABBREVIATIONS

WORD	DEFINITION
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
BREEAM	Building Research Establishment Environmental Assessment Method
CHTC	Convective heat transfer coefficient
FAR	Floor area ratio
GFA	Gross floor area
GIS	Geographic information system
HVAC	Heating, ventilation, and air conditioning
IES	Integrated Environmental Solutions, a software and consultancy company that specializes in building performance analysis
ISO	International Organization for Standardization
LEED-ND	Leadership in Energy and Environmental Design, ND: For Neighbourhood Development
MRT	Mean radiant temperature
PCRS	Pearl Community Rating System
PET	Physiological equivalent temperature
PMV	Predicted Mean Vote
Psychrometric Chart	is a graphical representation of the psychrometric processes of air, which are include physical and thermodynamic properties such as dry bulb temperature, wet bulb temperature, humidity, enthalpy, and air density.
SET	Standard effective temperature
STEVE	The estate environment evaluation
SVF	Simple Vector Format
UHI	Urban heat island

CHAPTER 1
INTRODUCTION

1 Introduction and Background

1.1 Sustainable Urban Design

According to a yearly report by the United Nations in 2015, more than half of the total population live in urban areas. By 2050, the figure is predicted to increase to 90%. This percentage is true mainly in developing countries, especially those situated in humid and hot zones. To accommodate this growth in urban population, the trend in urbanism has taken a spatial manifestation. Considering all the conditions, this process of urbanism will be embraced (Cowgill, 2011). Therefore, effective management and organisation to establish a sustainable urban area is of paramount importance for policy makers and planners.

Urban areas, including their spatial extensions, help reduce inequalities in society, promote sustainable and inclusive development, and decrease the wasteful utilisation of non-renewable resources, the aim of which is to mitigate the risk of disrupting the equilibrium in the ecosystem. Furthermore, urban sprawl has slowly risen to become the dominant urban spatial pattern of expansion all around the globe, without consideration of differences in causes, time and results.

Despite the advantages of urban developments, their disadvantages have seen a rising trend. 70% of CO2 emissions are attributed to urban developments. Certain tools are used to assess the environment for designing sustainable urban areas. These tools include LEED-ND, BREEAM, SBTool, Qatar Sustainability Assessment System, Pearl Community Rating System (which is located in the United Arab Emirates [PCRS]), and others (Cowgill, 2011). Two primary factors facilitate fast urbanisation in cities: economic stability, which provides better career opportunities, and efficient transportation, which facilitates movement from one place to another, especially with less expensive means of transport such as trains and buses. Climate change and global warming represent critical environmental conditions. Urban design and building focus on four metrics for sustainability: cultural, social, economic, and environmental factors (Siöström & Sternudd, 2011). As global cooperation and practical initiatives continue to increase, it is quite evident that the formulation of international standards and policies is trivial.

Among the sustainability metrics mentioned above, the most crucial issue is the concept of sustainable urban configuration. This issue is essential in satisfying the current needs of the increasing population while simultaneously maintaining a sense of community for the future (Siöström & Sternudd, 2011). Sustainable urban design provides city developers with ecological and social design patterns and increases awareness concerning aspects of sustainability. Urban development that integrates aspects of environmental friendliness is a fundamental trajectory for cities that are located in the governmental sector and fast-developing regions where growth in the economy has impacted the environment.

1.2 Current Status: Global Review

Currently, more than half of the world's population live in urban areas. With the urban spaces consuming the most energy, sustainable practices in the design of urban centres are essential. Most cities are adopting long-term solutions that may aid infrastructure in withstanding changes such as technological and economic shifts as well as short-term changes which are influenced by adverse weather conditions like tornadoes or earthquakes (Elchalakani, Aly, & Abu-Aisheh, 2014). Most of the elements in urban design focus on the issue of resilience. Research focusing on the complex relationship between urban design in natural systems and human behaviour continues to increase and helps in propelling the field of urban design further, facilitating the goals and objectives of sustainability.

1.3 Current Status: Local Review

Environmentalists are worried about the sustainability of the city of Dubai in the United Arab Emirates (UAE). Recent global analysis found that Dubai is one of the least environmentally friendly cities due to its heavy reliance on desalinated water and air conditioning (Taleb & Taleb, 2014). During the summer, the temperatures reach an astonishing 40 degrees Celsius, so inhabitants rely on technology to cool themselves. A recent study discovered that residents in Dubai use twice as many resources as the average American (Taleb & Taleb, 2014).

The government of Dubai has turned its plentiful sand into real estate, selling buildings for cash as an economic diversification strategy and moving away from oil exploration as the only source of revenue. Focusing on real estate development as a way of attracting tourists to Dubai at the expense of planting trees has significant environmental costs. Islands have been created within the city by dredging up to 33 million cubic meters of sand. This activity has significantly affected the current system of the Gulf, which is responsible for carrying coral and developing fish through the marine ecosystem. Dubai is highly dependent on cheap energy in the form of oil, and the city's per capita consumption of energy is one of the highest in the world figure 1.1 presents UAE place among world's countries in energy consumption. This energy is also used to desalinise the water from the ocean to irrigate the tropical landscape that has been planted in the desert.

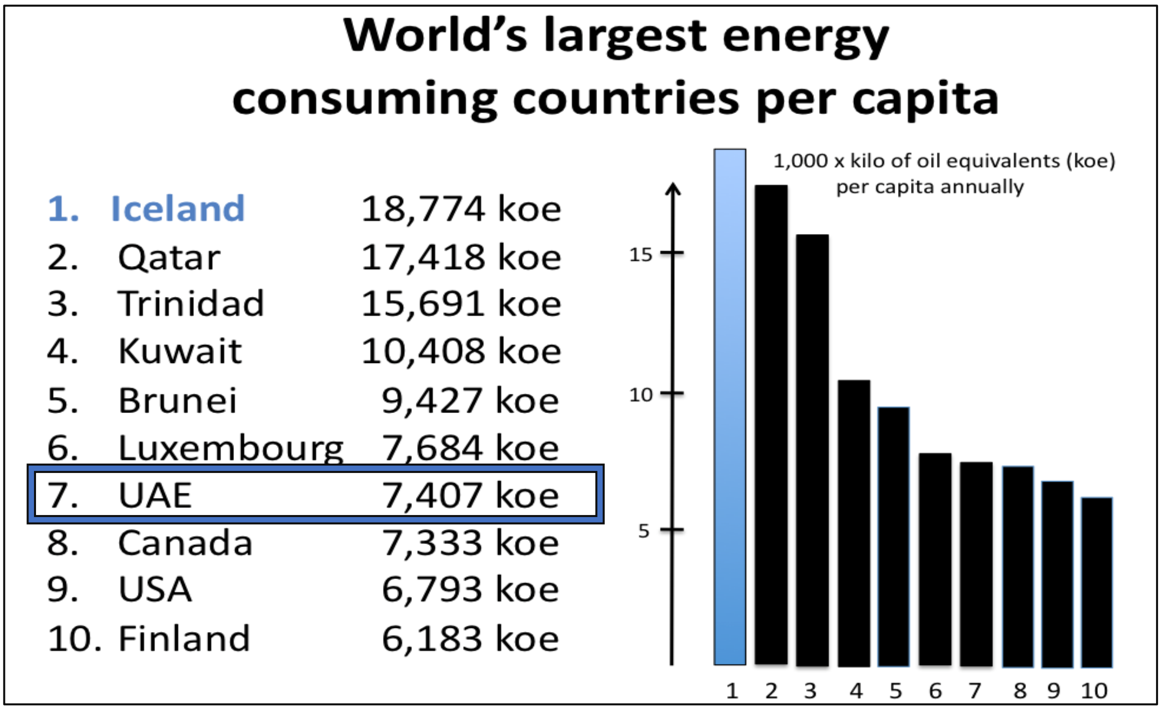


Figure 1.1: UAE Energy consumption per capita (Adapted from Dubai carbon sustainability report 2015).

1.4 Urban Communities in UAE

Dubai has experienced tremendous urban growth as an international hub over the past twenty years (Elchalakani, Aly, & Abu-Aisheh, 2014) and is still sorting out their aggressive economic diversification from the mid-nineties, under which programs of urban development have thrived. In the UAE, urban development has primarily been driven by internationalised and newly liberalised real estate markets funded heavily through international debt capital; as a result, real estate and construction have become two of the most important non-oil sectors in the country (Elchalakani, Aly, & Abu-Aisheh, 2014). Some of the urban communities in UAE include Abu Dhabi, Al Ain, Ras al-Khaimah, Umm al-Quwain, Dibba Al-Fujairah, Dubai, Sharjah, Ajman, Fujairah, and Khor'fakkan. By planting and properly maintaining healthy urban vegetation, these cities can reduce temperatures (Elchalakani, Aly, & Abu-Aisheh, 2014). Consequently, Dubai Sustainable City's expansion by communities alone might not be sustainable; more efficient means of sustainable expansion are needed. Therefore, the focus should also be on the Expo 2020 sustainable goals and ensuring that appropriate government regulations and legislation are aimed at making Dubai Sustainable City more sustainable than it is today.

1.5 Outdoor and Indoor Thermal Comfort

Interest in the assessment of thermal comfort has increased significantly within the last decade because of heat stress and climate changes in cities such as Dubai. However, very little research has been conducted on thermal comfort for the outdoor environment. Four main climatic parameters are used to analyse thermal comfort: radiant, airstream velocity, ambient air temperature, and air humidity. Urban outdoor spaces that people use have implications. Architects in the current era strive to design urban spaces and outdoor corridors as opposed to having them come up by accident or as a design by-product (Abdel-Ghany, Al-Helal, & Shady, 2013). Outdoor spaces are supposed to be used to their full potential; otherwise, there is no need for them. These spaces need as much understood in their plan as indoor spaces. In urbanising empty land and deserts, designers and planners have the advantage of a clean slate on which to apply optimum outdoor thermal comfort condition theories.

The physical features of a specific site must be considered at the onset of development. Outdoor spaces in Dubai have been modified by planners and designers using minor design details such as selection of surface materials, shading elements, and vegetation (Elchalakani, Aly, & Abu-Aisheh, 2014). Such design details have enhanced the outdoor environment quality and as a result individual thermal comfort levels. At the onset of the design, process designers predict the impact of factors that change specific climatic parameters and what effect they have on levels of outdoor thermal comfort.

Thermal comfort has been researched in various regions around the world, but little research on hot, arid climate regions has focused on the impact outdoor comfort can have on indoor levels. The Fanger’s equation and heat balance approach, which are international standards in ISO and ASHRAE, are thermal comfort equations which have been applied in Northern Europe and North America, both mid-latitude climatic regions as shown in figure 1.2 (Hirashima, Assis and Nikolopoulou, 2016). The only current impact of Fanger's equation is the assumption that outdoor thermal comfort affects indoor levels.

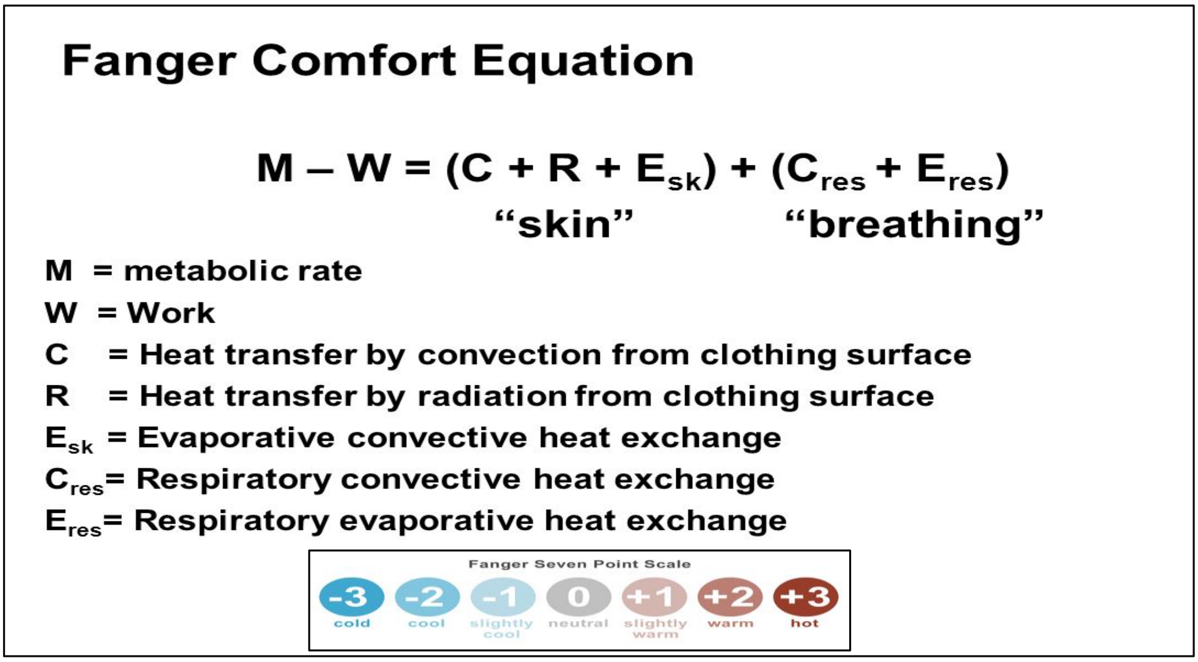


Figure 1.2: Franger's Comfort Equation (Adapted from Autodesk.com, 2017).

1.6 Factors Affecting Outdoor Thermal Comfort

The parameters that affect thermal comfort include air temperature, solar radiation, radiant temperature, wind velocity, and humidity. These parameters were ranked from greatest to least impact. In arid climates that are hot, the most significant parameter for thermal sensation is shading, followed by ventilation. Setaih, Hamza, and Townshend (2013) state that during conditions of direct solar radiation, doubling the speed of the wind from 1 m/s to 2 m/s reduces the physiological equivalent temperature (PET) index value by 5.5 degrees Celsius. Nevertheless, this impact is subject to change, especially from shaded conditions. Furthermore, a PET index value reduction of 6 degrees Celsius is noted in instances when the speed of wind increases from 1m/s to 3.5 m/s.

Thermal comfort is influenced by the temperature of the air coupled with the radiation of the sun. Thani, Mohammad, and Jamaludin (2013) define the mean radiant temperature (MRT) as the even temperature of a virtual spherical surface that surrounds a product where the emissivity equals 1. The configuration of an urban settlement impacts its microclimate. In arid climates, pedestrian comfort is affected by shade conditions that reduce the sun's exposure, especially during summer. A sparse urban setting has an adverse impact on thermal comfort because pedestrians face exposure to direct radiation from the sun. On the other hand, a compact urban setting has reduced exposure to the sun and less reflected radiation from street surfaces.

1.6.1 Thermal Comfort and Building Configurations

With the rise of energy costs, environmental awareness, and building thermal comfort requirements, the UAE has instituted numerous building codes which focus on certain aspects of building construction, such as HVAC system and envelope designs, with the objective of achieving thermal comfort in buildings (Algeciras, Consuegra, & Matzarakis, 2016). In the UAE, envelope thermal design is primarily guided by energy-efficient building regulations; buildings must meet a minimum envelope thermal resistance value (Kalua, 2016). The code also specifies that evaluations for minimum envelope performance requirements must be solely based on shading and thermal transmittance coefficients.

1.6.2 Thermal Comfort and Landscape Factors

Researchers prevalently argue that several urban factors, including lack of vegetation cover, urban design, thermal features of urban materials, and anthropogenic generation of heat, all cause changes in the climate of urban communities. Yilmaz, Irmak, and Matzarakis (2013) state that urban landscape and morphology features have a significant impact on the start of urban heating. Moreover, inadequate or inappropriate urban design and landscape planning which removes natural vegetation and replaces it with impermeable surfaces is known to cause further deterioration of the urban environment, as is often seen in Dubai. Climate changes in urban communities have led to the urban heat island (UHI) phenomenon with adverse impacts on thermal comfort (Sadeghnejad, 2013). The use of bioclimatic elements could improve the urban thermal comfort of Dubai. The figure below proves this point by demonstrating the relationship between thermal variation and the morphological concept.

Replacing natural vegetation with buildings changes the temperature near the ground level, and therefore reduced vegetation translates to an increased temperature in urban environments (Kenawy, Afifi, & Mahmoud, 2013). All these factors result in an increase in the consumption of energy. Landscape design is used in different ways to enhance or promote thermal comfort. The first technique involves the bioclimatic aspect, which refers to the relationships between life and climate, especially the impact of climate on all living things. The bioclimatic aspect is required for planning an urban landscape because it has strong ties with nature, climate, and human being’s living conditions. In the urban landscape plan, the bioclimatic technique also includes the extensive and intensive utilisation of water body elements and urban greenery. The utilisation of natural resources promotes the improvement of urban thermal conditions and good living conditions through adaptation to the climate. Table 1.1 shows the vegetation that should be planted to promote thermal benefits as opposed to focusing on ornamental plants (Kenawy, Afifi, & Mahmoud, 2013).

Table 1.1: Promoting thermal benefits through vegetation (Source: Chen & Ng, 2012).

Tropical Native Species	Vegetal Features	Use in Landscape Design
Mesua ferrea	Shade area: 35% Leaf area index: 6.1 Transmissivity value: 5%	Good moderator of the microclimate Thermal buffer planting
Hura crepitans	Shade area: 53% Leaf area index: 1.5 Modest cover of tree canopy as well as the twigs and branches Heat filtration: 79%	Planting in the streets Provides shade Suitable for planting in open spaces and/or parks
Maniltoa schefferi	Under the tree canopy, it increases the humidity to 3.9% while reducing the temperatures by 4.9 to 7.5 degrees Celsius. Large branches and leaves	Suitable for planting in open spaces and/or parks Increases the humidity and reduces air temperature

1.6.3 Outdoor Thermal Comfort Indices

Outdoor thermal comfort has been related with well-being and health (Walls, Parker, & Walliss, 2015). In areas with hot, arid climates such as Abu Dhabi, the outdoors is very humid and hot, and in the summer, many people experience heat stroke. Notably, thermal comfort is related to some approaches which include thermo-physiological, psychological, and one based on the human body's balance of heat. All these methods are different, but the psychological factor is more notable in outdoor areas since individuals have varying levels of adaptation to the environment. This differentiation explains the variability of actual models and theoretical approaches to thermal comfort. In arid, hot, humid climates, individuals are more likely to spend time in outdoor spaces; hence, scholars have extensively studied thermal indices that affect comfort in these environments (Walls, Parker, & Walliss, 2015). On the other hand, in areas that experience cold conditions, the indices are less significant since individuals opt to stay indoors. It is also worth noting that outdoor thermal comfort links climatology to biometeorology for the development of thermal comfort indices (Honjo, 2012).

Researchers have extensively studied the following three thermal indices in arid, hot climates to analyse human perceptions and outdoor thermal comfort: physiological equivalent temperature (PET), standard effective temperature (SET) and the Universal Thermal Climate Index (UTCI). The level of physiological stress differs between conditions of extreme cold stress and extreme heat stress; therefore, thermal perception variables range from very hot to very cold. The features of PET are similar to the comfort index because both utilise the same assessment scale: The Predicted Mean Vote (PMV) (Kwon & Parsons, 2013). The PET also includes critical variables for human thermal comfort, such as radiant temperature, air temperature, and humidity. One of the studies carried out by Thani et al. (2013) focused on outdoor thermal comfort. The study showed that PMV was first developed to analyse thermal perception for indoor areas which is affected by sensors connected to air-conditioning systems, and the scale was later utilised for outdoor spaces. Table 1.2 shows the researchers' results:

Table 1.2: Different degrees of human thermal comfort (Adapted from Taleghani et al. 2015).

PMV	PET C	Thermal Perception	Grade of Physiological Stress
-3.5	**4**	**Very cold**	**Extreme Cold Stress**
-2.5	**8**	**Cold**	**Strong cold stress**
-1.5	**13**	**Cool**	**Moderate cold stress**
-0.5	**18**	**Slightly cool**	**Slight cold stress**
0.5	**23**	**Comfortable**	**No thermal stress**
0.8	**25**	**Slightly warm**	**Slight heat stress**
1.5	**29**	**Warm**	**Moderate heat stress**
2.5	**35**	**Hot**	**Strong heat stress**
3.5	**41**	**Very hot**	**Extreme heat stress**

1.7 Sustainability Initiatives

In United Arab Emirates (UAE) construction is considered one of the major industries, and hence produces a significant portion of pollution. The same status is applied to the other gulf countries that like UAE found the need to develop an infrastructure able to cope with the growing population and developed tourism. The construction projects reached around $1.67 trillion in GCC in 2013, of which more than 68% belonged to UAE & Saudi Arabia. (Issa,2015).

Estidama, the initiative established by Abu Dhabi Urban Planning Council in the UAE, put a rating system assessing 7 fundamental elements in the construction projects. Examples of the assessed pillars are: live able communities, precious water, resourceful energy, stewarding materials, and innovation practices. Each element contains sub- elements that are all assessed by sub-accreditation point system and the live able communities, for example, can get up to 35 points. A level aimed by the government's image (ADUPC,2010). Table 1.3 presents the liveable community rating system.

Table 1.3: Estidama Community Rating System (ADUPC,2010).

LC	Livable Communities	Maximum Credit Points
LC-R1	Plan 2030	R
LC-R2	Urban Systems Assessment	R
LC-R3	Provision of Amenities and Facilities	R
LC-R4	Outdoor Thermal Comfort Strategy	R
LC-R5	Minimum Pearl Rated Buildings Within Communities	R
LC-1	Transit Supportive Practices	2
LC-2	Neighborhood Connectivity	3
LC-3	Open Space Network	3
LC-4	Accessible Community Facilities	2
LC-5	Housing Diversity	2
LC-6	Community Walkability	4
LC-7	Active Urban Environments	1
LC-8	Travel Plan	1
LC-9	Improved Outdoor Thermal Comfort	4
LC-10	Regionally Responsive Planning	2
LC-11	Pearl Rated Buildings Within Communities	10
LC-12	Safe and Secure Community	1
	TOTAL	35

Another initiative was the green building regulations put by the government of Dubai in 2011 were initially obligatory to the governmental buildings, however, the private projects were also included in the regulations in 2014. In 2016, different green building rating systems were put with the establishment of *Al Safaat*. These systems involved platinum, silver and gold certification. Several governmental entities in Dubai co-operated to put a plan aiming at achieving Dubai 2021 vision, as per Dubai Executive Council. Figure 1.3 represent the improvement of six aspects of sustainable growth: people, society, place, economy, government, and experience.

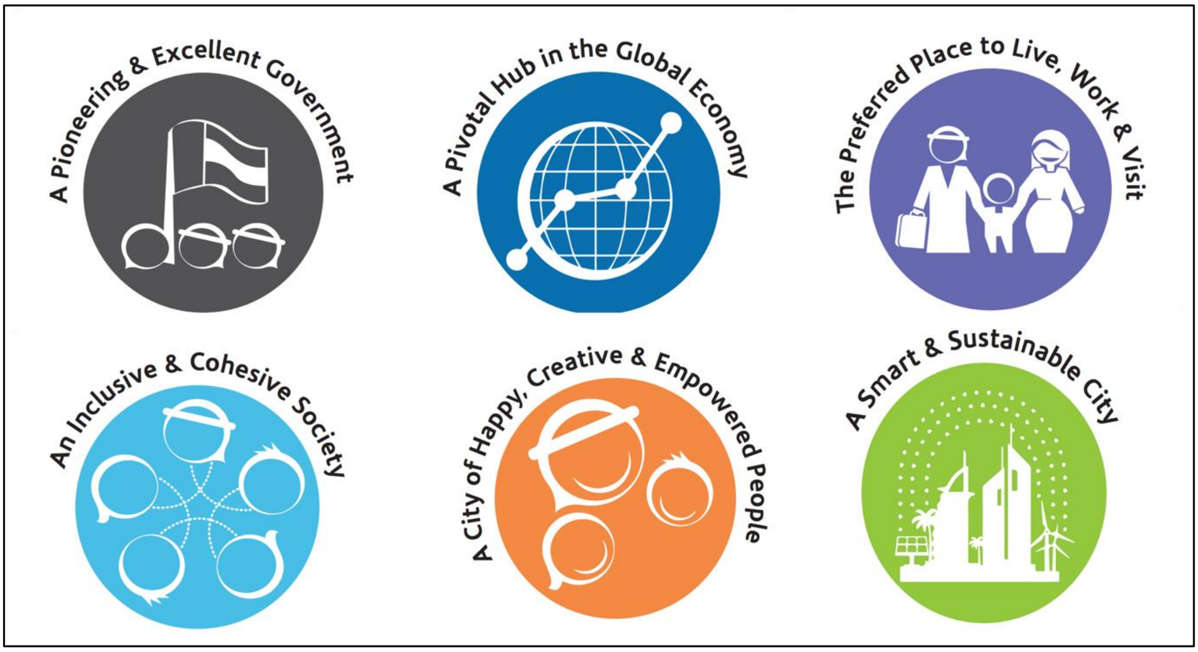


Figure 1.3: 2021 Dubai plan goals (Adapted from Dubai 2021 plan brochure, 2017).

1.8 Statement of the Problem and Research Interest

Some people perceive sustainable urban design as a new phenomenon, even though it has been around for thirty years. Furthermore, researchers link global warming to UHI because of the greenhouse effect as well as an increase in the temperatures experienced in urban areas (Makaremi, Salleh, Jaafar and Matzarakis, 2012). Rural areas experience lower air temperatures in comparison to urban areas because of the capability of construction materials to store heat and the low speed of the wind. Moreover, researchers who focus on sustainable urban design have a significant contribution in helping to enhance awareness regarding sustainability goals, which revolve around the issue of living while making observations for conservation to ensure better lives.

The current study has been influenced by the practical issues that human beings face because of global warming coupled with the changes in the climate of the region. Honjo (2012) asserts that people should aim to have a better life, especially in hot, humid climates. They can do this by reducing the time they spend indoors with air conditioning and instead spend most of their time in outdoor spaces (Makaremi, Salleh, Jaafar and Matzarakis, 2012). For the past ten years, the number of studies that address global warming has continued to increase, but there is still a lack of studies that focus on outdoor thermal comfort and its effect on indoor energy efficiency, especially in urban communities. This gap in knowledge has motivated the need to carry out this study. Furthermore, attaining thermal comfort is not only limited to indoor spaces but also includes urban communities, where the outdoor space and similar activities are crucial to the operation and function of people in those areas.

The study comprehension is that the effect of urban configurations and the plantations percentage in outdoor thermal comfort is an area that has not been comprehensively and extensively researched. Therefore, the research believes that if it took the initiative to examine the topic more, the study could make a significant contribution to what has already been covered. This study will focus on achieving thermal comfort in outdoor and its effect on indoor levels in urban communities by implementing passive configuration and landscaping factors.

The case study will be on Dubai Sustainable City. Some of the research interests of this paper include the current expansion of Dubai by communities which are unfortunately not sustainable. The Dubai Sustainable City goals aim to be achieved in the year 2020, and they will only be achieved through legislation and regulation.

1.9 Aims and Objectives

1- The goal of the research is to investigate the thermal comfort in outdoor and indoor levels in urban communities by implementing different passive configuration and landscaping factors. To conduct this research, a case study will examine Dubai Sustainable City. The research question is whether different urban configurations urban settings behave in a variety of ways regarding wind variations, temperature, PMV and relative humidity in the days with the most heat during summer. Dubai is the chosen location for the study to make a comparison of thermal behaviour that exists in urban configuration with 8 urban design proposals which are all different in several aspects. The configurations which will be examined include proposed U shape buildings form and Rectangular courtyard, U shape buildings with square courtyard, Linear Central buildings form with square courtyard, linear buildings form with rectangular courtyard. The following are the objectives which will be used to achieve the aim of the research:

i. To study the status of UAE microclimate in residential communities.

ii. To review a comprehensive literature review and investigate the most significant microclimatic factors that have an impact on outdoor thermal comfort in UAE climate.

iii. To select a case study and propose a set of parameters of sustainability which will then be applied to the case study.

iv. To propose several urban configurations for examining the effect of different orientations, courtyard layout and proportions.

v. Identification of the most favourable green cover percentage of open space and its impact on outdoor thermal comfort.

vi. To run the simulation using computer software and compare the results by graphical and numerical values and identify the most favourable orientation, buildings layout, courtyard design and green cover percentage against the fundamental parameters that impact the outdoor thermal behaviour: speed of wind averages, air temperature humidity, and PMV.

vii. To investigate wither the outdoor thermal behaviour influences the indoor energy efficiency by running the computer simulation and compare the results with base case.

viii. To draw recommendations that will be used in the future based on the research findings of this study.

1.10 Research Outline

This research presents a holistic study of three urban configurations which are Building orientation, spacing and courtyard layout and, investigate the favourable green cover percentage to identify the best scenario out of all proposal.

This paper is divided into six chapters. The first chapter presented insights into sustainable urban development, especially urban configurations, including types and definitions. Furthermore, it presented information concerning human thermal comfort.

Chapter 2, is a comprehensive literature review, studying the effect of different urban configuration in addition to landscaping factors influencing outdoor thermal comfort, also this chapter discussing the need for a sustainable urban design of urban communities, the climate, and the microclimate parameters. At the end of chapter 2 the effect of outdoor thermal comfort on indoor energy consumption will be highlighted. The previous studied have been evaluated based on the selected methodology to decide the best evaluation tool for thermal comfort.

Chapter 3 covers the methodology of the study which includes comprehensive research that entails the approaches and tools used in similar topics to compare their pros and cons. Additionally, Chapter 3 will provide justification for the methodology and its validation.

Chapter 4 covers computer model setup for two simulation software: Envi-met and DesignBuilder, which provides insights regarding the proposed and existing urban configurations. Moreover, it will present the parametric variables and model set-up to study the research proposed parameters and investigated them. The current urban configuration will be defined as a base case in addition to several design scenarios to identify the best scenario of urban configurations in terms of outdoor thermal performance.

After that Chapter 5 contains the results and findings, and a set of simulation findings will be in comparison to understand the advantages and disadvantage characteristics in each design. The best scenario between them will be addressed and fallowed by the conclusion in Chapter 6 which provides recommendations for future researches.

CHAPTER 2
LITERATURE REVIEW

2 Literature Review

2.1 Introduction

Taleb and Taleb (2014) state that thermal comfort exists when the body can constantly maintain a body temperature of 37 degrees Celsius. Thermal environments encompass the elements of the physical environment which determine the exchange of heat between the surroundings and the body and thereby control the thermal comfort of human beings. These elements include velocity of the wind, air humidity, infrared and solar radiation, and so on. Undoubtedly, the individuals' activities are also one of the aspects that should be considered, because increase in activity translates to the production of metabolic heat as well.

The past decade has seen an increasing interest in the analysis of thermal comfort due to changes in the climate and heat stress experienced in cities (Landry, 2012). However, the number of studies that have focused on thermal comfort in the outdoor environment has been limited, primarily because most scholars choose to focus on thermal comfort for the indoor environment. The external environment has a profound impact on the way individuals live their lives, and outdoor thermal comfort levels is determined by the amount of space covered in vegetation, urban construction density, anthropogenic factors, natural conditions, and so on. The increase in constructions, decrease of areas of vegetation, and use of warm ground and building surface materials all have an impact on the microclimate conditions in urban spaces and can, in turn, affect the usage of urban spaces (Monteiro, 2010).

When individuals spend time outdoors, they expect to have a different experience than when they stay indoors (Xue & Xiao, 2016). They expect variance in the circumstances of their exposure, such as modifications in the direction and speed of the wind, variations in shade and sun, changes in the rate of humidity, and so on. One of the most significant indications of how much time an individual will spend in outdoor public spaces is the pedestrian satisfaction level within the thermal environment. Nonetheless, judging the level of satisfaction with the thermal comfort proves challenging because it differs from one individual to another.

2.2 The Need for Sustainable Design of Urban Communities

2.2.1 Environmental Challenges of Urban Communities

Air pollution is a notable challenge for urban communities as it has the risk of hosting a myriad of health problems. According to de Abreu-Harbich et al., (2011) an estimated 60% of people live in cities that violate the standards of federal air pollution. The inhalation of bad air is related not only to higher eye problems and blood lead levels but also with asthma which is caused by levels of particulate matter. Clark (2009) states that most people of colour live near water management facilities, oil refineries, and power plants; unfortunately, any industrial waste that a company does not dispose of well can get into the land and water systems in urban communities. The land and water may be used for agriculture and housing in urban communities; if the companies do not dispose of waste materials properly, health issues may arise. Some of the health problems prevalent in such urban communities include lung cancer and asthma. Landry (2012) stipulates that safe water is a fundamental human right which is vital for a healthy environment and populace. Some urban communities do not to have access to clean drinking water, which is a critical environmental problem. Poor quality of water could also potentially lead to health problems, such as diabetes and kidney failure (Svedin, 2015).

2.2.2 Social Challenges of Urban Communities

The first social challenge of urban communities is quality education, which is only provided to people who reside in the most affluent regions of urban areas. In particular, the poor or those from families that are not well off do not get a high-quality education. This failure of education faced by urban communities is attributed to factors such as residential segregation, inequality in the allocation of funds, and a reduction of the cultural institutions. Another social challenge is access to high-quality health care. For instance, individuals who have a lower socioeconomic status do not usually have health insurance; hence, they may lack access to quality health care, which derails the successful continuation of the urban communities' projects (Patel, 2015).

2.2.3 Transformation Challenges of Urban Communities

The most significant problem in transforming urban communities is the issue of finding qualified personnel to manage and complete the necessary projects. In some instances, the local authorities find the least expensive means of rehabilitating the environment, and this most often results in hiring incompetent contractors who damage the environment. Another challenge in urban transformation is the communities' resistance to change. People tend to prefer the life they know and resist change, but with proper orientation, they can learn to accept it and embrace the new environment.

2.2.4 Solution Synopsis and Key Idea

The first step should be to ensure high-quality education is accorded to each member of the urban community (Svedin, 2015). Next, the relevant authorities should ensure that all the companies within the area or vicinity have proper waste disposal mechanisms to reduce the current health issues that emanate from lack of adequate tools for waste management and elimination. Lastly, competent and qualified contractors should be contracted, because their work will be of better quality, as compared to that of people who are incompetent and unqualified.

The key idea is to ensure that all the dealings in the community are prioritised and that a fair amount of funds is allocated for the projects. The proper allocation will support proper dealings in all these areas and allow the synopsis to be fully implemented for the best results.

2.3 Open Public Space

Worpole and Knox (2008) define open public space as land that is mostly used for leisure, amenity, and recreational reasons. Local authorities manage most of these lands. Furthermore, open spaces encompass several spaces in the urban environment which can be freely and readily accessed by people in the community, despite its design, size, and physical features which are primarily intended for recreational reasons. Examples include plazas, squares, public spaces for health and physical activity, and parks.

2.3.1 The Role of Public Open Space in Social Sustainability

The public open space network is an important part of the physical and visual environment and provides cities with varied scenery and character. In Dubai, the public open spaces must adhere to public objectives and policies such as sustainability, livability, protection of natural habitats and resources, and biodiversity, among others (Taleb & Taleb, 2012). Public open spaces can be stressed by inappropriate use or overusing, pressure development which emanates from technological and social change, and the provision of insufficient resources. Figure 2.1 present an example of how a public open space may look.

Figure 2.1: An example of an open public space (Tolba, 2015).

In several cities, especially Dubai, public open spaces play a role in meeting the objectives of sustainability. Some of the public open spaces in the city are incorporated into a wide array of green corridors that contain attractive and safe routes used by pedestrians and cyclists (Taleb & Taleb, 2012). These swatches of green improve sustainability by reducing reliance on cars for short journeys. Another advantage of the open public spaces in Dubai and other cities around the world is that it aims at delivering schemes of sustainable urban drainage systems, which are good for the environment. Lastly, socially sustainable use of land is necessary, as it entails health and social benefits for members of the community (Worpole & Knox, 2008). Through such schemes, people could seek solace whenever they want to gain insights on how to live a socially sustainable life (Tsitoura, Michailidou, & Tsoutsos, 2016). Furthermore, people get health benefits from these lands, whereby some are used for health centres that are either free or inexpensive.

2.3.2 Urban Communities and Open Public Space

Xue & Xiao (2016) define an urban community as a large town or city where population exceeds 2,500. Usually, the most central location in a region is the city, which is often crowded and busy. Examples of open public spaces include green spaces and parks (Bo-ot et al., 2012). Furthermore, open space landscaping ranges from environments that are highly maintained, to playing fields, to natural landscapes, and more. Though certain spaces exist outside of city boundaries, such as national parks, these are not considered to be open public spaces in urban areas. Several benefits emanate from the planning of urban public spaces. In particular, they include recreational, ecological, and aesthetic value, which all benefit both the state and the people using them.

2.3.3 Thermal comfort and outdoor activities

Thermal comfort and outdoor activities are crucial aspects of residential communities. For instance, it enhances the ability of people in residential communities to take part in community activities. Thermal comfort also promotes the wellbeing of individuals (Thani et al., 2013), mainly through facilitating the healing process by relieving the stressful conditions people undergo, which often leads to mental and physical stress. The stress they endure may render them incapable of performing their functions and may have an adverse impact on the communities and family as well (Chen & Ng, 2012).

People especially experience more stress in their workplaces, when they must separate from their families, or when they lack funds to finance their projects. The governments of some countries, such as the UK and US, provide outdoor spaces with the aim of ensuring public access for relaxation (BOUMARAF & Tacherift, 2012). These outdoor spaces aid the individuals in the communities to have normal lives, whereby they can engage in recreational activities, such as farming, walking, gardening, or sitting in the park. Some people are used to jogging or cycling, and they get to continue with the usual activities in outdoor spaces. Outdoor spaces are as important as rehabilitation centres; hence, the importance of outdoor spaces is evident as it fosters the members of the residential communities' well-being.

2.3.4 Thermal comfort and Indoor activities

Indoor thermal comfort is an individual's subjective assessment of satisfaction with the internal thermal environment. The maintenance of standards of internal thermal comfort for occupants of enclosures or buildings is one of the critical goals of HVAC design engineers. Thermal neutrality has been achieved in Dubai Sustainable City when the heat which is generated by human metabolism can dissipate slowly and as a result thermal equilibrium is maintained (Wong et al., 2016). Some of the important factors that influence thermal comfort are those that dictate heat loss and heat gain: clothing insulation, MRT, relative humidity, metabolic rate, air temperature, and air speed. One of the most recognised indoor thermal comfort models is the Predicted Mean Vote (PMV).

2.3.5 Case of the United Arab Emirates

Heavily populated cities of the UAE, such as Dubai, have fewer public spaces than required by the population. Public spaces that are lacking include playgrounds and parks. The design and land layout of the public spaces are crucial, and UAE has focused on providing easy access to waterfronts, pedestrian streetscapes, and parks. Polished marble and air conditioning are the main designs included in the construction of these public places to ensure that, even during hot days, the people of the UAE may still enjoy community events.

The indoor thermal comfort in the UAE has seen residents work, travel, live, shop, and create in an environment that is air conditioned 24 hours a day, 7 days a week. Such environments use immense amounts of energy, ranging around 60% to 75% of commercial and domestic building electrical usage in air conditioning alone. The average year temperature in the UAE is above 5 degrees with 350 days of unbroken sunshine (Wong et al., 2016). Maintaining an indoor temperature of 21 degrees Celsius would involve the displacing of around 2,971 cooling degree of heat energy.

2.4 Passive Urban Configurations

This section of the literature review concentrates on the parameters of urban morphological configuration and their application in urban space. The categories that are discussed in this section are:

- Studies on the impact of urban configuration parameters –buildings orientation, forms, and spacing.
- Studies on the impact of urban configuration parameters- courtyards and open spaces
- Studies on the impact of urban landscape factors – Type of vegetation and outdoor floor materials.

Urban neighbourhoods and developments are always evolving and changing; as a result, urban identity is characterised with social, natural, and built elements. Urban developments are currently not created by processes of regular evolution but through the local urban context in relation to economic aspects. Urban development is mostly an imposed reaction to needs that are often economical and selfish; for instance, the finance sector determines the material selection irrespective of the environmental ability of these materials to mitigate the phenomenon of UHI (Shamsuddin, Sulaiman, & Amat, 2012). Natural evolution processes developed traditional urban configurations, and as a result, they are viewed as being more organic. In contrast, contemporary urban settings are mostly linear, in block form, and simpler. The growth of economic-oriented urban development challenges the environment and results in adverse impacts, such as UHI. The objective of sustainable urban configuration is to arrange buildings such that softscape is inserted within urban open spaces, natural ventilation between buildings is increased, and the effects of solar radiation are reduced (Svedin, 2015).

In urban design, the connection between places and human beings involves many elements which include public space, transport, hardscape, buildings, streets, and landscape figure 2.2 shows the five elements of passive solar design. The hierarchy of urban spaces starts from small public spaces referred to as blocks (such as buildings and streets), to neighbourhoods (including corridors and districts), to whole regions (towns and cities) (Shamsuddin et al., 2012).

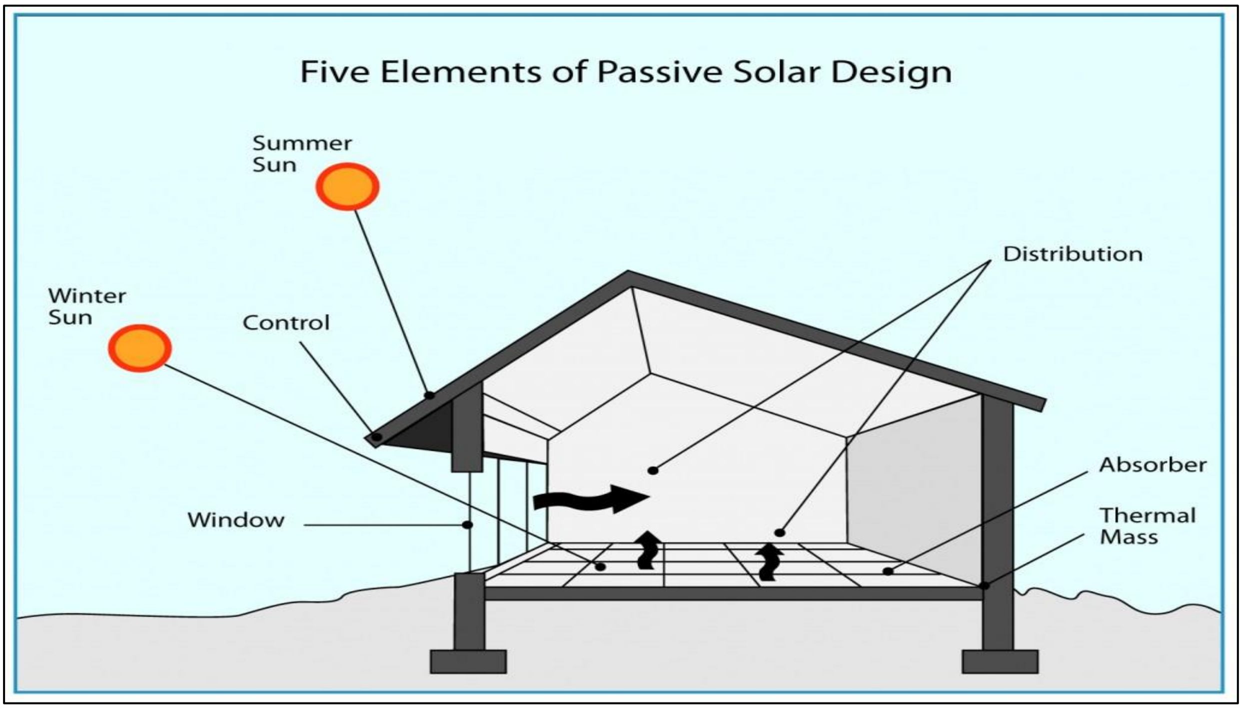


Figure 2.2: Five elements of passive solar design (Source: Svedin, 2015)

2.4.1 Building Orientation

Orientation is the way in which a building is situated with regards to positioning of rooflines, windows, and doors. A building that is oriented for solar designs takes advantage of active and passive solar strategies. Active solar systems make use of solar panels or collectors to power fans and pump to distribute the energy that is collected from the sun (Futcher, Kershaw, & Mills, 2013), figure 2.3 present the preferable building orientation by Futcher, Kershaws and Mills. Heat is transferred for storage to be used later or for direct heating. Passive solar strategies, on the other hand, use the heat that the sun dissipates to illuminate and heat buildings. Passive designs, unlike active solar strategies, do not involve the use of electrical and mechanical devices such as fans, lights, pumps, and electrical controls. Building materials and building orientation facilitate natural day lighting and temperature moderation.

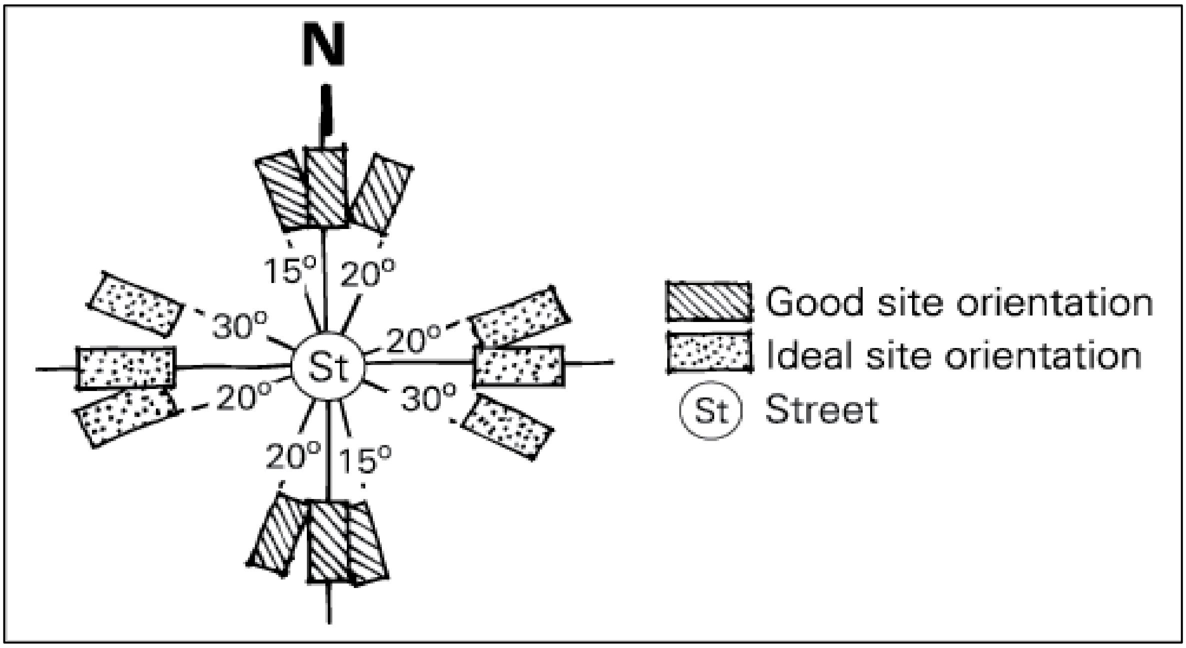


Figure 2.3: Different building orientations (Futcher, Kershaw, & Mills, 2013)

Huynh and Eckert (2012) identified the impact of using urban design to reduce heat and to improve thermal comfort in urban areas. The study compared building orientations based on the materials used for construction and greenery to establish the impact of urban design on the distribution of air temperatures and ventilation. In waterfronts, winds flow freely through buildings and results in a reduction of air temperatures by up to 0.2 degrees. This study concluded that wind ventilation is significant in improving urban cooling. Building orientation where buildings are parallel to the wind direction also improves urban cooling. However, constructing taller buildings in front of shorter buildings results in wind blockage and decreases wind penetration. For this reason, urban design often results in uneven improvement of cooling, as there is unequal distribution or wind penetration.

Roofing and roofing materials also affect building ventilation and air temperature. The use of cool paving material was identified to reduce room temperatures by 0.1–0.2 degrees. Green roofing also reduces air temperatures by 0.2 degrees, while light roofing reduces air temperatures by 0.1 degrees. The difference in these two materials is that green roofing dissipates heat just like a cooling system but a light roof relies on the mechanism of light reflection. Dark roofing made from dark-coloured concrete reduces air temperatures by only 0.07 degrees because dark colour absorbs heat.

2.4.2 Building Spacing

Urban planning and modern architecture are carried out by professional individuals from different fields. The design process of buildings, as well as new development in the urban setting, is driven by market forces in response to demand for retail space and housing. The space between buildings in urban environments is referred to as alleys, which are mostly shaded since buildings cast shadows (Shamsuddin et al., 2012). The alleys are often paved with bricks, and what very little vegetation they have is only in vases or areas that are secluded for the purpose of tree planting (Zhao, Liu, & Zhou, 2016). The spacing between buildings is designed in such a way to control shading of public spaces and buildings. The spacing between buildings is approximately eight meters in an urban configuration where buildings reach maximum storeys of around seven storeys. This spacing is also important as it allows for summer night breezes to ultimately cool interior spaces. Radiation to buildings is maximised and maximising shading in the winter. As a result, the temperatures are kept moderate.

2.4.3 Building Forms

The physical properties of open spaces and building structures are referred to as urban configurations, which are mostly designed to follow specific arrangements. There are two types of widely known building forms: courtyards and linear form (Futcher, Kershaw, & Mills, 2013). City configurations and urban forms are affected by factors including industry, distribution of various functions, social structures, and density within the city. Urban forms include built elements such as forms, buildings, and open space forms. Berkovic, Yezioro, and Bitan (2012) compared three urban forms—parallel slabs, courtyards, and tower blocks—to investigate optimal thermal behaviour. Courtyards mostly create a strong sense of community. Buildings reduce heat gain and control sun exposure with self-shading effects, which happen when the orientation, height, and width of built forms are controlled. The tower structure casts shadows to other buildings and maximises open space, depending on the urban context. The slab, on the other hand, is viewed as boring. Therefore, it is important for urban planners to have careful considerations of this form to ensure that a community sees it as a lively and enjoyable place.

2.4.4 Courtyards

The courtyard is the optimal form because it provides adequate shading area and reduced exposure to direct sun, improving thermal comfort. Additionally, courtyards reduce air temperature, allow better natural ventilation, and improve the liveable space that the community experiences. Courtyards divide urban spaces into public, private, and semi-public space to improve natural surveillance which distinguishes private and public areas, enhance privacy, and provide a flexible form for urban transformation (Svedin, 2015). The courtyard building form is considered to have the best thermal behaviour out of the five existing forms.

Courtyards proportion considered one of the main criteria at the designing stage for enhancing the outdoor thermal comfort (Kurt Grutter, 1987)

Courtyards in hot, arid climates play a multifunctional role by protecting against harsh weather, such as sandstorms, and providing shaded recreational areas. Overnight, courtyards release the heat that has been stored during the day, especially those that are covered with thermal mass material. This functionality makes courtyard forms appropriate for hot, arid climate regions, as temperatures during the night are low while during the day they are extremely high. Regarding seasons, courtyards perform equally well during the winter and the summer. Courtyards proportion considered one of the main criteria at the designing stage for enhancing the outdoor thermal comfort (Soflaei, Shokouhian, and Shemirani, 2015).

2.4.5 Case of United Arab Emirates

In the UEA, passive design is utilised to improve thermal performance in the buildings. Passive cooling strategies respond to the local climate and modify the heating of buildings to maximise comfort using the least energy. This technology adopts features in the building that reduce the air temperature without using additional energy in hot climates. The strategy reduces the contrast between the indoor and outdoor temperatures and improves the quality of indoor air, thus improving thermal performance. Some of these strategies used in the UAE include the use of glazing or skylights for windows, daylight designing, window placement, shading glass, and the use of reflective-coloured materials.

2.4.6 Studies on the Impact of Urban Configuration Parameters

Studies reviewed the effects of an open courtyard, both unshaded and shaded in hot, arid climates, on outdoor thermal comfort. Some researchers and practitioners examined the function of an open courtyard in moderating UHI. Some articles and journals, however, focused on open courtyard impact on microclimate, and open courtyards have been considered as an urban design strategy. Quantitative and qualitative assessments of courtyards were provided by some journals using field measurements and computational software.

Futcher et al. (2013) showed the influence of different circumstances of unshaded courtyards and design configuration in improving outdoor thermal comfort in Kuala Lumpur using computational simulations (Taleb & Taleb, 2012). Two software programs were used—Rayman and ENVI-met 3.1—to calculate PET and PMV, respectively. The values of PMV were compared to the PET values to make sure that there was consistency in the findings. There was mean air temperature of around 27 degrees Celsius in Kuala Lumpur. The city has a hot, arid climate; the monthly mean maximum air temperature ranges between 31.9 degrees Celsius and 33.5 degrees Celsius, and the minimum temperature ranges were between 24.3 degrees Celsius and 23.1 degree Celsius. The average humidity in the city ranged between 70% and 90%, and the daily levels rose to a maximum of around 94%.

In Zhao, et al. (2016), several urban configurations investigated for a square courtyard of approximately 24 m by 24 m surrounded by a Ground floor building. The study investigates open space orientations parameters, including reflectance of wall enclosures, the height of the wall enclosure, and greenery, to evaluate the performance of different courtyard configurations. The evaluation of the microclimate factors to study thermal comfort included RH, mean radiant temperature, air temperature, and wind speed. There were examinations of five different courtyards orientation: closed and opening facing south, west, north, and east. The orientation and location of the courtyard determined microclimate; there was a significant difference in temperature, which was high. The temperature of those courtyards facing east and north was lower by 0.5, and the humidity levels were higher. The study showed that high levels of humidity and temperature, long durations of solar radiation, and a lack of shading showed that all the five orientations were comfortable thermally.

According to Taleb and Abu Hijleh, another case study in Dubai represent the investigation of the modification of UHI, and the also how structured urban configurations and organic urban configurations impact on temperature variation. Adopting Dubai's Bastakiyah area as the traditional organic urban configuration and 2 structured configurations designed in linear and perpendicular form for Dubai's new part urban design. The study achieves the simulation part of the influence of the three different configurations by using the ENVI-met tool. The study climate condition input data was 32 °C for the temperature, and the wind speed between 0.1m/s, 3.6m/s and 7m/s subject to certain season. Figure 2.4 illustrates the result of the air temperature in Bastakiyah and the linear form at 14:30 in June.

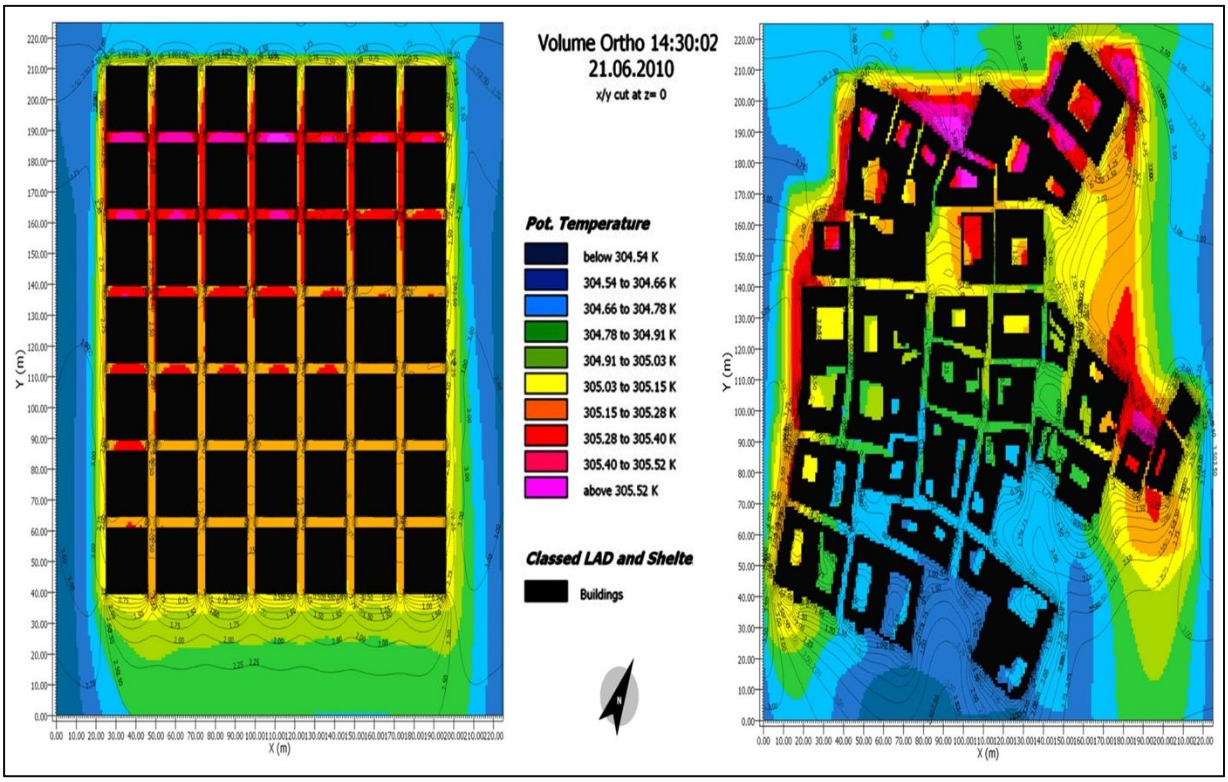


Figure 2.4: Temperature in Bastakiyah organic form to the left and the linear configuration to the right (Adapted from Taleb & Abu-Hijleh 2013, p. 112).

The results prove that organic urban form shows lower temperatures in summer compared to an urban configuration in a new part of Dubai, but temperature changes in other seasons were negligible. According to ENVI-met simulation outcomes, the three different forms had a major effect on wind speed value, and Bastakiyah area considered one of the best example of organic form, provided the enhancement of outdoor thermal comfort behaviours.

A holistic study of the impact of building configuration on enhancing outdoor thermal comfort and energy efficiency also, was investigated by Okeil (2010). The study want to take to investigate the possible of a full approach to efficient building forms in terms of energy consumption.

Three main urban forms were examined: two are the conventional forms (block and linear forms), and optimized urban form which was called residential solar block (RSB), as shown in Figure 2.5. This form was planned as an L-shape form to develop the functionality of a residential building forms. Photo-voltaic (PV) panels were integrated for heated purposes in this research, where increasing sun coverage in winter was a required; however, the RSB design also attempted to reduce heat exposure in summer.

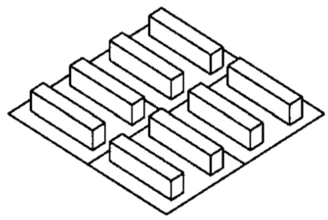
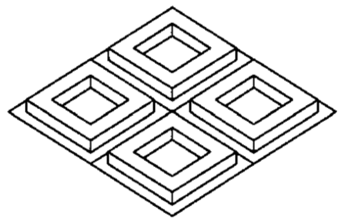
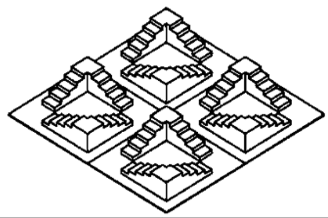
Module parameters		Layout (2 × 2 modules)
Urban form: linear		
Module size: 76.8 m × 76.8 m Building length: 60 m Building height: 15 m Street width: 26.4 m, 16.8 m Foot print/module: 1440 m^2 Surface area/volume: 0.28	Total area: 5898 m^2 Building width: 12 m Court: 60 m × 26.4 m Orientation: 0°, 45°, 90° Floor area ratio: 1.2	
Urban form: block		
module size: 76.8 m × 76.8 m Building length: 60 m Building height: 9 m Street width: 16.8 m Foot print/module: 2304 m^2 Surface area/volume: 0.2	Total area: 5898 m^2 Building width: 12 m Court: 36 m × 36 m Orientation: 0°, 45° Floor area ratio: 1.17	
Urban form: RSB		
Module size: 76.8 m × 76.8 m Building length: 60 m Building height: 3–15 m Street width: 16.8 m Foot print/module: 1840 m^2 Surface area/volume: 0.31	Total area: 5898 m^2 Building width: 12 m Court: 36 m × 36 m Orientation: 45° Floor area ratio: 1.1	

Figure 2.5: Solar radiation model parameters of different urban forms (Adapted from Okeil, 2010).

Other studies focussed on other characteristics of height/width ratios on courtyards design as well as the effect on energy consumption of H/W. Al-Masri and Abu- Hijleh (2012) chose a rectangular building for assessment with a courtyard block of a midrise building in the hot climate of Dubai. Different factors were investigated, and an optimal courtyard model was explored which included types of different material such as, insulation thickness and types, glazing layers, and wall thickness.

The results that were obtained in the study showed a 6.9% reduction in courtyard solar radiation in comparison to the rectangular building block as shown in figure 2.6. Heat move was higher in the courtyard comparing to the rectangular building block since more area was directly exposed to the sun. The total energy consumption of the courtyard design was reduced by around 7%. This study assumed that lighting was constant as well as other building systems and the most prominent cost actor was cooling load in the hot, arid climate. The effect of the courtyard design apart from the summer was important for the rest of the year on energy consumption.

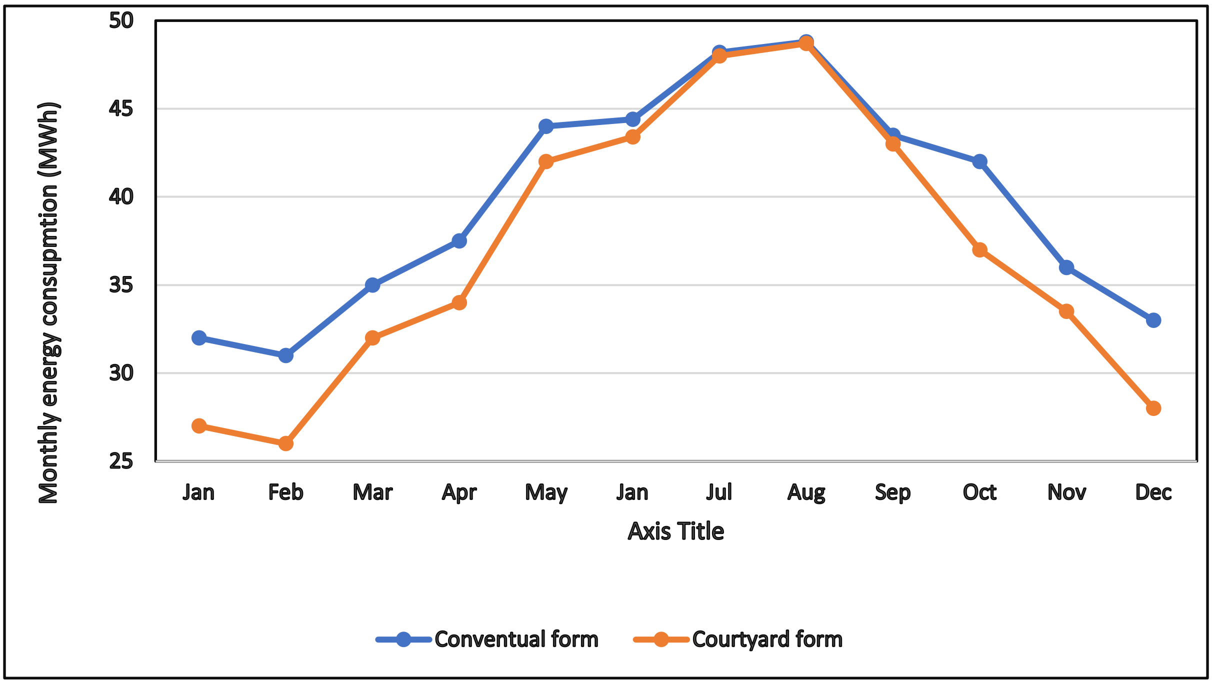


Figure 2.6: Monthly energy consumption of conventional and courtyard forms (Adapted from Al-Masri and Abu- Hijleh, 2012).

According to the study, in terms of energy consumption, a 6-storey building was the optimum building height. The total energy consumption was reduced by about 0.34% by increments in building height to ten storeys from eight storeys.

An optimised model of courtyards, according to the results, was realised in a six-storey courtyard building which had a wall thickness of 40 cm, cellular polyurethane with a thickness of 10 cm, and triple-glazed Low-E windows. There was a total energy reduction of around 11.2%, according to the optimised model.

Wang and Akbari (2014) believed that critical urban configuration elements, road direction, and hardscaping and softscaping material influenced urban open space microclimate and formed a exclusive local climate for each neighbourhood in the city.

A study was carried out by Ragheb, El-Darwish, and Ahmed (2016), in Alexandria, Egypt, which focused on examining human comfort in an old historic district that concentrated on design parameters of air movement, relative humidity, and air temperature, which significantly impacted outdoor thermal comfort. These parameters were simulated using ENVI-met software for three different urban configurations. Two of the configurations were proposal designs, and one of them was the current urban space. The first proposal had a 36 m height, and the second proposal with a 13 m height, with coverage of 60% and 55%, respectively. The simulation was done in four areas: secondary street level, pavement level, open space, and street level.

The results showed similarities in three scenarios: street level, open space, and pavement level. The building height of 13 m decreased relative humidity by 2.5% and improved air movement in comparison to the current situation, and MRT was not impacted as much, as there was an increment of 2–3 degrees Celsius. The 35-m height of the proposed open space increased MRT by 3–6 degrees Celsius and decreased relative humidity by around 2.5%. Increasing the building height to 35 m on the secondary street significantly influenced outdoor thermal comfort with a reduction of 20 degrees Celsius in MRT and 5.3% in relative humidity.

Three main climatic functions were taken into consideration by Wastvedt and Spim (2013). The first function considered wind circulation between courtyards and exterior spaces as well as ventilating interior buildings in tropical regions with courtyard air where the temperatures inside and outside buildings are close to each other, meaning that the courtyard is mostly used for refreshing interior air. The second function of the courtyard, when correct orientation is taken into consideration, plays a multifunctional role as sun protector and collectors. The third function is to increase humidity. To achieve comfort in arid areas, humidity is required, and this can be achieved by significantly increasing the relative humidity of the air.

2.5 Landscape Factors and Outdoor Thermal Comfort: Vegetation

Urban outdoor spaces are vital elements in cities because they host the highest human interaction and contact. This functionality has led to a massive increase in public interest in urban outdoor spaces, particularly in landscape factors. Several factors have an impact on the outdoor spaces' success, including microclimatic comfort. Toudert (2015) noted that in hot regions, the conditions of the outdoor thermal comfort in daytime usually surpass the acceptable standards of comfort. This effect is attributed to the high solar elevations and the intense radiation from the sun. The following sections will focus on landscape factors such as vegetation, outdoor floor materials, and water features.

In a study carried out by Ali-toudert and Mayer (2006), paving materials in outdoor applications gained the advantage of having concrete slabs that have a four-inch contact with the earth and that provide thermal lag and thermal storage. These advantages result in the continuation of the nighttime cooling to the next day with thermal dampening and time delay. Dense or concrete masonry materials take an hour to be penetrated by heat. The performance of a concrete paving in the shade is better than one in the sun, so the design must incorporate the shading of the paving (Yang & Zhao, 2015).

In another study carried out, the authors noted that colour also influences the material's performance (Cook et al., 2013). Concrete which was coloured lightly had a better performance than darkly coloured concrete. Furthermore, the study showed that concrete had a lower surface temperature compared to black asphalt. To test outdoor paving material, the researchers poured water on tiles of different material and started to note the results. Clay tiles had the most significant reaction; after 10 minutes of pouring water onto it, the temperature dropped by 32 degrees and further reduced to 11 degrees, lower than the ambient temperature of the air (Yang & Zhao, 2015).

2.5.1 Vegetation

Vegetation modifies the local climate of a particular area, and climatologist and urban designers consider it an essential element of design in a bid to improve the urban microclimate as well as urban spaces' outdoor thermal comfort (Kenawy, Afifi, & Mahmoud, 2013). Although scholars have proved that vegetation is one of the primary tools for improving thermal comfort in outdoor spaces, people also use it for utility purposes, aesthetics, and recreation. Scholars such as Taleb and Taleb (2014) emphasise the utilisation of greenery to mitigate UHI and improve the microclimate. The combination of the urban spaces' process of planting design climate dimension lacks, due to the lack of enough research around urban design, urban climatology, and the architecture of the landscape.

For hot climates, vegetation should be used for shading to mitigate the extreme solar radiation during the summer (Tolba, 2015). Overheating is mainly caused by the sunlit surfaces' heat storage. In such areas, there is a weak state of evapotranspiration, because of the soil's lack of water. Experts in the field stipulate that sparsely placed vegetation placed in the urban structure to provide shade is best for dry and hot conditions. In cold climates, vegetation acts more suitably as a shield against prevailing winds, and climatologists advise that densely spaced vegetation should be placed at the urban edges.

Kenawy et al. (2013) note that single trees that are planted within wide intervals do not have much cooling effects. Hence, urban designers should plant many small groups of trees, as opposed to planting them within large intervals. In a dense urban environment, the vegetation can be planted in several places such as in street intersections, along sidewalks, and in parking areas. Nevertheless, to gain the cooling and shading effects of urban vegetation, urban designers have to take into account what is required to plant and maintain trees that are healthy. The figures below show plantation and sun control, plantation and wind control, and plantation temperature, respectively.

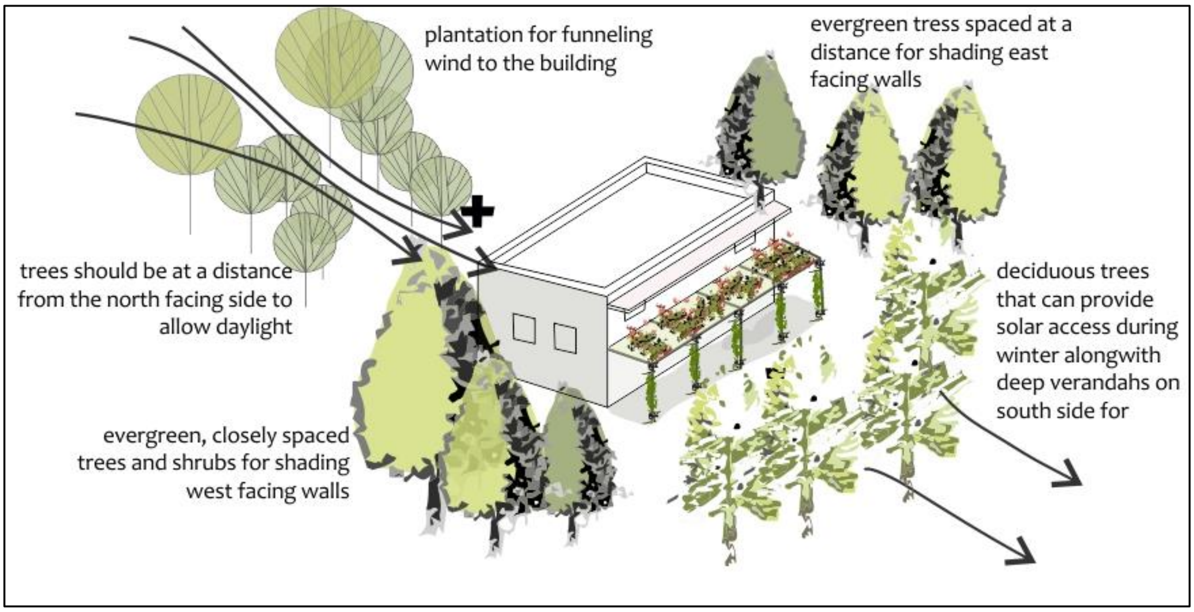


Figure 2.7: Achieving desired cooling and shading effects through plantation controls (Tolba, 2015).

Akbari et al. (1997) and Finnigan (1994) identified that vegetation is beneficial in the modification of thermal comfort in climates that are hot and dry. Large plantings are effective in reducing UHI effects and causing of microclimate effects on the rooftop absorption, reflection, and heat emission.

In a study to investigate the impact of vegetation at the street level in Melbourne (Australia), Bruse and Skinner (1999) established the microclimatic effect vegetation may have on city temperatures. This study observed city centres that lack vegetation and have many buildings; the researchers found a change in energy balance on the surface of the earth which causes a UHI effect. Less solar radiation gets to earth's surface, and therefore the latent heat emitted is turned to sensible heat. The lack of trees and vegetation has an impact on the radiatively active surfaces, especially the rooftops in densely built environments. Heat absorption and emission take place in the rooftop, and introducing vegetation on the rooftop results in a microclimate that influences the local climate. Air temperatures reduced by up to 2.4K due to the tall trees in the southern side of the town and a reduction in the speed of wind by 1.30 ms.

Middel, Chhetri and Quay (2015) found out that a tree canopy covering about 10% of a city reduced temperature by 2 degrees, and this vegetation is predicted to have an offsetting effect on the urban warming. Tree spacing, layout, and location are the key factors that influence the cooling effect because they affect shading. Shading from canopies mainly affects night temperatures, and this is effective in controlling UHI.

Shahmohamadi et al, (2012) found three main negative effects of UHI, including its impact on the quality of the air, diseases and mortality rate, and the degradation of natural resources. Urban warming, for instance, influences the demand for water and electricity, as these are the main resources used to provide cooling in buildings. Heated air creates smog from photochemical, and when this reacts with other pollutants in the air, the resulting quality of air is poor and poses a health threat.

2.5.2 Studies on the Impact of Urban Landscape Factors: Vegetation and Outdoor Floor Material.

Floor covering materials such as travertine, andesite, asphalt, grass, empanel wood, and soil were studied to examine their effects on thermal comfort. Three different landscape design projects covered around 500 square meters and were analysed for thermal comfort with the various floor materials. The PET values were measured during cloudless days by using Rayman software with air temperature, humidity, surface temperature, and wind data obtained and recorded (Cui et al., 2016). The temperature of travertine was 26.1 degrees Celsius, andesite 27.1 degrees Celsius, asphalt 28.5 degrees Celsius, grass 25.9 degrees Celsius, empenyel wood

28.9 degrees Celsius, and soil 27.5 degrees Celsius. In the initial project, the PET value that was noted was 26.3 degrees Celsius, and the floor material coverage was mostly travertine and grass, while the second project that was carried out was 27.02 degrees Celsius. The final project which had a floor covering of asphalt and wood had a PET value of 28.1 degrees Celsius. The conclusion was that design-based suggestions in urban areas which were related to the use of floor material are made to reduce the effects of UHI and to design places that are comfortable in hot cities.

A study conducted by Amirhosein Ghaffarianhoseini, Berardi, and Ali Ghaffarianhoseini (2015), emphasize the positive effect of several design configurations and proposals of unshaded courtyard on outdoor thermal comfort, in their study in Kula Lumpur, Malaysia. Also, they represent the impact of vegetation by comparing grass groundcover with bare groundcover, and the result showed the ability of grass to decrease the air temperature by 0.13 °C during the morning paralleled to bare ground. In term of the relationship between trees and thermal comfort, the peak point of comfortability in shaded areas can have a reduction in temperature by 3.3 °C, if the ground covered by 75% of trees. On the other hand, relative humidity increased by 11.5% due to the reduction of air movement and wind speed.

In large cities in the UAE, such as Dubai, urbanisation has resulted in different environmental issues. One of the leading issues is the UHI that is a result of increased heat in large city centres. To identify the effect of vegetation in reducing urban heat energy in Dubai, Rajabi and Abu-Hijleh (2011) found that the use of medium density trees around structures is an effective vegetation strategy to reduce heating in large cities. The study investigated two strategies; one involved determining the impact of greenery roofing from a generalised position, and the other specified the impact of greenery roofing using two structures in Dubai.

Prior research to determine the state of thermal heating in Dubai was referenced and revealed that urban heat was higher in older structures than in more modern buildings. Three scenarios were tested: filling the empty areas between the buildings with trees, use of the situation without alteration, and the addition of a greenery roof after inserting trees figure 2.8 shows the three different scenarios.

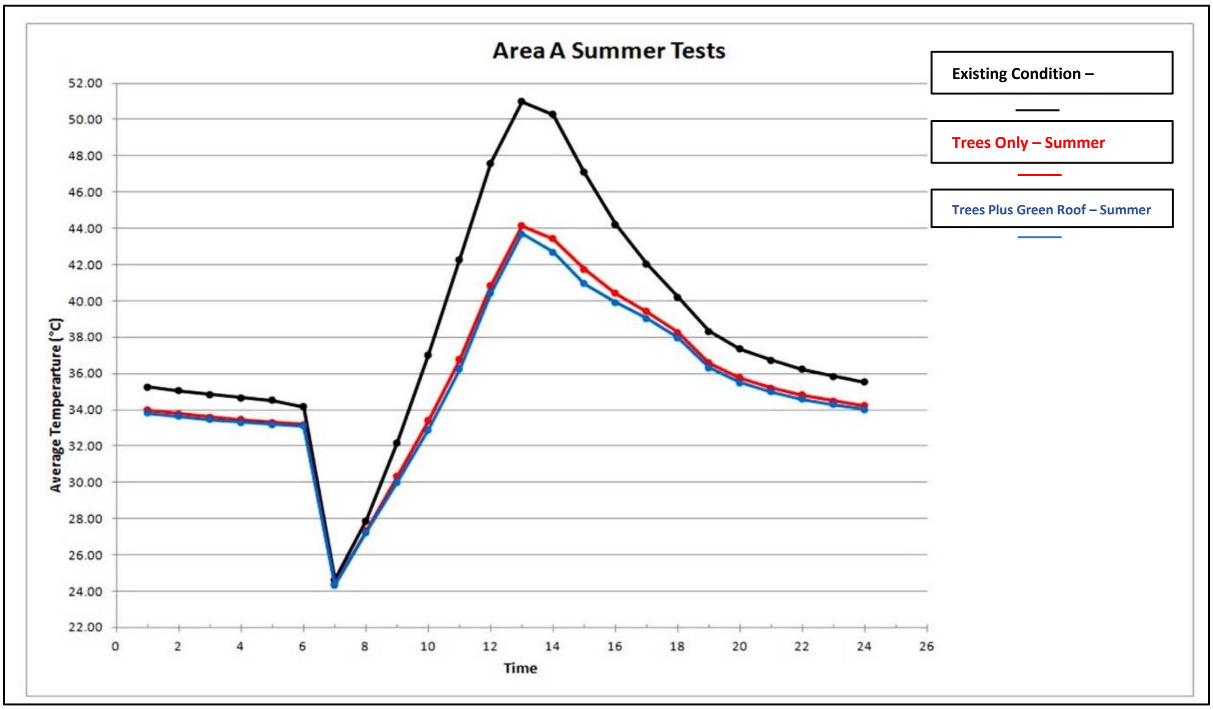


Figure 2.8: Temperature differences based on the study findings Dubai (Adapted from Rajabi & Abu-Hijleh, 2011).

The study was performed during summer and winter, and in both cases, the addition of a greenery roof and trees was found to be the most effective strategy in reducing the surface temperatures. Greenery roofing has been identified to effectively reduce temperatures in both winter and summer. Particularly, the insertion of trees in free spaces between buildings resulted in the lowest surface temperature, thus effectively reducing UHI in Dubai (Rajabi and Abu-Hijleh, 2011). Some greenery strategies such as the use of grass instead of trees with greenery roofs has also been tried in Dubai to determine whether they are effective in reducing surface temperatures. This strategy is less effective but can still be employed.

Least but not last, Vegetation converge percentage has an important role in reducing the heat island effect throughout controlling the urban microclimate. Also, Vegetation converge has an influence on energy demand through the cooling influence provided by shading. Absorption of solar radiation by the walls and the roofs of the buildings are considered the main contributor of the heat island effect, in case of heat gained in the morning and heat release at night (Nuruzzaman,2015).

2.6 The Climate

Ali-Toudert and Mayer (2006) defined climate as the visible features of weather over several years in a particular region. Furthermore, climate constitutes of two different fields: the macroclimate (the climate of a largely significant area such as a country or a region) and the microclimate (climate on a small-scale basis). Climatologists have carried out several studies and put significant effort into classifying the climate with two different spectrums that have the same features, wherein each of the spectrum and individuals can live a lifestyle. Taleb and Taleb (2012) further stipulated that bioclimatic urban design is the designing of buildings and urban spaces where people embrace the setting to reduce their ecological footprint and energy use (Zhang & Lian, 2015).

2.6.1 The Microclimate

The microclimate is the differences climates, such as around a building (Thani et al., 2013). Buildings also form microclimates by changing the patterns of wind flow and shading the ground. One of the examples of how the local climate is affected by buildings is the UHI effect in large cities as shown in figure 2.9, particularly where the surrounding area's temperature is lower than the average temperature. Improving microclimate around buildings can decrease the costs of winter heating, provide an ambient and beautiful scenery in spaces that surround the building, maximise comfort in the outdoors during the winter and summer, and promote the growth of plants (Thani et al., 2013).

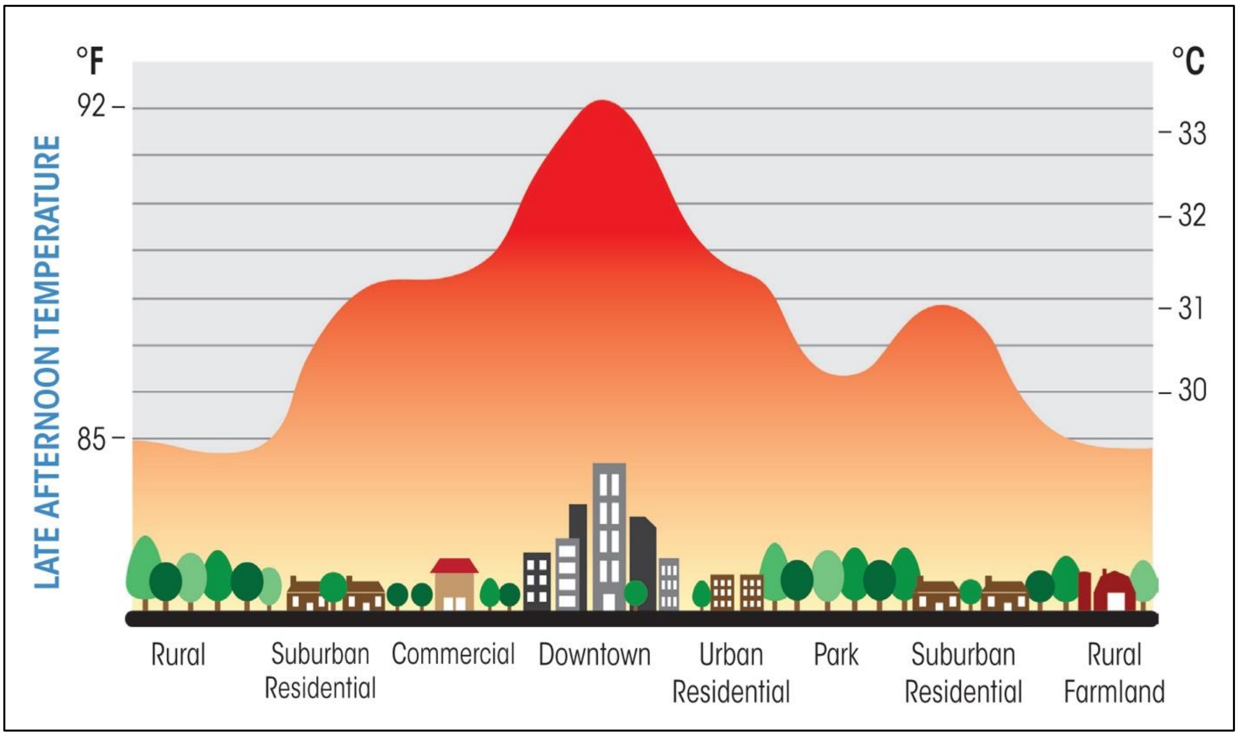


Figure 2.9: A graphical illustration for the effect of UHI in different urban areas (Zhang & Lian, 2015).

2.6.2 Parameters that Affect Microclimate

The parameters that influence outdoor thermal comfort are more complicated than indoor areas. This is attributed to the limited and controllable number of surfaces that impact indoor spaces. Nonetheless, it is very difficult to control outdoor spaces, hence; people calculate outdoor thermal comfort on the basis if some assumptions. Because the parameters of microclimate are quite complicated, scholars continue to explore them. According to Ragheb, El-Darwish, and Ahmed (2016), various factors impact microclimates. The first is topography, which is the urban land's shape. The systems of weather have a predictability which can be changed by features of the topography, such as slope and aspect. The second factor is soil, whereby the soil's composition affects microclimates mainly through the amount of water which evaporates from or is retained in the soil. For instance, soil that contains a significant amount of clay usually retains a larger amount of moisture compared to the soil that contains sand.

The next factor is water positioned in the land's surface. More specifically, streams, ponds, and other water bodies in the urban design will affect the temperature. The presence of reservoirs and lakes can also lead to a climate that is more moderate. All these impacts are attributed to the fact that the land loses and gains heat more quickly as compared to water. The fourth factor is vegetation, whereby the microclimate is affected by the water and soil where the vegetation is planted (Monteiro, 2010). In particular, vegetation filters particles and dust from the air, regulates the soil's temperature, and can be used as a suntrap or a windbreak.

The last factor is artificial structure, whereby a building can affect the microclimate of a region as it absorbs heat during the day and releases it during the night.

This is carried out by the process of wind deflection, shading, and sunlight reflection. Temperature is moderated by paved surfaces, such as driveways and patios, by the process of heat absorption and emission. Walls and fences protect the plants from wind, and the rocks placed in gardens have an effect because they also store and release heat. Ragheb et al. (2016) states that microclimates are dynamic, as they can store and release heat. This translates to the fact that rocks can be placed in an urban space to modify the microclimates.

Some primary physical parameters that impact on thermal sensation in an open space include air velocity, relative humidity, MRT, and ambient air temperature (Thani et al., 2013). Climatologists classify these parameters as important based on their climatic features. The most important parameter in both cold and hot regions is air temperature, according to climatologists and other scholars in the field. Toudert (2015) stated that urban planners basing their designs for urban spaces on any design plans, environmental regulations, and guidelines which are established by analysing the features of the climate of a location. This is referred to as bioclimatic urban design, which is discussed in detail in the next section.

2.6.3 Bioclimatic Urban Design

One of the main advantages of bioclimatic design is the improvement of outdoor thermal comfort. A significant improvement of the urban space's environmental quality can be achieved with tested and established bioclimatic parameters. Bioclimatic urban design translates to collecting, investigating, and analysing the urban space's climate conditions to create spaces which are environmentally friendly for people (Zhang & Lian, 2015). One of the most common features of urbanism is that urban open spaces are warmer than their surrounding areas (Amor, Lacheheb, & Bouchahm, 2015). This is attributed to the positive thermal balance which results from the reduction of softscape and the utilisation of dark-coloured hardscape, figure 2.10 present some of the bioclimatic design strategies.

Taleb & Taleb (2012) explained that this feature is identified as UHI and has a negative impact on human comfort, mostly by reducing the movement of air and raising the ambient temperature of the air.

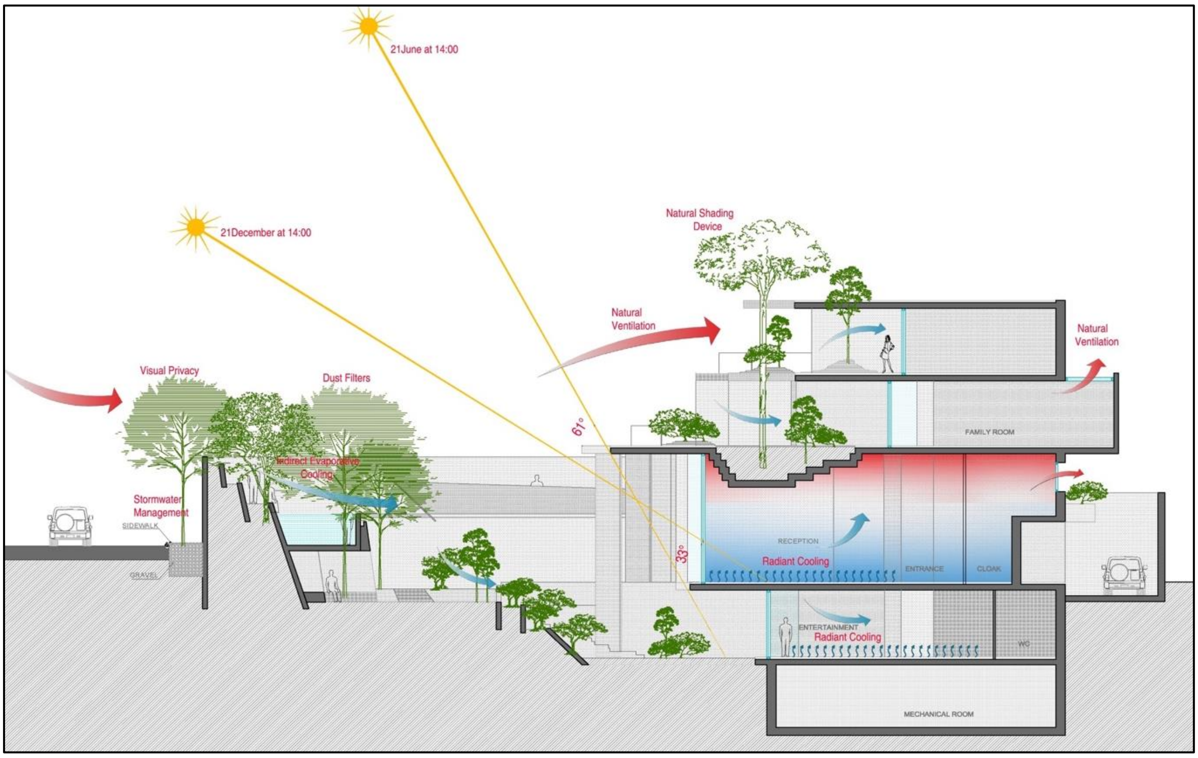


Figure 2.10: Some of bioclimatic design strategies (Amor, Lacheheb, & Bouchahm, 2015).

For instance, Monteiro (2010) concentrated on passive design plans for a Lhasa building in China's mountain climate. An examination of the parameters of basic climate, such as solar radiation, relative humidity, temperature, and air velocity, was carried out to formulate design plans and strategies, including thermal mass, solar windows, and vegetation (Monteiro, 2010). The strategies are useful for consideration in the future, as architects can use them as guidelines to create buildings that are energy efficient. In yet another study, the scholars analysed the effect of urban microclimatic conditions on the renovation sites that exist in Albanian open spaces. The findings showed that utilising the parameters of microclimates can potentially decrease the temperature by more than 3 degrees Celsius for the improvement of outdoor thermal comfort (Ragheb et al., 2016).

2.6.4 Dubai Climate

In Dubai, the highest temperature that has been recorded is 45 degrees Celsius experienced from July to August, while the lowest to be registered has been 5 degrees Celsius in February. Figure 2.11 clearly show the average low and high temperatures, and figure 2.12 shows the ranges of sunny days in Dubai (world weather online.com, 2017).

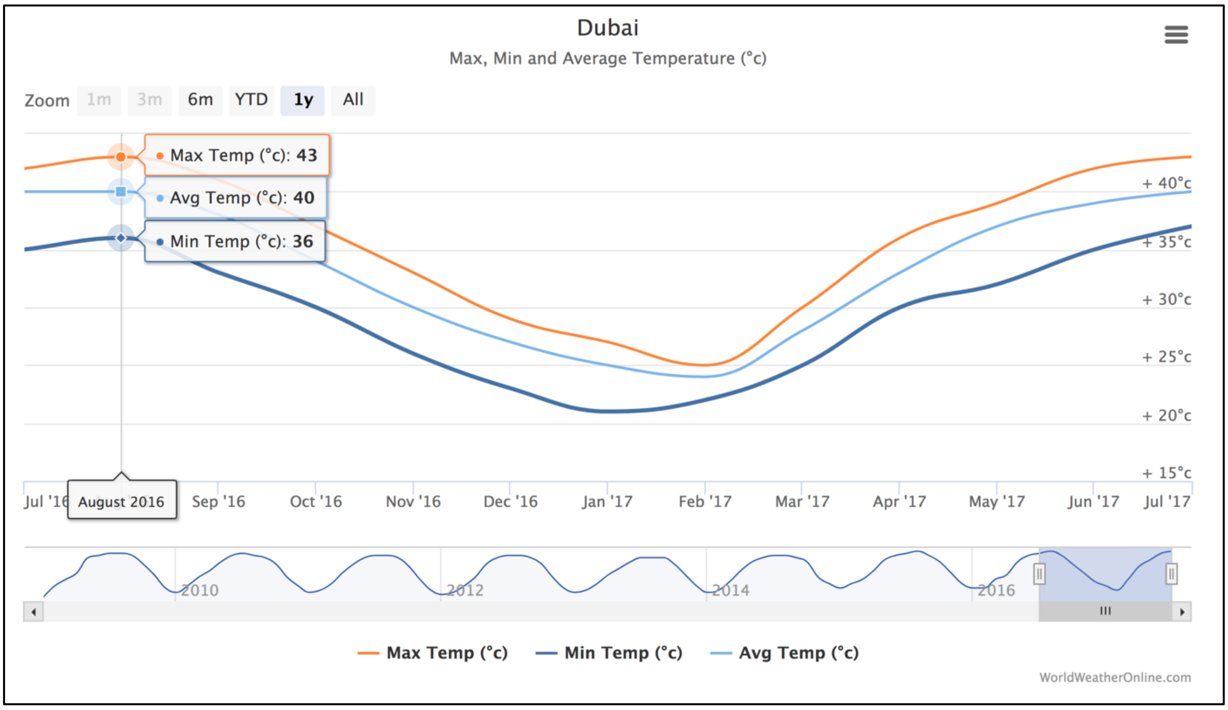


Figure 2.11: Average high and low temperatures, (World weather online.com, 2017).

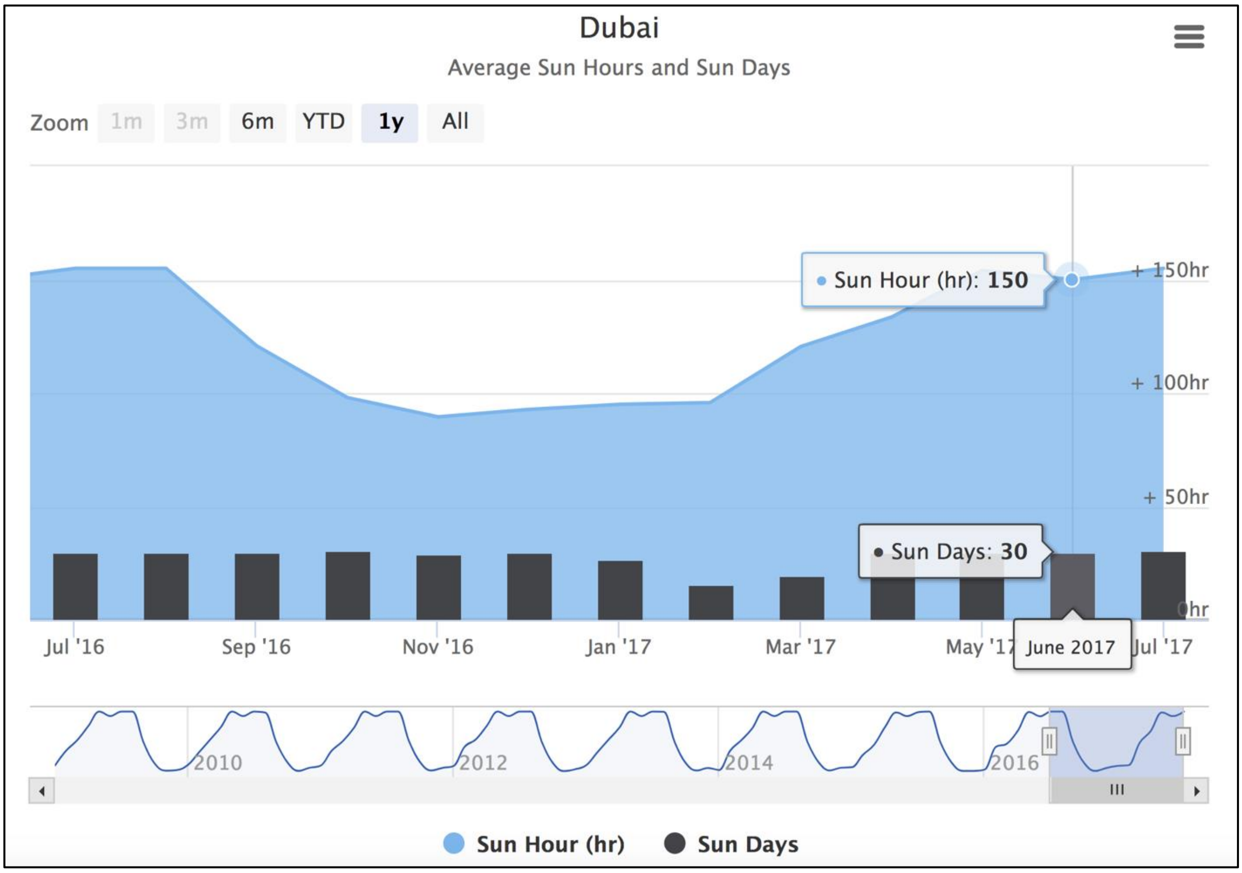


Figure 2.12: Dubai sunny days (World weather online.com, 2017).

Because Dubai has sunlight in several months of the year, it has high levels of illumination, whereby the highest flux that has ever been recorded was from May to August and was more than 110,000. The lowest illumination was recorded in December and had lux levels that were below 7,000. These facts show that urban designers should consider lux levels in all designs, whether on an urban level or a building level.

Climatic classify Dubai as area that experiences extreme humid and hot summers, as it is a hyper-arid climate area. Furthermore, Dubai lies on the coordinates of 26.43_°N, 55.45_°E, where the temperature is estimated to be 41 °C (105 °F) which is linked to the region's humidity of 94% (Thani et al., 2013). In the UAE, the range of temperature is between 17 and 26 degrees Celsius in winter. During the summer season, the sun is usually high between June and

December, and people experience stresses from heat during June to September. In winter, the rains come between December and March because these are the year's coolest months.

Figure 2.13 shows that the direction of the prevailing winds is usually on the northwest axis, and the maximum speed of the wind that was marked in May by climatologists was 9 m/s. Climatologists consider humidity to be a vital issue that has a negative impact on outdoor thermal comfort. In the summer, high degrees of relative humidity significantly contribute to the decrement of the sensation of thermal comfort since the air temperature heating effect is amplified by the humidity (Thani et al., 2013). This type of weather helps people enjoy the outdoors for a few months in a year, because some of the buildings are cooled by the weather. However, the cooling is artificial and lasts for only some few months, as opposed to throughout the year.

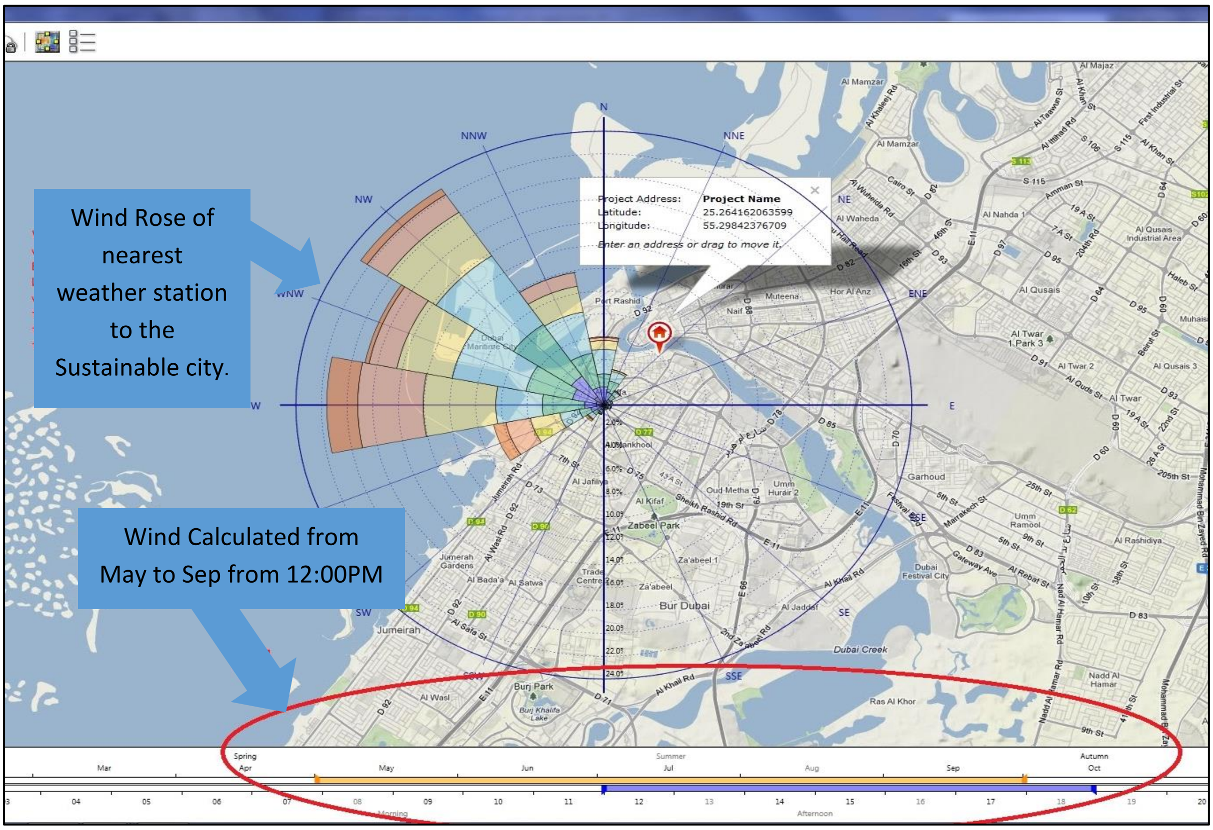


Figure 2.13: Wind Rose showing wind direction from May to Sep (Adapted from Ecotect software, 2016).

Table 2.1, shows the average of humidity, prevailing wind, and temperature in the UAE. Due to some adverse weather conditions in Dubai, the region continues to be a complex environment for the urban planners who are striving for thermal comfort. Nonetheless, developing the bioclimatic design and comprehending the primary parameters that control the environment results in increased outdoor thermal comfort. Setaih et al. (2013) asserted that people experience thermal periods of stress in June and July, with the highest values in August.

	Temperature					Humidity				Wind			
Month	Max	Mean Max	Mean	Mean Min	Min	Mean Max	Mean	Mean Min	Rainfall	Mean	Max	Mean Max	Solar Radiation
January	31.8	24.2	19.3	14.5	7.7	82	65	45	16	12.4	59.3	22	3787.6
February	37.5	25.6	20.4	15.4	7.4	83	64	43	21.7	13.5	53.7	24.2	4648.5
March	41.3	28.5	22.9	17.7	10.1	82	61	38	22.3	13.8	48.2	25	5417.6
April	43.5	33.1	26.9	21.1	12.8	75	54	31	5.3	13.6	72.2	25.8	6172.2
May	47	37.8	31.1	24.9	15.7	71	49	27	0.4	14	40.7	26.1	6770.4
June	47.9	39.7	33.1	27.4	20.7	77	55	30	0	14.1	38.9	25.4	6731.7
July	48.5	41.1	35	30.2	24.1	75	54	32	0.8	14.3	42.6	25.6	6261.1
August	48.8	41.4	35.2	30.5	24	73	53	30	0	14.1	38.9	26	6070
September	45.1	39.1	32.8	27.7	22	80	59	31	0	13	40.7	24.6	5756.9
October	42.4	35.6	29.6	24.2	14.6	81	60	34	1	12.2	42.6	23.5	5047.1
November	38	30.7	25.2	19.9	10.1	79	60	39	4.3	12.2	48.2	22.5	4169
December	33.2	26.3	21.3	16.3	8.2	82	65	45	15.3	12.1	40.7	21.7	3768.3

Table 2.1: Average of humidity, prevailing wind, and temperature in the UAE (NCMS, 2016).

It is essential for urban planners acquire information regarding the weather, levels of moisture, and temperature in the climate when related to one another. In the psychometric chart in the figure 2.14, the main signs for the level of thermal comfort in different climatic conditions are shown.

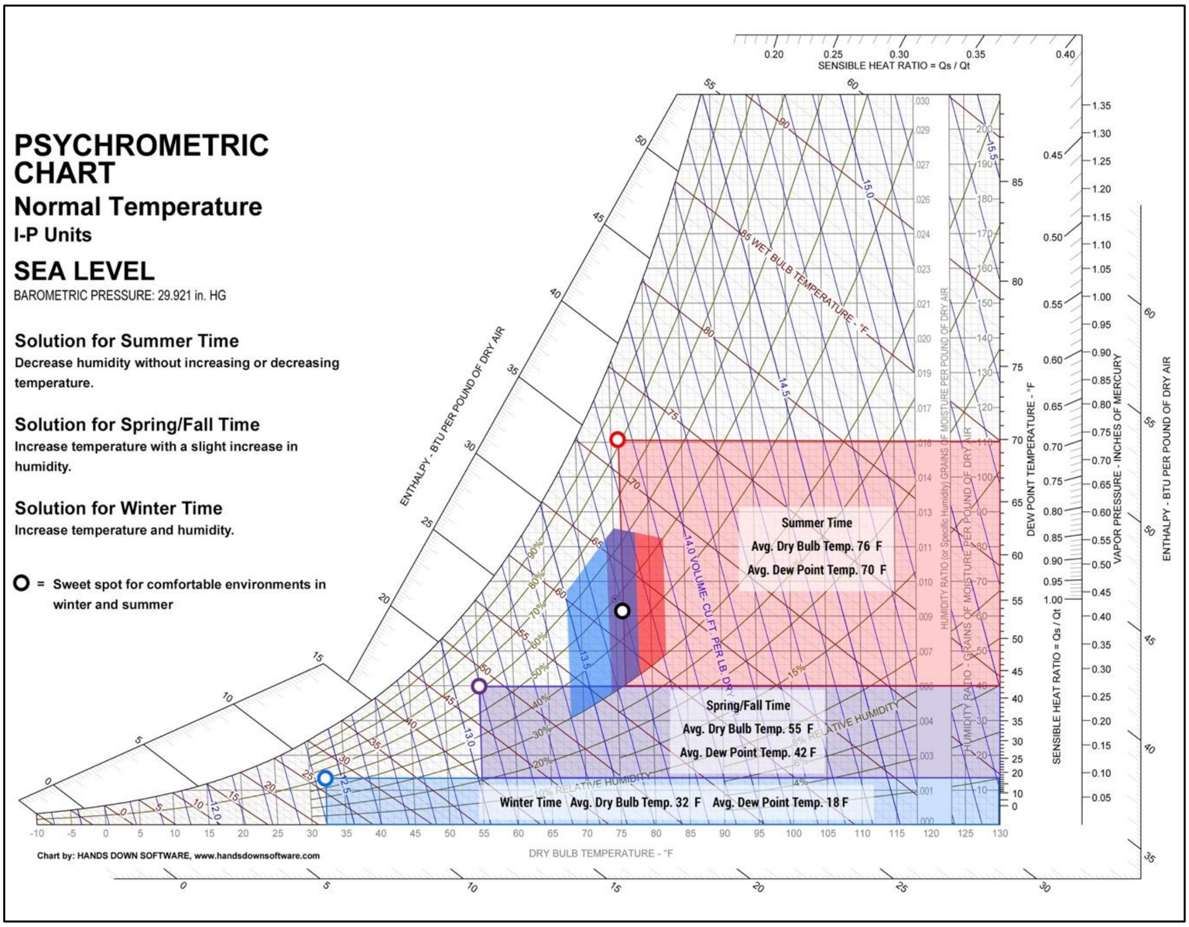


Figure 2.14: The level of thermal comfort in various climatic conditions (source: www.handsdownsoftware.com,2017).

2.6.5 Urban Configuration Parameters

Numerous uncontrollable variables affect outdoor thermal comfort. Parameters can be divided into morphological and climatic variables. Some of the most important climatic parameters in outdoor thermal comfort levels are wind speed and air temperature (Taleb & Taleb, 2012). Open space proportions and building forms are the critical morphological parameters that are complementary, and they are in mostly interrelated. The aim of this research is to concentrate on the interrelationship between climatic and morphological parameters to control the factors of thermal comfort and enable urban planners to improve thermal comfort through bioclimatic urban design; as a result, the most constructive urban configurations can be achieved in urban communities. It is important to gather sufficient information carefully about all various parameters, especially when dealing with an outdoor environment.

Many urban design professionals and researchers have pointed out the interrelationship between outdoor thermal comfort and urban configuration as an area of interest and as a result completed numerous studies in those areas (Taleb & Taleb, 2012). Early research can be characterised into three significant groups. The first group concentrated on physical and psychological impacts of urban green spaces that impact thermal outdoor comfort. The second group focused on human comfort considerations and thermal performance characteristics of parameters of urban morphology. The third group studied how different urban configurations impact UHI mitigation.

2.7 The Impact of Outdoor Thermal Enhancement on Indoor Energy Consumption

The United Arab Emirate State of energy report for 2015 indicates that residential sector is consuming 29% out of total electricity consumption up to 2013 records, it is known that U.A.E has produced 75% of its electrical energy from the petrochemical power plants that runs on Gas and the Petroleum refining industry sector that construct the base for energy production in U.A.E as mentioned stated by (DEWA sustainability report, 2015). adding to that the fact that global warming is linked to the process of generating, transmitting and distributing electricity which is correlated to Green House Gases emission. Gasses such as C02 and CH4 and N2O are emitted through the process of electricity production (Kgabi, Grant and Antoine, 2014). Which is contributing to the international heat waves, floods, hurricanes and raise in water bodies level and other incidents that are related to the impact of Global warming over different regions around the world.

The rapidly increase in electricity demand is undeniable yet the need for deep cut in international percentage of GHG emission is needed urgently as formally recognized by 196 parties of the (UNFCCC) U.N framework convention on climate change that took place in Cancun Dec.2010. It was clearly admitted that global warming is happening know and a demand for an urgent action to prevent the increase of 2C˚ on global average temperature to face the real threat of climate change. (World Energy Outlook Special Report, 2015)

In alliance with the national and international effort to reduce energy consumption demand in the residential sector that will additionally reduce overall energy production. It was found that the use of air conditioning, ventilating equipment, and thermal regulating technologies at the indoor spaces in order to mitigate the thermal conditions and reaches the thermal comfort level these systems are adding load to the energy consumption especially the electrical supply that thermal regulating technologies use (Hong et al., 2016) this eventually leads to the increase in electricity demand level which will add to the production percentage with eventually will increase the GHG emission to the microclimate which leads to increase in heat and air temperature that requires more machinery systems to mitigate and the loop continue.

Nei et al. (2015) observed that since the indoor environment has a direct effect on the human's health, in residential buildings, various methods are utilized to make the environment comfortable for humans. As a result, energy is required to ensure that the right thermal conditions are created. In the study, it was noted that beside regulating the environment internally in the buildings, an supportive solution would be the enhancement of the outdoor thermal.

Another study conducted by Yang, Yan, and Lam (2014) sought to determine ways through which outdoor thermal comfort may be attained to reduce the energy consumed in buildings. According to this study, it was established that buildings contribute to over 30% of carbon emissions and accounts for at least 40% of the total global energy consumption for thermal comfort. The study further suggested that future consideration of climate scenarios should be utilized to inform the energy distribution and planning systems as a strategy to respond to expected changes in thermal regulation requirements.

Kwok et al. (2017) noted that in Hong Kong, in dense urban environments, people experience poor living conditions because of buildings overheating during summers. Through a comparison between the indoor and outdoor temperatures, a linear relationship was observed. Also, a positive correlation was seen between the responses of buildings to the changes recorded in the outdoor temperatures. In Abdallah (2015), it was established that attaining thermal comfort in residential buildings would be planned at the designing stage of construction. The study found out that buildings designed with climatically responsive structures were effective in reducing the energy consumed in building cooling. It was also established that many causes increase microclimate around residential buildings. Among the leading causes, it was found that air pollution, the imbalance between indoor and outdoor comfort as well as indoor energy consumption when heating and cooling buildings contribute to the creation of microclimate. The paper utilized two case scenarios to establish a comparison between indoor thermal comfort and energy consumption. It was found that on the hottest day of summer, the indoor and outdoor temperature difference was 11 degrees Celsius for buildings that have open spaces in the outer courtyards.

others were influenced also to study the impact of Urban microclimate on air-conditions energy needs such as Feng, Ming, Ruey. (2015) were the case study of the second largest city in Taiwan were examined by following morphing approach as well as software model simulation using Energy Plus to simulate cooling and heating load needed for a typical flat design used for the research study purpose. The study found that the site were the hottest urban microclimate data were collected from the weather station consumed 10% more cooling energy than the base line site. this proves in deed the impact of outdoor microclimate thermal change over indoor thermal condition.

Table 2.3: Summary of the results of recent studies into strategies for improving the outdoor thermal comfort in urban environments.

Study	Study Parameters	Climate	Key Findings	Methodology Used
Rajabi and Abu-Hijleh, (2011).	The Study of Vegetation Effects on Reduction of Urban Heat Island in Dubai	Tropical	-A composition of green roof and trees results to the lowest surface temperature. Grass showed the least effect in reducing urban heat.	Software Simulation using ENVI-met
Huynh, C., & Eckert, R. (2012).	Reducing heat and improving thermal comfort through urban design-A case study in Ho Chi Minh City	Tropical wet and dry climate	-Wind ventilation is significant in improving urban cooling -Wind blockage when taller buildings are erected in front of shorter buildings results to uneven cooling improvement. -Green roofing reduces air temperature by 0.2 degrees.	Software Simulation using ENVI-met
Middel, A., Chhetri, N., & Quay, R. (2015).	Urban forestry and cool roofs: Assessment of heat mitigation strategies in Phoenix residential neighborhoods.	Hot and dry climate	-1% increase in tree canopy reduces air temperature by 0.14 degrees Celsius -10% canopy covering reducing urban temperature by 2 degrees	Empirical Field study and case study .
Bakarman, M. A., & Chang, J. D. (2015).	The Influence of Height/Width Ratio on Urban Heat Island in Hot-arid Climates.	Hot arid climate	-As the H/W ratio decreases, the intensity of urban heat island increases	
Amor, B., Lacheheb, D. E. Z., &Bouchahm, Y. (2015).	Improvement of Thermal Comfort Conditions in an Urban Space (Case Study: The Square of Independence, Sétif, Algeria	Hot and cold	-Vegetation is effective in the regulation of the quantity of radiation transmitted, the speed of air and air temperature and humidity generating improvements in thermal comfort	Software Simulation using IES
Patel, K. (2015).	*Perceptions of Thermal Comfort: Landscape Design Attributes Based on The Shops at La Cantera in San Antonio, Texas*	Subtropical humid climate	-Shading, water features, plantings affects thermal comfort	Empirical Field study

Thani, S. S. O., Mohamad, N. N., & Jamaludin, S. N. (2013).	Outdoor thermal comfort: the effects of urban landscape morphology on microclimatic conditions in a hot-humid city	Hot humid climate	-Landscape morphology influences the variations in climate parameters resulting to microclimates. -Bioclimatic landscapes lowers temperature.	Empirical Field study and Software Simulation using ENVI-met
Okeil (2010). A holistic approach to energy efficient building forms.	A holistic approach to energy efficient building forms.	Hot arid climate	The courtyard formed by innovated L-shape and U- Shape showed a better thermal comfort results due to enhanced air flow.	Software Simulation using ENVI-met
Al-Masri & Abu-Hijleh 2012. Courtyard housing in midrise buildings: An environmental assessment.		Hot arid climate	Courtyard design reduced total energy consumption by 6.9 % compared to rectangular block, and a 6-storey height of courtyard achieved a total energy reduction of 11.16%.	Software Simulation using ENVI-met
(Soflaei, Shokouhian and Mofidi Shemirani, 2016) Investigation of Iranian traditional courtyard as passive cooling strategy (a field study on BS climate)		Hot arid climate	- North–south, southwest or northwest-southeast ordinations are the best direction to increase the usage of summer and winter breeze in living area. - Square courtyard shape was recommended in hot climate. - Linear equation was proposed to calculate the best L to W ratio.	Empirical Field study
Feng-Chi Liao, Ming-Jen Cheng, and Ruey-Lung Hwang (2015)	Influence of Urban Microclimate on Air-Conditioning Energy Needs and Indoor Thermal Comfort in Houses	Hot -Humid climate	- Morphing approach is accurate when it is related to climate data collection as Air temperature and R.H. but in term of cooling load a margin of error is expected. - The increase of 1C° in ambient temperature will result in 14.2% increase in cooling energy load used for Air conditioning at the flat subject for study.	- Morphing approach - Software Simulation using Energy Plus.

S. de la Torre, C. Yousif. (2014)	Evaluation of chimney stack effect in a new brewery using Design Builder-Energy Plus software	Mediterranean climate	- During summer natural ventilation is not sufficient at its own to cool indoor spaces - At noon time forced ventilation is needed to cool down the facility - It was found that air temperature increase rapidly from top of the chimney downward by 10m.	Software Simulation using Design Builder & Energy Plus
Kwoka, Y. T., Laua, K. K. L., Laic, A. K. L., Chand, P. W., Lavafpoure, Y., Hob, J. C. K., & Nga, E. Y. Y. (2017)	A comparative study on the indoor thermal comfort and energy consumption of typical public rental housing types under near extreme summer conditions in Hong Kong	Sub-Tropical Climate	- It was confirmed that building envelope features such as U-Value and percentage of wall exposure have a direct effect on building energy consumption. - In poor -dense Urban communities it is essential to set design guidelines related to air velocity and R.H to ensure better living quality. - Further parametric studies are needed to supplement the conclusion of this research.	- Software simulation using - Design Builder v5 - Energy Plus v8.5
Amr Sayed Hassan Abdallah (2015)	The Influence of Urban Geometry on Thermal Comfort and Energy Consumption in Residential Building of Hot Arid Climate, Assiut, Egypt	Hot Arid Climate	- Canyon design effects solar radiation impacts over facade area. as deep canyon is quite comfortable but shallow canyons are completely not advisable in design. - Rooms that are facing deep canyons in El-Abrahimia complex records 11C˚ less than outdoor air temperature. - Deep canyons impact courtyard temperature as it decrees air temperature by 6-9C˚ which impacts the indoor temperature for rooms surrounding the courtyard.	Data field Measurements using - Thermo Recorder model TR72Ui - Hot wire anemometer model AM-4214SD

2.8 Research Questions

Based on an extensive literature review conducted on sustainable urban design in over-all, and outdoor thermal comfort in specific, these questions are emerged with ultimate hope that the research will answer them. The research questions are:

- What is the most favorable form of buildings and spaces between them that contribute to the urban thermal comfort in the UAE?
- What are the most significant microclimatic factors impacting the outdoor thermal comfort in UAE?
- What is the impact of the outdoor thermal comfort improvement on the indoor energy efficiency on urban community?
- What is the potential of applying the recommendations and how the UAE is the best in terms of sustainability practice among the Gulf Cooperation Council?

2.9 Research Limitations

After a review of literature in journals and articles that focused on outdoor thermal comfort and urban configuration, it was worth noting some limitations. One limitation was an inadequate holistic view of an urban configuration which included open space proportion, orientation, building form, and height and the influence these factors have on outdoor thermal comfort. The research that was included in the literature review had strong findings and evidence which were only linked to single relationships as opposed to being linked to these factors simultaneously.

It is worth noting that the study linked strategies for mitigating UHI to suitable urban design, especially in hot, arid climates. Another significant limitation was that there was very little literature on studies that were conducted on the impact of urban landscape factors focused on water features and types of vegetation (Hilaire et al., 2008). Many scholars from the literature review concentrated their research on the effects of softscape in outdoor thermal comfort conditions. The air temperature, humidity, comfort zone, and wind speed were some of the key findings. Outdoor thermal comfort was studied on how urban configuration had an impact according to the thermal indicators. Many journals have recently addressed the hot, arid climate, but very few have addressed how this climate has impacted urban configuration in the outdoor thermal comfort in Dubai. The aim of this research is to find the relationship between air temperature and wind conditions of different urban configurations while focusing on urban design and outdoor microclimatic conditions (Svedin, 2015).

According to Dubai municipality building regulation this project is in a zone where the maximum height allowed for the residential villas is G+1 therefore this study didn't include changing in the height of the residential unit within our proposed enhancement strategies.

CHAPTER 3
METHODOLOGY

3 Methodology

3.1 Overview

This chapter presents an analysis of the processes and steps which are followed. In all stages of the study, different methods, tools, and techniques should be used to ensure that the results of the study are valid. All these methods, tools, and techniques will be identified and critically justified. The complicated nature of the physical urban modelling coupled with the variable parameters that impact one another results in wasted time, which in turn causes a delay in the research (Driscoll, 2011). Nonetheless, there has been an increase in the number of urban planning professionals who have started to use this approach. The literature review shows that researchers utilised several methodologies due to the complex nature of parameters in some way impact the microclimatic variables and outdoor thermal comfort of urban areas. All the parameters connect and build upon one another; hence; complex software and tools were needed for the evaluation of the microclimatic variables. All the previous studies have used a methodology, whereby all of them have similar goals and objectives. Notably, the scientific methods of research that were used should be based on other researchers' attempts at conducting research in a similar field.

3.2 Methodology Literature Review

This part of the paper aims at discussing a literature review of the various research approaches and methodologies that are suitable to the matte of investigation. This literature review is based on various urban morphologies as well as the effect they have on outdoor thermal comfort. This format is solely because the research is about outdoor thermal comfort, which translates to the extent of the importance of urban morphologies. Urban morphologies are the study of the kind of human settlements coupled with the procedure that takes place during their formation and changes. This process has a direct impact on outdoor thermal comfort, which shows the reason as to why it should be investigated. In addition, the advantages and disadvantages of all the discussed methodologies and approaches will be presented. This discussion will help in justifying the selection of the best study approach for this study.

3.3 Methodologies for Similar Topics

Early research to investigate and assess indoor and outdoor thermal comfort mostly concentrated on wind speed and air temperature indicators. Several methodologies needed to be considered for use to significantly simplify the complexities of variable parameters which directly affect thermal comfort in outdoor and indoor settings on the research resources of each study (Walls et al., 2015). Acquiring an adequate overview of all the methods that have been used by other scholars and practitioners is important to arrive at similar goals and guarantee the quality of research that will be added in the area of thermal comfort (Bayulken & Huisingh, 2015).

The literature review in Chapter 2 identified two main approaches that should be considered for use to understand the relationship between various outdoor thermal comfort and urban morphologies when understanding the different parameters of the outdoor thermal behaviour of urban configurations. The first approach is the simulation, which been used widely for similar topics. The second approach is observation, which includes field measurement, and it has mostly been used for collaboration and validation (Kumar & Krob, 2005). There are two tools for the simulation approach, the estate environment evaluation (STEVE) and the ENVI-met model, which equates to the creation of real situations of urban configurations that effect outdoor thermal comfort. The methodological method that were sparingly used in this study are experimental methods, computer simulations, social surveys, and field measurements for outdoor parameter investigation. The methodologies that have been mentioned will need to be separately clarified while at the same time justifying the reasons why they were selected for the current investigation.

3.3.1 Observation Approach: Field Measurements

Driscoll (2011) stated that field measurements are one of the observation approaches that is mostly used by researchers for validation. In this section, vast information about the approach is provided by sample papers that made use of field measurements as the sole tool for their methodology. Using the sample papers helps in confirming whether it is wise to use field measurements or not. For instance, in situ data collection is showcased to be a crucial approach for most scientific research. It is a translation of the situation into data that can be further used in another research study. Therefore, this approach mostly complements the primary method used in a study (Centers for Disease Control and Prevention, 2008). However, this revelation does not mean that the field measurement approach is not essential, as it is also an important addition even though it may only be used as a complementary tool.

Various studies have utilised field measurements as a helping tool to the main methodology which they choose to use, which is usually computer simulation. Driscoll (2011) stated that field measurements used to be the primary source of input data needed for simulations. Studies carried out by Driscoll (2011) utilised field measurements to analyse various ways of creating effective courtyard building for the Netherlands' temperate climate. During his research, he used field measurement to validate the findings that were acquired from their choice of a methodology tool, the Design Builder. Their analysis was carried out while the courtyard house was conditioned on a free-running mode. This timing is advantageous because it helped in preventing the effect of cooling or heating in instances when one measures the temperature of the air of the courtyard building's internal rooms. This is shown in the figure 3.1.

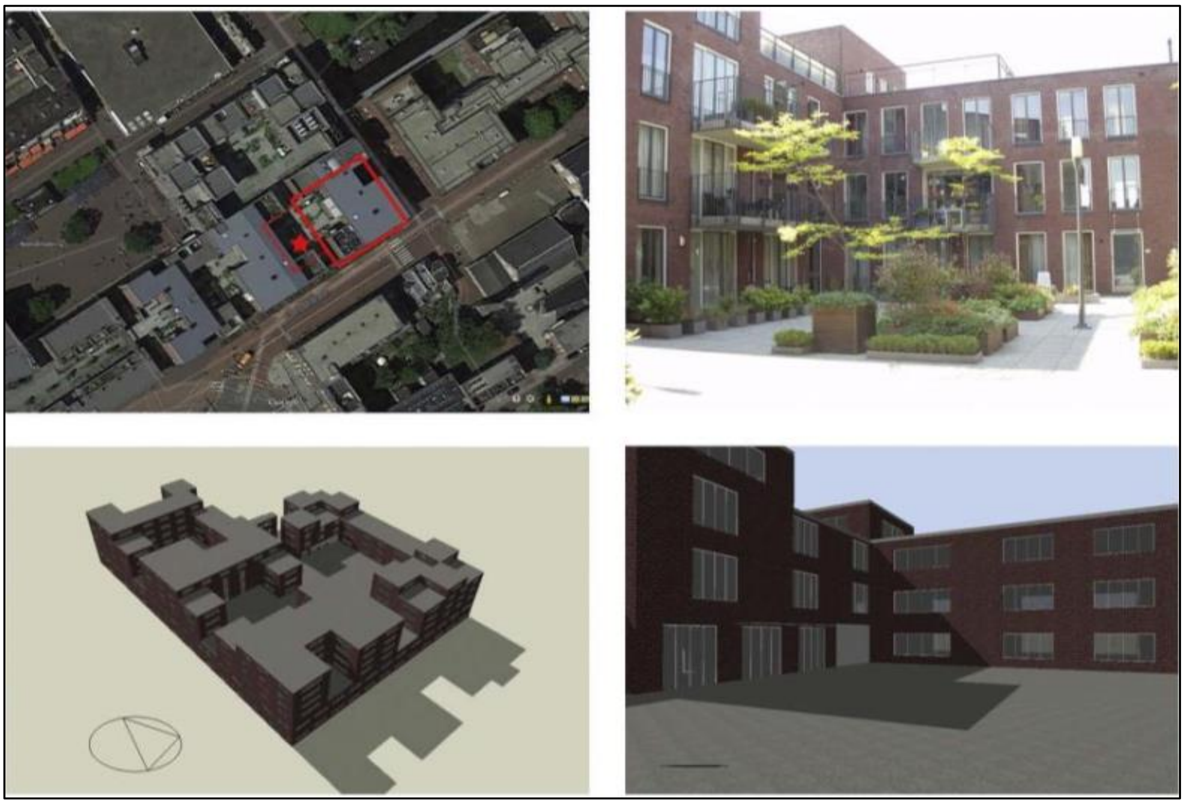


Figure 3.1: The view and location of the courtyard building (Source: Driscoll, 2011).

Field observation studies can be used distinctively to show theories and features. The preciseness of this specific approach is based on the accurateness of the tools of measurement. Some researchers prefer the field measurements, because they state that the method can be relied on due to its simple nature. In instances when the method is utilised in the investigation of a particular case, it puts into account the fact that the records of thermal comfort are predicted to cover all the different conditions of the climates. Measurements are expected to cover all the seasons of the year, without stopping in whichever season (Ozkeresteci et al., 2013).

The intervals of time that are needed in conducting research of some features is quite long. Measurements of the climatic records should be conducted with precision, especially in instances when the researchers are conducting tests on thermal comfort in outdoor urban spaces. Hence, the in-site survey becomes necessary and needs high levels of preciseness (Driscoll, 2011). In addition, the intervals of time regarding the data that is recorded in all the case studies take long periods of time. This extended period is essential because it facilitates acquiring valid measurements. In the field, the presence of various independent and dependent variables needs the researchers' vast awareness, regarding the way the variables can have an impact on the readings. The type of field measurements that analyse the complicated parameters of the outdoors have always been integrated to the simulation approach or social surveys.

3.3.2 Case Study Approach

The case study that was identified was the city of Tunis, Tunisia, with the climate identified as hot and arid. The two urban fabrics that were presented by this case study of Tunis where characterised by dense and compact fabric with winding and narrow streets. The buildings in these areas are grouped in clusters (Achour-Younsi & Kharrat, 2016). Close to the Medina of Tunis, the city is characterised by relatively high buildings which are organised in streets of medium width in an orthogonal grid. The sky factor view is an immediate measure of the solid angle when seen from an urban space. The photographic method is used to calculate the simple vector format (SVF) by taking pictures from a fish eye lens headed skyward to calculate the ratio between obstructions and the sky.

Masdar City in Abu Dhabi is another city which was considered as a case study of thermal comfort in determining comfortable conditions for a sustainable city. Exposure to the rays of the sun is the limiting factor for achieving thermal comfort in this city. The heat in indoor buildings in Masdar City gets released as soon as the wall temperature exceeds the temperature outside. As a result, there are high temperatures in the area.

3.3.3 Simulation Approach: Numerical Model Tool

The BES City Sim is a numerical simulation tool that model's energy fluxes in towns and cities of different sizes, ranging from an entire city to a small neighbourhood, and this type of simulation was conducted in a study by Kumar and Krob (2005). Urban heat fluxes were evaluated for different urban morphologies for the climate of the specific area in Saudi Arabia. The current version of the City Sim is not able to calculate convective heat transfer coefficient (CHTC); consequently, simulations of computational fluid dynamics are hard to carry out using City Sim. The disadvantage of using BES is that the system limits the number of building morphologies for computational resources that are available and required for the computation fluid simulations. This tool is advantageous as it has highly spatial-resolved flow fields and temperature. As a result, it can easily determine heat fluxes. Convective and turbulent fluxes are greatly considered in this research study (Bayulken & Huisingh, 2015). The results show the essence of the strong influence of buildings upstream on temperature and heat fluxes, and buoyancy for low wind speed cases.

It is difficult to understand or use numerical simulation for non-scientists, even if they are educated, and therefore, this tool is beneficial in studies which are limited to the domain of academics. However, the support and involvement of scientists in this study are important as it helps urban planners. The simulation results that have been obtained from occupational software is easy to understand and simple (Velikov & Thün, 2013). The best programs that apply to this topic are STEVE and ENVI-met.

3.3.4 Simulation Approach: Computer Simulation Tool

I. ENVI-met Software

The ENVI-met model that has been considered for this study is a three-dimensional microclimate model which has been designed in such a way that it mimics the relationship between plant, surface, and the air in an urban environment, including the application of urban areas, architectural factors, and landscaping. The ENVI-met uses predictive modelling in line with fundamental laws of thermal dynamics and fluid dynamics (Marshall-Ponting, 2008). The software can carry out simulations of the effects of hardscaping and softscaping, bioclimatology of the local climate, building physics, and air ventilation between and around buildings. The calculation of heat exchange processes at building walls and ground surface, and the ENVI-met software can examine mass and heat exchanges to other surfaces. More than 5,000 simulations over the past 2 decades have been conducted in more than 150 countries using the ENVI-met model, figure 3.2 shows a holistic image of Envi-met software capability.

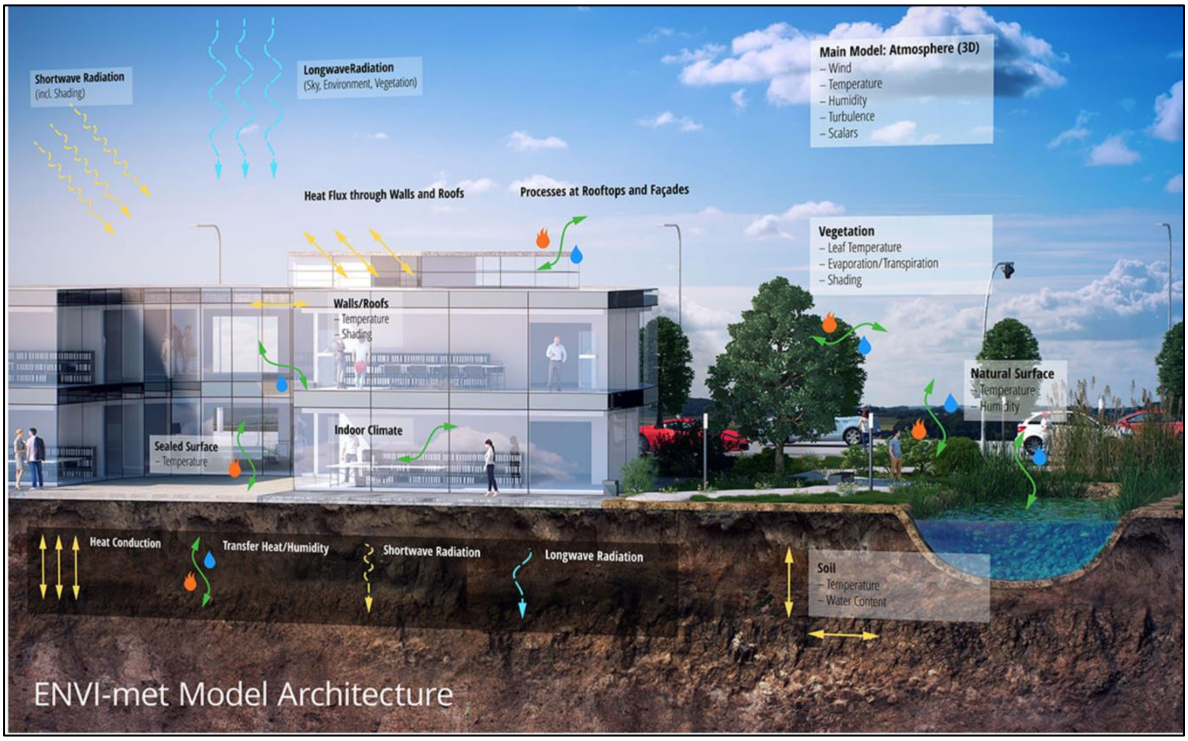


Figure 3.2:An image of ENVI-met, a holistic microclimate model (Source: http://www.envi-met.com, 2017).

Scholars and practitioners have used the ENVI-met model for the examination of indoor and outdoor thermal comfort parameters and the values of mean radiant temperature, solar radiation, relative humidity and air temperature which were validated against experimentally measured values in the field. The calculations of the ENVI-met are significantly influenced by the nest area and size of the grid calculated on an x-y axis. The specified grid distance dictates the required resolution for analysis of large and small-scale connections between surfaces, plants, and buildings (Bayulken & Huisingh, 2015). Two sets of applications characterise ENVI-met: helper applications and core applications. The application set comprises of ENVI-met Core, LEONARDO, Headquarter, BioMet, and Spaces. Building the main model for the applications are time-consuming. The other core application set consists of Alberto, Eagle Eye, Projects Organize, DB Manager, Project Wizards, and Manage Workspaces. They are viewed as smaller applications in comparison to the first set but critical in the simulation (Taleb & Taleb, 2012). The ENVI-met model has been employed in numerous studies in the evaluation of outdoor thermal comfort and microclimatic conditions. This model was used widely to assess greenery and landscape in examining the amount of water that is absorbed by various types of vegetation and trees and how they affect soil balance. Other morphological features apart from studies of the landscaping have also been studied using the ENVI-met model.

Addressing the effectiveness of a form of urban configurations and physical density on urban ventilation, surface ambient temperature, and outdoor thermal comfort and external heat gain would provide a basis for comprehensive investigation in the analysis of urban microclimate (Velikov & Thün, 2013). The study focused on urban areas in commercial office buildings in Singapore with some 6 buildings in a total area of 65,000 square meters on a plot area of 10 ha. The height of the six buildings was unified to simplify the analysis, and SVF were calculated for the buildings.

II. Developed ENVI-met 4.0

Huttner, Bruse, and Dostal (2010) stated that there have been developments in this field of study, and the introduction of the ENVI-met version 4.0 has various advantages. Undoubtedly, it is the last beta configuration, which translates to the fact that it has been improved severely. Therefore, it has some improvements more advantages as compared to all other versions. The introduction of this new version has made it a possibility to acquire more precise representations of the elements of architecture, setting various materials for all façade roof elements and ground with 3D representations of various configurations of buildings

(Bruse, 2009), figure 3.3 present a comparison the values of MRT and air temperature predicted through ENVI-met 3.1 and ENVI-met 4.0.

The quality of the architectural presentations has also improved, coupled with the properties' façade treatment (Ozkeresteci et al., 2013). Apart from the changes of atmospheric boundary conditions, the configuration file is the same as the one belonging to the software's previous versions. The new features also include "Forcing", which enables meteorological scenarios for relative humidity and air temperature.

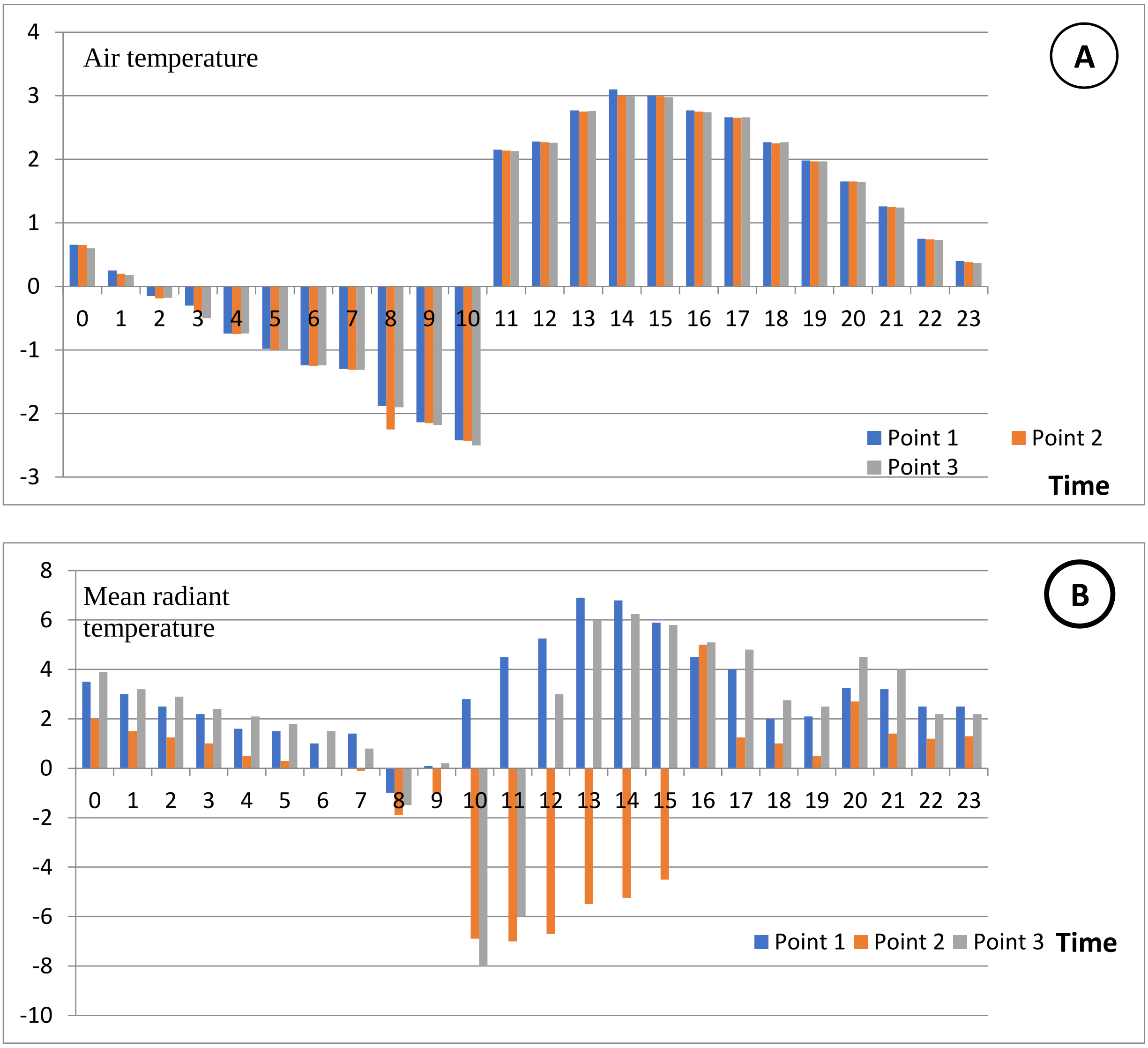


Figure 3.3:Comparing the values of air temperature (A) and MRT (B) predicted through ENVI-met 3.1 and ENVI-met 4.0 (Adapted from Bruse, 2009).

III. Estate Environment Evaluation (STEVE) Model

STEVE is a web application that calculates the temperature averages of the points of interest for future conditions, as well as the conditions already in existence (Ozkeresteci et al., 2013). An example of future conditions is the master plans or proposed conditions for an estate. At any point, the temperatures are the result of the environments in the buffer zones. From STEVE, the output data utilises the geographic information system (GIS) database in the production of a raster map of variances in temperature in a certain estate.

Through trial and error, the STEVE model has been developed to predict the temperature of the air at the estates based on the conditions of the climate as well as the urban features of the morphology. Hien et al. (2011) used the STEVE tool to show a more inclusive microclimate examination on a precinct by investigating various components. The findings of this study were integrated with outdoor temperatures, which had an overall impact on the building's energy performance.

IV. Comparison of ENVI-met and STEVE (Outdoor Level)

Two computational software programs are used in the prediction of outdoor thermal comfort and temperature for specific urban settings in buffer zones: ENVI-met and STEVE. ENVI-met utilises a local model of air quality and computational fluid dynamics that is based on the microclimate to come up with computations of temperature in time intervals of one to two days (Huttner et al., 2010). In contrast, STEVE uses GIS data for the output data in the production of a raster map locations, (Ahmed. A. and Abu-Hijleh B, 2016).

Most of the variations are in relation to the climate variables, such as surface temperature and the speed of wind. STEVE solely makes calculations of temperature at the eye level, while ENVI-met makes calculations on air temperature at varying heights. Ozkeresteci et al. (2013) asserted that the calculations in ENVI-met consider the speed of wind as being inconstant, while in STEVE, the speed of wind is considered constant on exact days. Regarding the quality of maps, ENVI-met's generated raster maps are based on grid pixels' figure 3.4, (Hien et al. 2012).

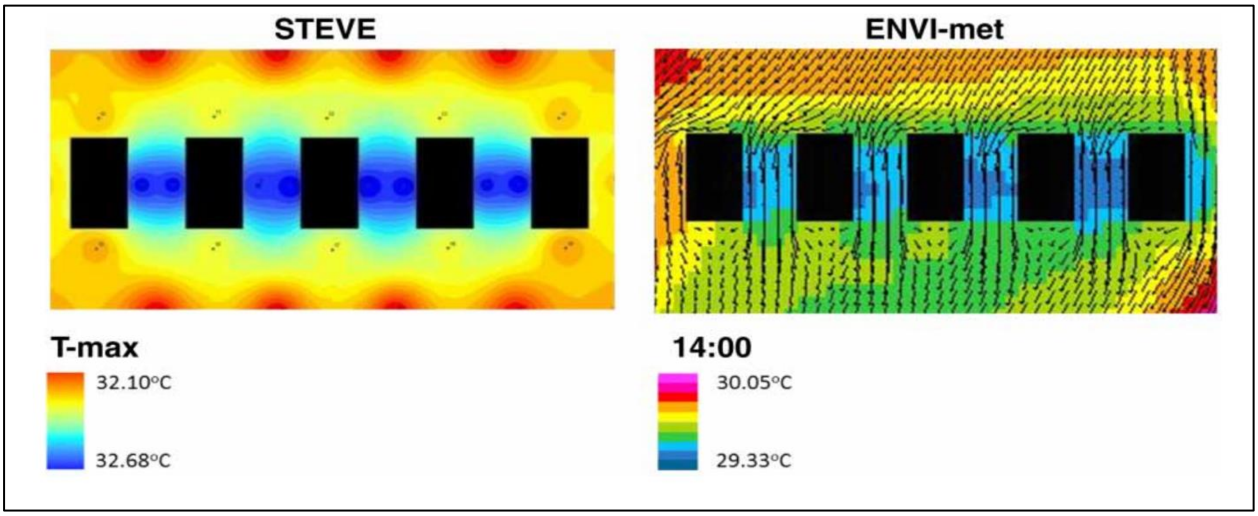


Figure 3.4: STEVE and ENVI-met temperature map (afternoon) result comparison (Hien et al. 2012).

This is a better resolution when compared to that of STEVE, because these ones are acquired based on buffer zones whereby the diameter is specified table 3.1present a comparison between Envi-met and STEVE.

Table 3.1: Compression between Envi-met and STEVE, (Ahmed. A. and Abu-Hijleh B, 2016).

Factors	STEVE	ENVI-met
Base	GIS	Computational Fluid Dynamics (CFD)
Wind speed	Considered as a constant	Wind speed within specific day is inconstant
Map output	Low resolution raster map, based on buffer zone with specified diameter	High resolution raster map
Height of air temperature readings	Based on pedestrian eye-height only	Generated for different heights
Validation	With field measurements in Singapore	With field measurements in 24 different countries

V. Comparison of ENVI-met and IES (Indoor Level)

ENVI-met uses both shortwave diffuse and shortwave direct radiation components, and clouds can be included. ENVI-met model is designed for local air quality and microclimate analyses. The model can solve three-dimensional flows, including complex turbulence fields, short- and long-wave radiation, temperature, and relative humidity (Roset, Calzada, & Vidmar, 2013). IES, on the other hand, is a cutting-edge suite of simulation tools for building performance. Building experts around the world use the tool as it creates an understanding of the performance effects of low-energy design strategies that are different.

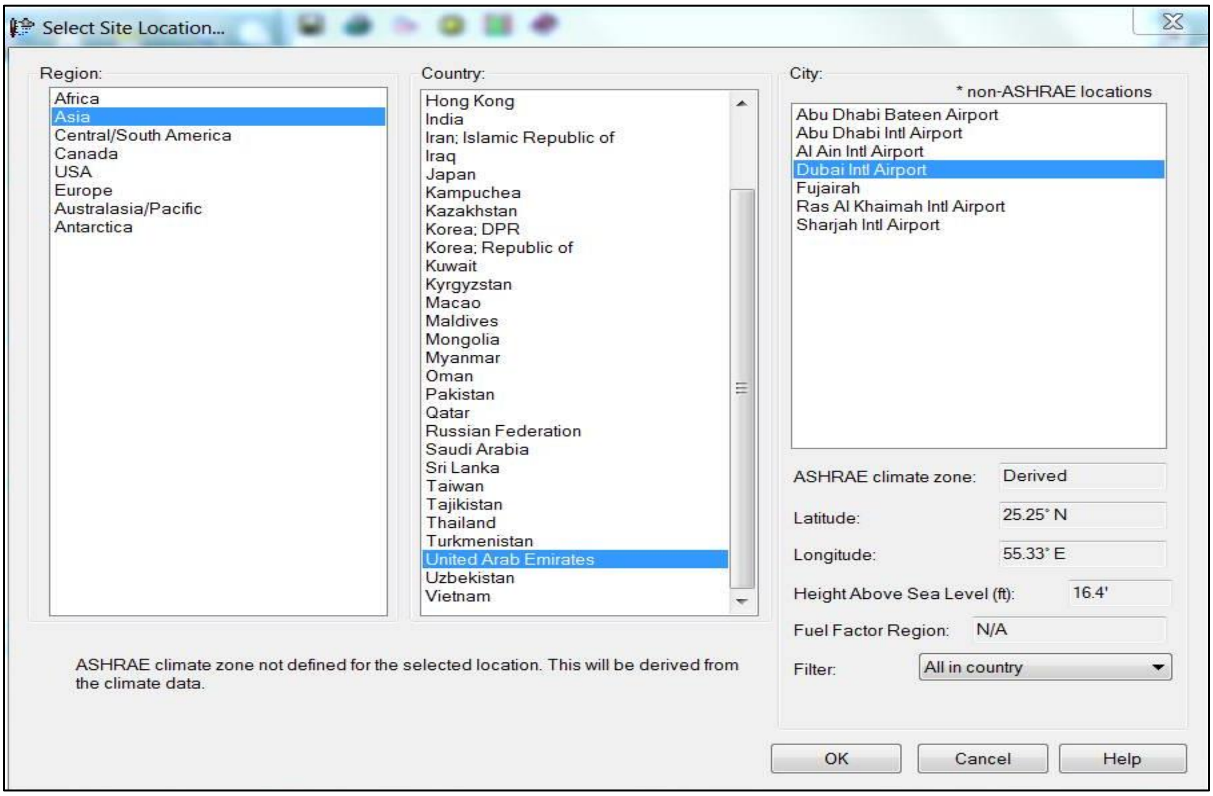
VI. Comparison of ENVI-met and Design Builder Software (indoor level)

Design Builder is very user-friendly and provides a modelling environment where one can integrate with building models. The software provides a wide range of data on environmental recital including energy consumption, inner comfort data and HVAC module sizes. Design Builder uses Energy Plus simulation engine and provides an output based on detailed sub-hourly simulation time steps. The software can, therefore, be used for simulations of various HVAC types, buildings with day-lighting control, naturally ventilated buildings, advanced solar shading strategies, and double facades among others. ENVI-met also utilizes shortwave diffuse and direct radiation components but also provides for the inclusion of clouds unlike Design Builder (Roset Calzada, & Vidmar, 2013). The model is designed mainly for analyses concerning local air quality and microclimate. ENVI-met can solve complex three-dimensional flows (turbulence fields), short/long wave radiation, and relative humidity, and temperature.

VII. Comparison of IES-VE and Design Builder Software (indoor level)

On the other hand, IES-VE is another programme commonly used to valuate indoor thermal statues as well as energy consumption and other environmental parameters. Both softwares are using the same weather files built in at their data base which is related to Abu Dhabi but, IES-VE has other files related to UAE climate range also built in the data base yet it does not necessary complies with ASHRAE standards as noted by the programme see figure 3.5 that indicate Dubai location does not defined ASHRAE climate zone which will impact the climate data recorded at the data base. The same thing goes for other cities like Sharjah and Al Ain and all other cities shown at figure 3.5, even though the latitude and longitude is specified correctly.

Figure 3.5: IES software interface indicate the weather file data location for Dubai (IES-VE software, 2017).



But it was noticed that by selecting Abu Dhabi International airport as a location the programme does not show the note that were addressed earlier as seen in figure 3.5.

Figure 3.6 indicates that Abu Dhabi International airport is a standard ASHRAE location as well as Bateen Airport located in Abu Dhabi as well see figure 3.7 it is noted that the latitude and longitude in addition to the height from sea level all are mentioned and noted for each city, yet ASHRAE Climate zone was indicated only for Abu Dhabi area referred to as one.

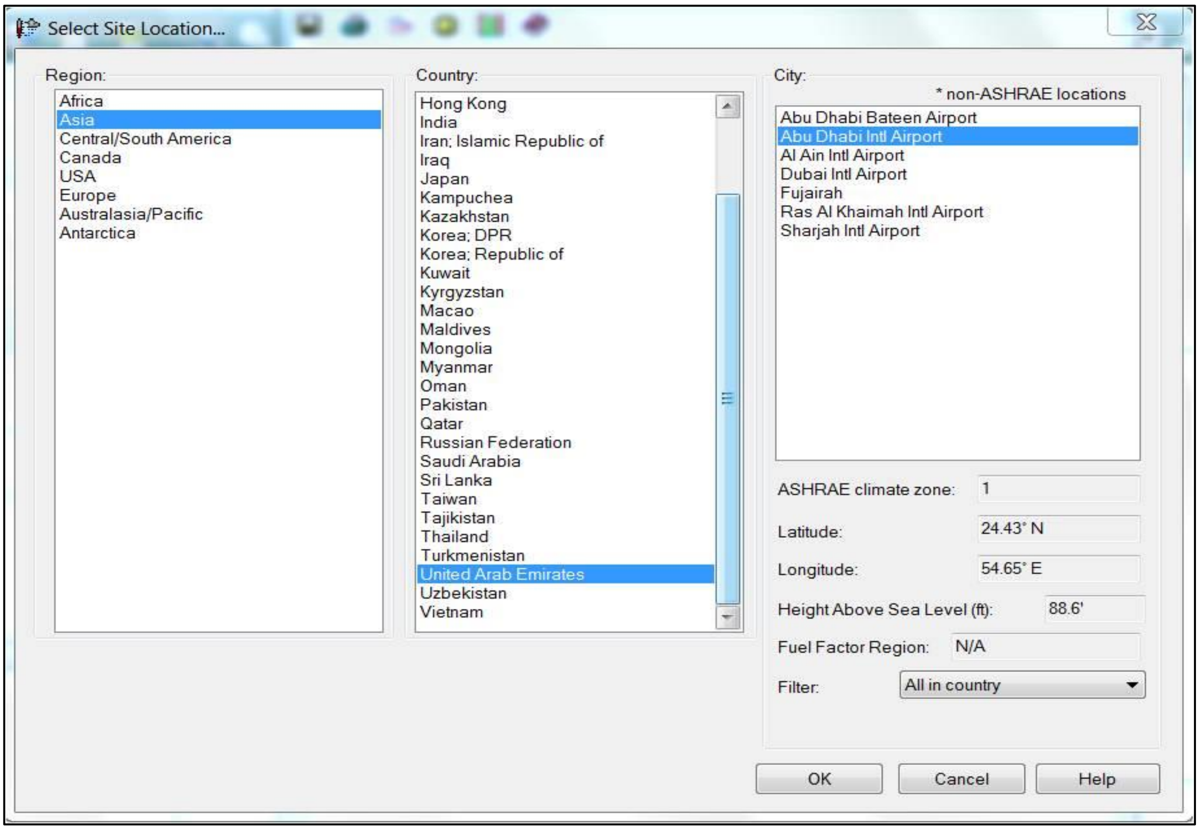


Figure 3.6: IES software interface indicate the weather file data location for Abu-Dhabi (IES-VE software, 2017).

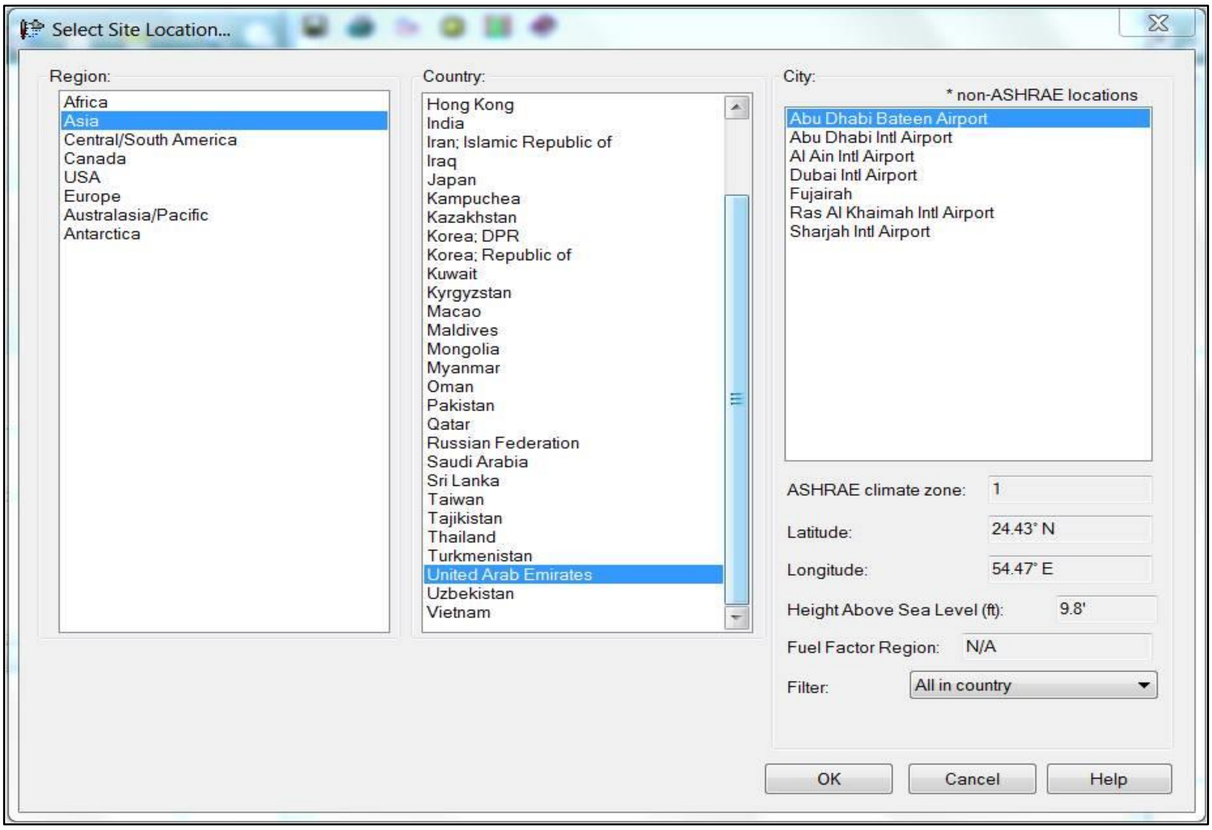


Figure 3.7: IES software interface indicate the weather file data location for Abu-Dhabi (IES-VE software, 2017).

Even though both programs allow modification over the temperature and other initial weather data allow users to change initial temperature to meet any other recorded data used at the research that can help in calibration process for the virtual model results.

The same thing with IES-VE as it also allows users to modify basic weather files regarding Dry-Bulb temperature or wet-Bulb temperature, as well monthly data as seen figure 3.8 that is like Design Builder.

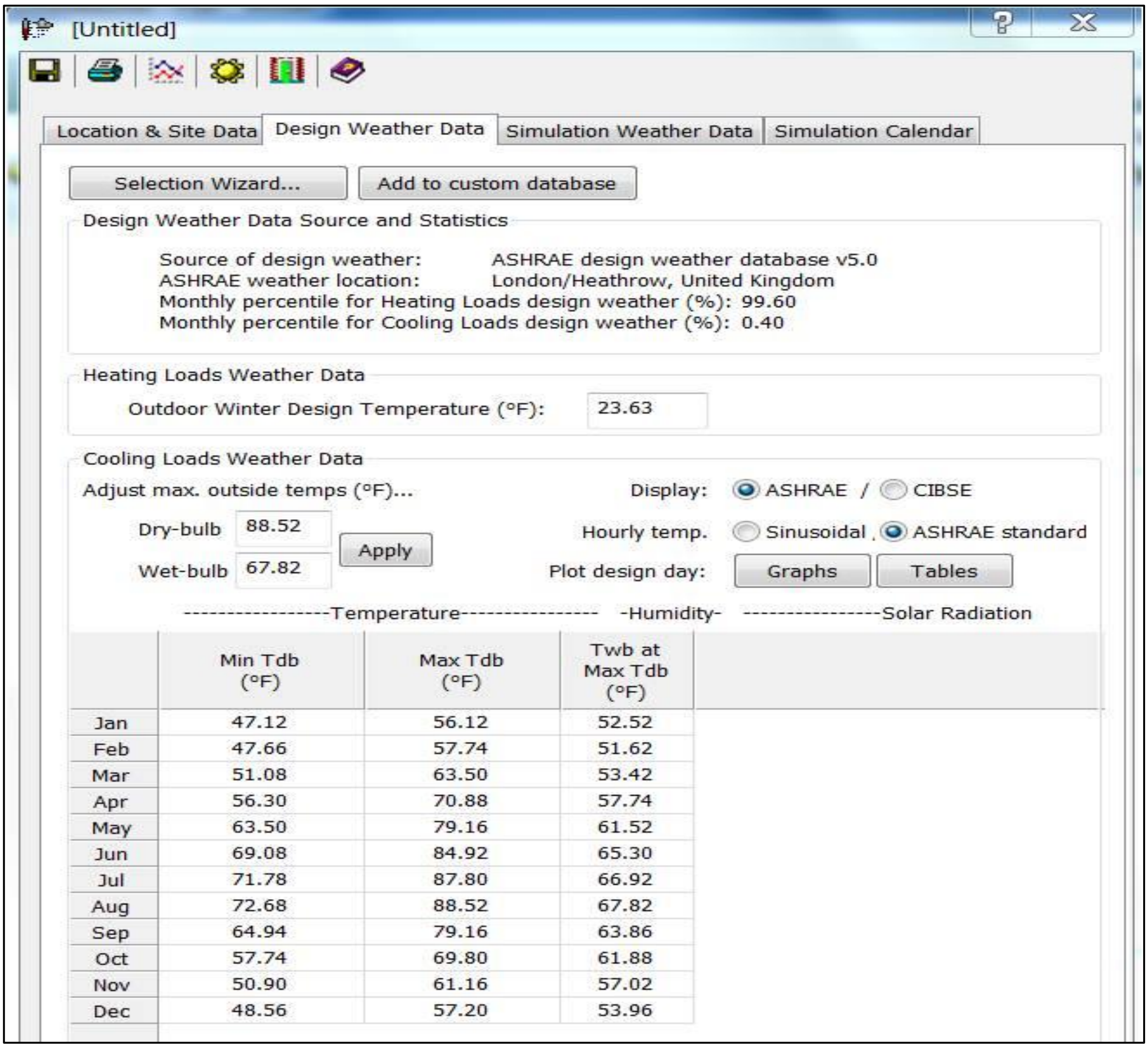


Figure 3.8: IES software interface indicate the capability of changing the weather data (IES-VE, 2017).

But in IES-VE the next step after selecting the location and modifying the initial weather data as seen earlier it is required to select Nearest weather file were a list of cities surrounding the selected location will be shown as saved weather files saved in the data base of the programme and will be linked to the working, file, see figure 3.9. It was noted that the only weather file close to Dubai is Abu Dhabi. This indeed raised a red flag even though Design Builder also presents Abu Dhabi as the only city in UAE recorded at its Data base but further investigation was carried by comparing air temperature in June23 the date subject for this research using both programmes with the initial weather files built in without any modification.

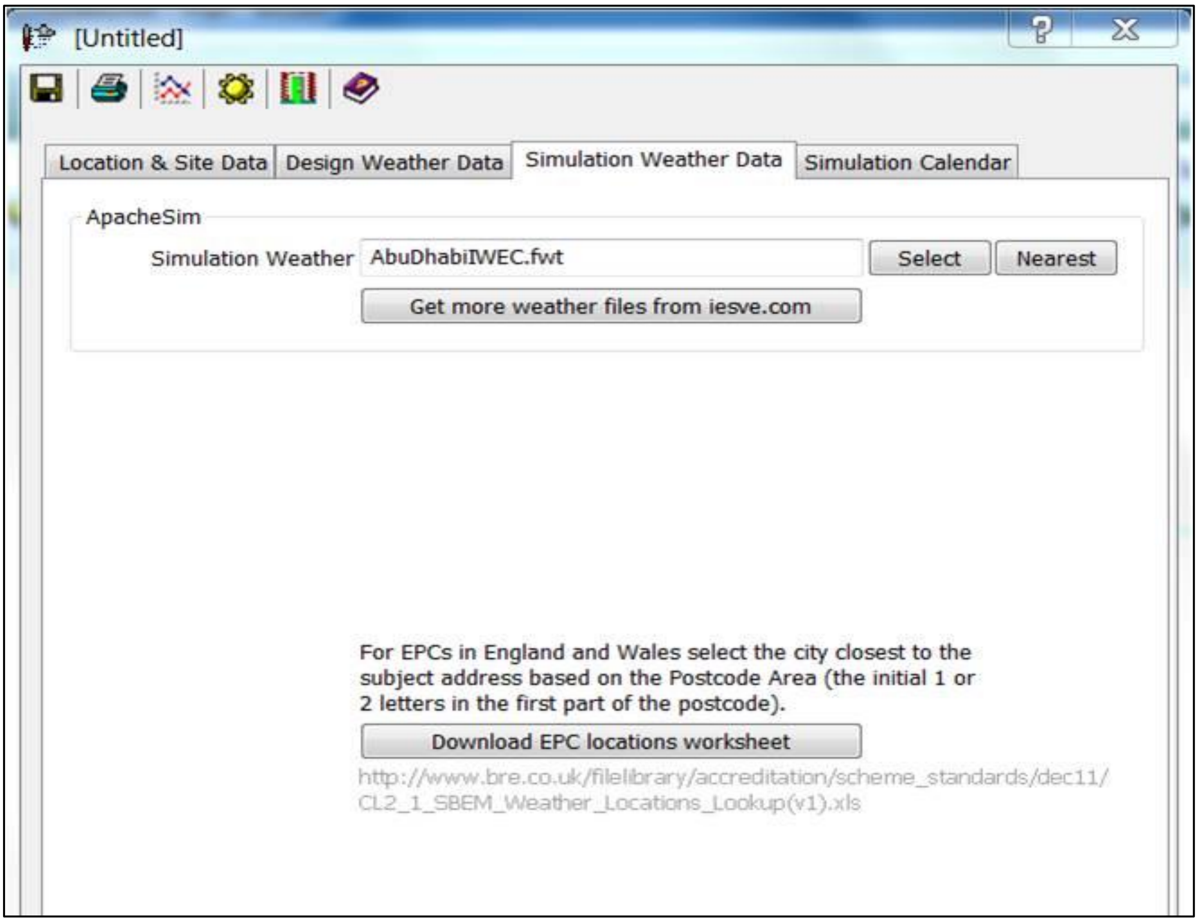
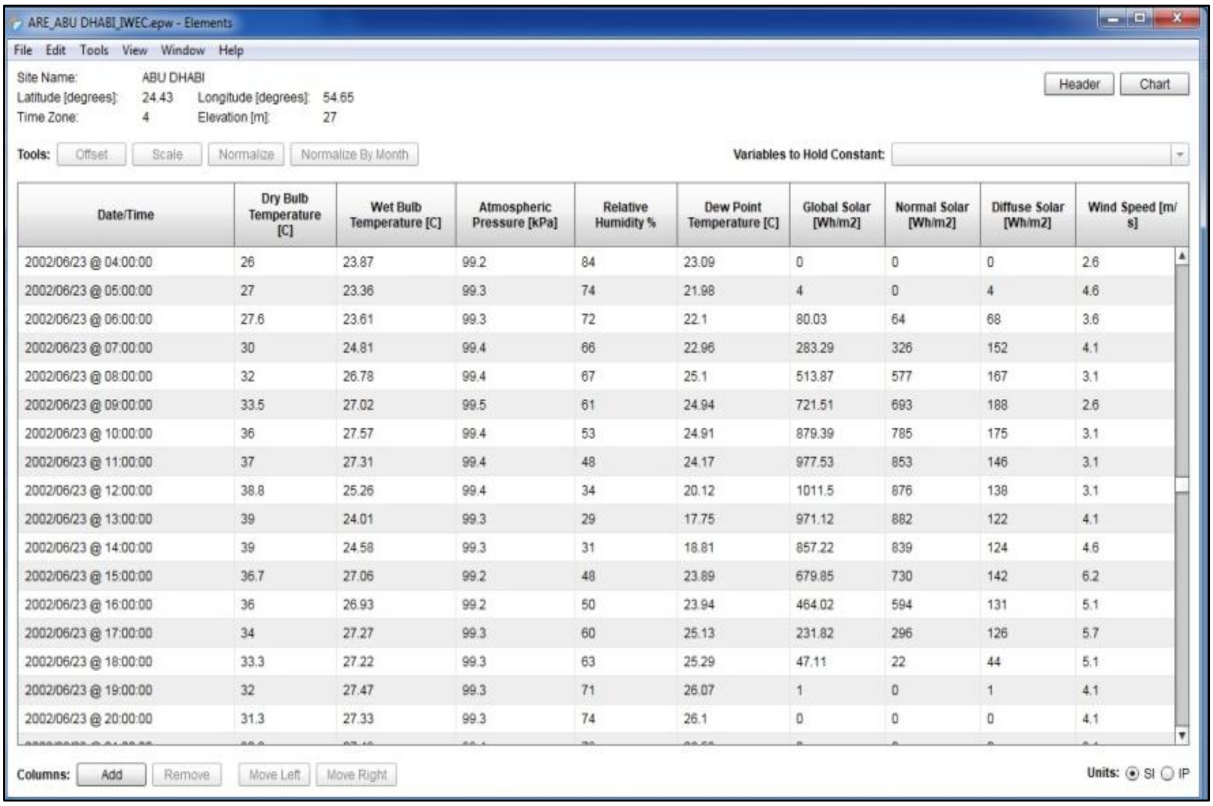


Figure 3.9:Nearest weather file were in a list of cities surrounding the selected location (IES-VE, 2017).

Design Builder shows that on 23 June at 12:00 the air temperature was 38.8C˚ that is 10 degrees less that the temperature collected at the site visit on the same day and same hour see figure 3.10 also on 15:00 the Design builder record shows the air temperature as 36.8C˚ that is 13 degree less than the temperature recorded on site visit. It is believed that this difference because Abu Dhabi has a higher percentage of humidity therefore the programme is referring to Abu Dhabi based on its built in the weather file.



Date/Time	Dry Bulb Temperature [C]	Wet Bulb Temperature [C]	Atmospheric Pressure [kPa]	Relative Humidity %	Dew Point Temperature [C]	Global Solar [Wh/m2]	Normal Solar [Wh/m2]	Diffuse Solar [Wh/m2]	Wind Speed [m/s]
2002/06/23 @ 04:00:00	26	23.87	99.2	84	23.09	0	0	0	2.6
2002/06/23 @ 05:00:00	27	23.36	99.3	74	21.98	4	0	4	4.6
2002/06/23 @ 06:00:00	27.6	23.61	99.3	72	22.1	80.03	64	68	3.6
2002/06/23 @ 07:00:00	30	24.81	99.4	66	22.96	283.29	326	152	4.1
2002/06/23 @ 08:00:00	32	26.78	99.4	67	25.1	513.87	577	167	3.1
2002/06/23 @ 09:00:00	33.5	27.02	99.5	61	24.94	721.51	693	188	2.6
2002/06/23 @ 10:00:00	36	27.57	99.4	53	24.91	879.39	785	175	3.1
2002/06/23 @ 11:00:00	37	27.31	99.4	48	24.17	977.53	853	146	3.1
2002/06/23 @ 12:00:00	38.8	25.26	99.4	34	20.12	1011.5	876	138	3.1
2002/06/23 @ 13:00:00	39	24.01	99.3	29	17.75	971.12	882	122	4.1
2002/06/23 @ 14:00:00	39	24.58	99.3	31	18.81	857.22	839	124	4.6
2002/06/23 @ 15:00:00	36.7	27.06	99.2	48	23.89	679.85	730	142	6.2
2002/06/23 @ 16:00:00	36	26.93	99.2	50	23.94	464.02	594	131	5.1
2002/06/23 @ 17:00:00	34	27.27	99.3	60	25.13	231.82	296	126	5.7
2002/06/23 @ 18:00:00	33.3	27.22	99.3	63	25.29	47.11	22	44	5.1
2002/06/23 @ 19:00:00	32	27.47	99.3	71	26.07	1	0	1	4.1
2002/06/23 @ 20:00:00	31.3	27.33	99.3	74	26.1	0	0	0	4.1

Figure 3.10: DesignBuilder weather data record for 23th of June 2016 (DesignBuilder, 2017).

On the other hand, IES-VE is showing one degree less in air temperature value at 12:00 on the same day and almost 3 degrees’ difference at 15:00 see figure 3.11 below. while same weather file of Abu Dhabi city that is built in and saved at the programme data base is used.

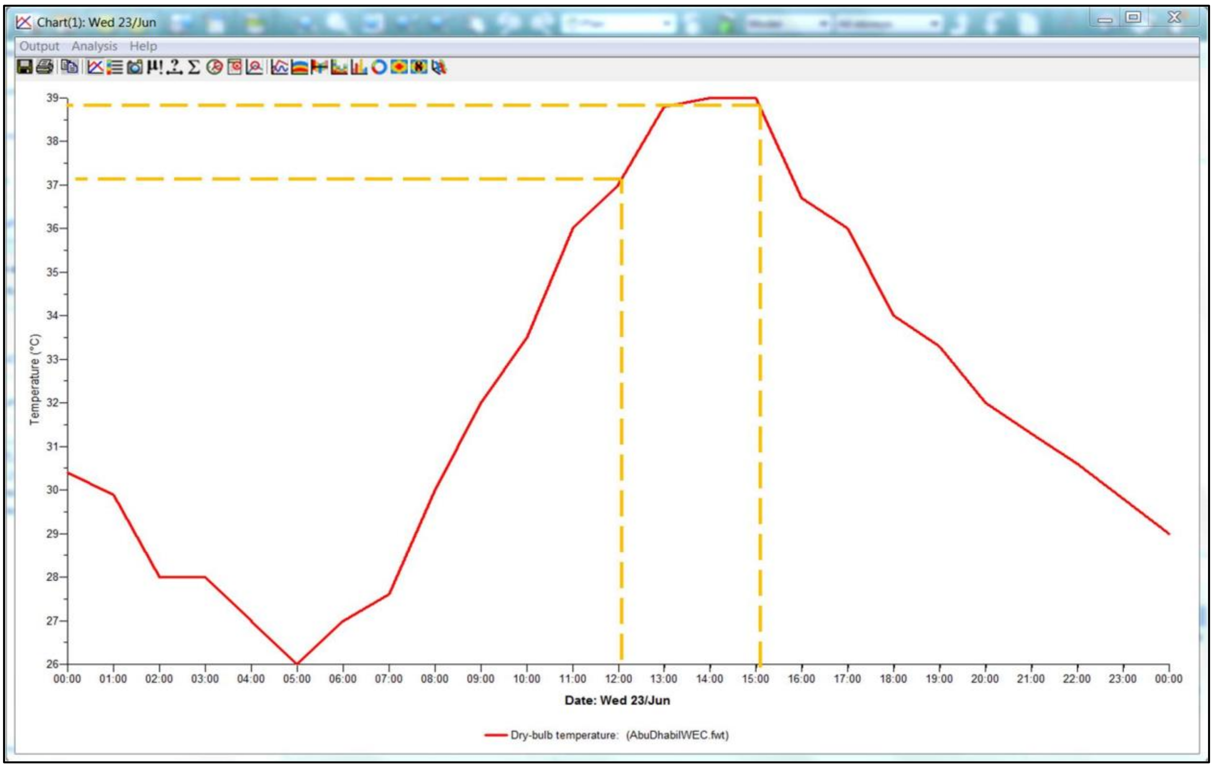


Figure 3.11: IES-VE weather data record for 23th of June 2016 (IES-VE, 2017).

This step was needed in the calibration process yet it was concluded that using Design Builder will allow users to input weather data recorded from site visit and Ministry of presidential affairs-The National centre of meteorology without any doubt of the impact of built in files as the case in IES-VE that insist on linking the recorded weather file to the working file used to build the virtual model. This conclusion meets the work of Kwok et al. (2017) and Chung et al. (2015) and Boafo et al. (2015) where Design Builder was used as reliable programme to evaluate indoor energy consumption as well as thermal comfort. Therefore, this research will proceed by using Design Builder Version 000 at phase five were indoor energy consumption is evaluated and studied.

3.4 Adapted Methodology for This Research

3.4.1 Methodology Selection and Software Selection

It is quite evident that there are several differences of the various methodologies, whereby the chosen main study in this research is computer simulation. The research methodology has been divided into two stages. The first stage is software validation using modelling with applications, whereby the researchers then adapt a simulation process to acquire the expected findings. The second stage is different from the first, as it entails the analysis of the obtained data. There exist several reasons as to why the most preferred methodology is simulation, and the reasons will be discussed in this section. Furthermore, there will be a validation of the software, to make sure of the preciseness and capability of the ENVI-met and DesignBuilder as the main simulation tools.

Elnabawi, Hamza, and Dudek (2013) noted that there is an increasing interest in the global scientific community regarding outdoor thermal comfort and microclimates, and this paper will mainly focus on the software ENVI-met. Huttner et al. (2010) further stipulated that it is a non-hydrostatic model which is three-dimensional and is used to simulate plant, surface, and air interactions. Furthermore, researchers use ENVI-met to analyse urban environments and examine the microclimate that emanates from various urban morphologies. Bruse (2010) further stated that urban morphologies either have a positive or a negative impact on microclimates in urban outdoors and that it is important to study this by using the non-hydrostatic model.

3.4.2 Methodology Justification

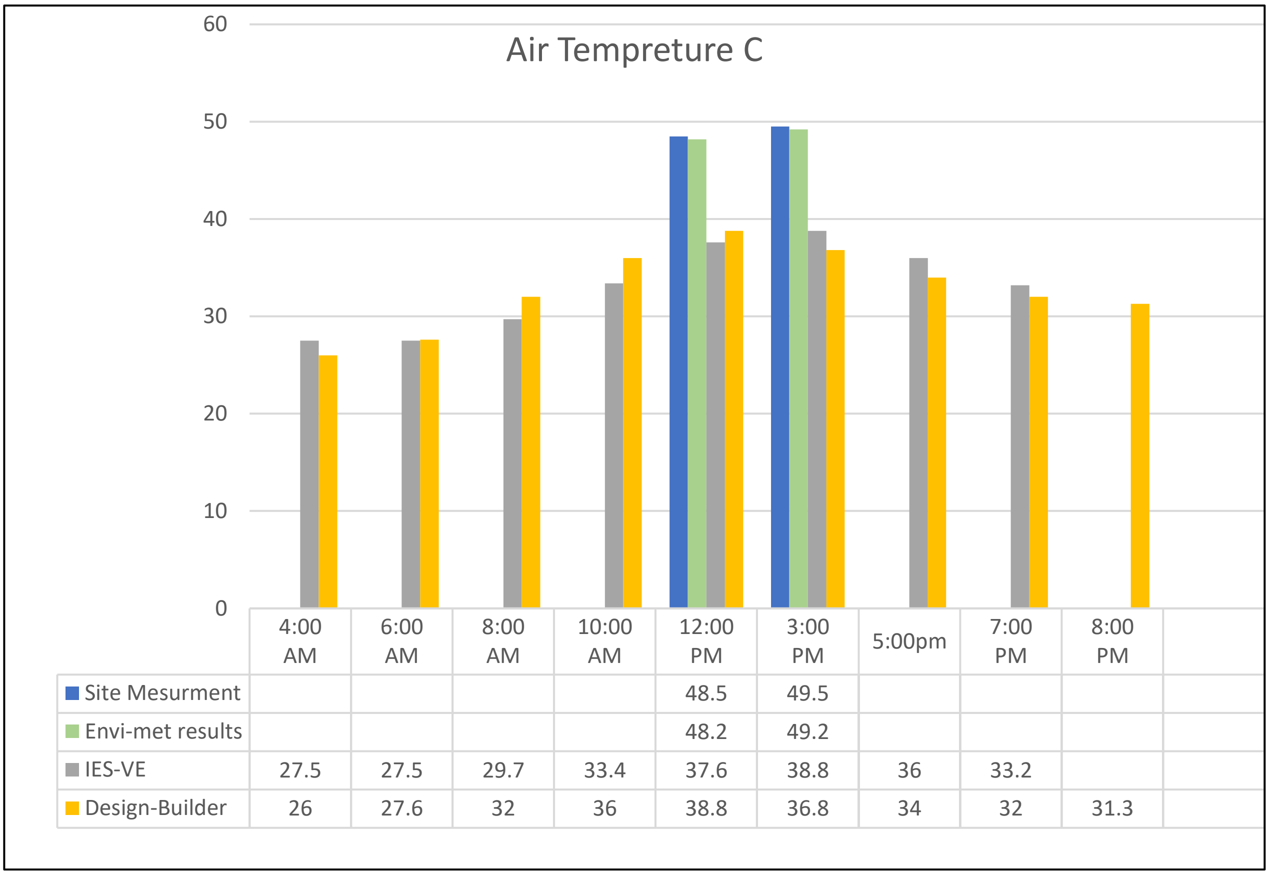
The preferred method for examining the impact of different urban configurations on indoor and outdoor thermal comfort is computer simulation because of efficiency and time factors. Design strategies have been proposed by this research to investigate the optimal urban configurations focusing on thermal behaviour for different configurations (Velikov & Thün, 2013). One of the configurations is for outdoors and the second for indoor thermal comfort, while the others focus on a hypothetical situation according to the recommendations written by (Johansson et al., 2014). Field measurements in this research methodology are not practical since the research needs to be conducted in different locations over a long period and the other hypothetical basis for urban configurations need to be found. This research focused on numerous urban configurations in sites that already existed to arrive at results that were valuable.

Another factor for consideration is the impact of cost: human resources and field measurement equipment for data collection have a cost impact which is not directly applicable to this current research. With the proposed urban configurations, over-simplified models and numerical approaches are not applicable since the parameters involved in evaluating the outdoor and indoor thermal comfort are complex (Barrett et al., 2004). The development of a more realistic model is enabled by computer simulation of the potential conditions and concentrates simultaneously on the impacts of multiple variables (Johansson et al., 2014). Computer simulation provides a cheaper and faster means to research the impacts of urban greenery and is a methodological solution that is sustainable considering the resources that have been made available in this research.

To acquire efficient and valuable research within a limited timeframe, the methodology that was considered was the computational tool. The ENVI-met model was considered in the simulation of different urban configurations in the analysis of outdoor thermal parameters which influence human comfort in arid and hot climates. And DesignBuilder was chosen for the indoor level energy consumption. An experimental measurement process consumes a lot of time as well as being costly to get results that are valuable, while the formulation of mathematical equations is made simpler by the numerical models. The preferred and considered methodology is the three-dimensional computational simulation for the investigation of urban design parameters. The urban area that has been selected for this research is in Dubai (Taleb & Taleb, 2012). For the simulation, summer climatic conditions are selected in the period that is considered the most comfortable in arid and hot regions. Numerical and field measurement models have been used in the validation of results that have been acquired from using the ENVI-met models.

To make sure of selecting the most accurate software for both indoor and outdoor analysis, software validation and calibration was studied using the weather data file from each software and comparing them to the real measurements collected at the site visit, figure 3.11 shows the three softwars's air temperature data in 23th of June comparing to the real site readings. The graph indicate that ENVI-met is the most accurate software in terms of the real site measurement so it was chosen to be the outdoor parameters analysis.

Although, DesignBuilder software showed a big difference between the weather data file and the real measurements, DesignBuilder allows the user to enter the weather data manually which make it the best option for the indoor analysis



	4:00 AM	6:00 AM	8:00 AM	10:00 AM	12:00 PM	3:00 PM	5:00pm	7:00 PM	8:00 PM
Site Mesurment					48.5	49.5			
Envi-met results					48.2	49.2			
IES-VE	27.5	27.5	29.7	33.4	37.6	38.8	36	33.2	
Design-Builder	26	27.6	32	36	38.8	36.8	34	32	31.3

Figure 3.11: Software calibration using the weather data files from ENVI-met,IES-VE and DesignBuilder compared to the real site measurements.

3.5 Methodology Validation

3.5.1 Envi-met Validation

Several studies have tested the validity of ENVI-met software. The studies mainly conducted comparisons of the simulation results acquired from the software against the measured figures for the same place and time of input data for simulation. Bruse (2009) carried out a validation of the ENVI-met software with findings for various micrometeorological parameters, and the PMV was derived from ENVI-met and validated against experimental values measured while in the field during different times and locations. There was preciseness of the chosen mesh grid, which had dimensions of 2x2 square meters, and the researchers did not note any significant deviations.

The most significant differences that were recorded of the international radiation was estimated to be 10% while the temperature of the air was 0.6% and the MRT was 0.9% (Ozkeresteci et al., 2013). On the other hand, there were negligible values when it came to the differences in the values of the relative humidity. The simulation is executed by the software under the ideal situation of a cloudless sky (Hien et al., 2011).

The capability of the software in the evaluation of outdoor thermal comfort is analysed, and the findings are compared to a conducted field survey with random sample of individuals who answer questions asking about their thermal views and who take part in answering structured questionnaires. The participants to the study stood within three meters of the chosen points, and then the researchers conducted micrometeorological measurements at a height of 1.1 m. The steps used followed the ASHRAE seven-point scale that ENVI-met used for PMV. The figure below shows more details of the scale and makes it easy to comprehend. The scale ran from -3 (cold), to -2 (cool), -1 (slightly cool), 0 (neutral) +1 (slightly warm), +2 (warm), and +3 (hot), figure 3.12.

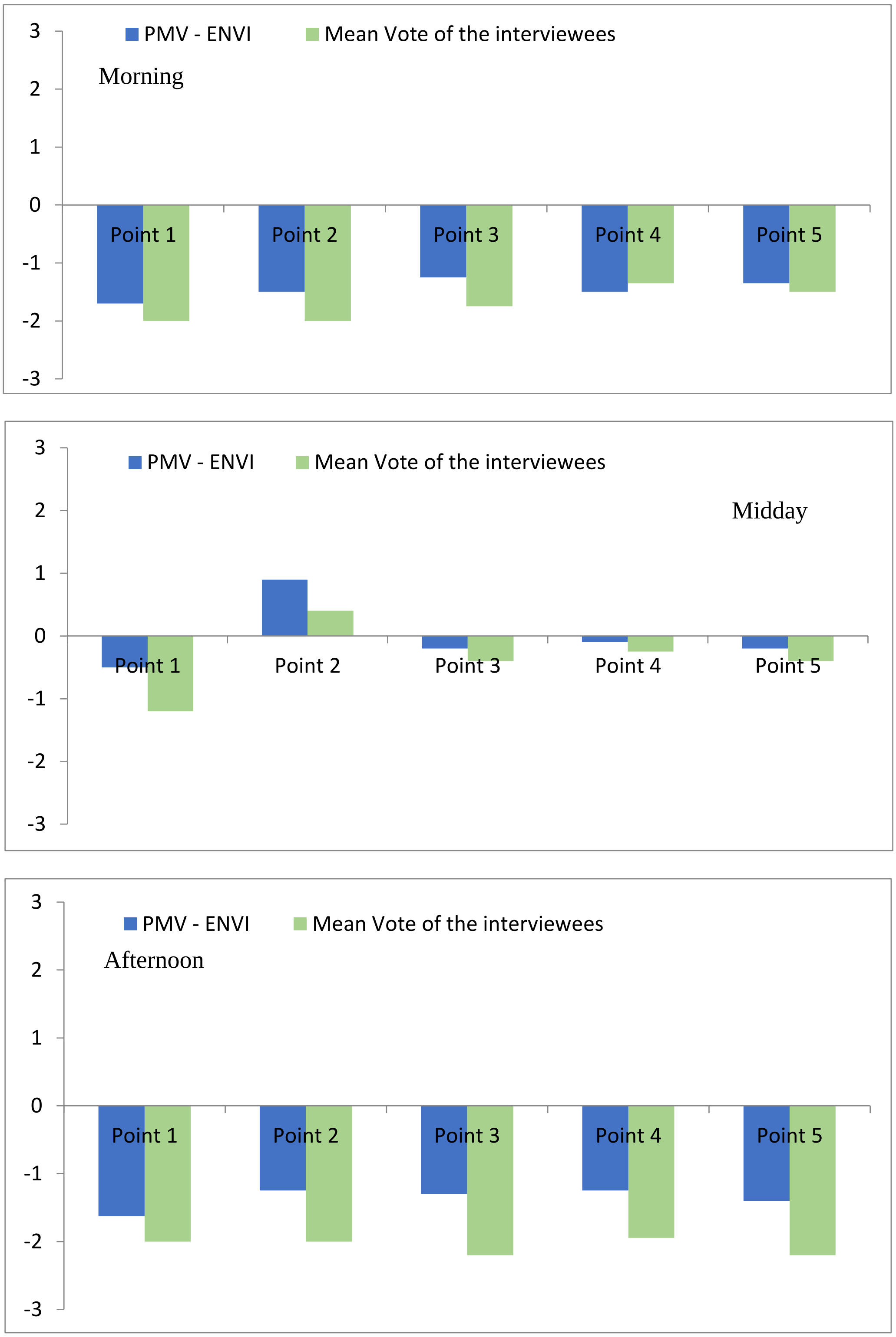


Figure A 3.12: comparison of the PMV values from ENVI-met and the PMV value provided by the people who participated in the interviews during the field survey (Adapted from Salata et al. 2016).

3.5.2 DesignBuilder Validation

In De la Torre and Yousif (2014), the study sought to determine the effectiveness of natural ventilation through a chimney using Computational Fluid Dynamics (CFD). To get the actual CFD boundary conditions, EnergyPlus weather data is used and run in DesignBuilder software. A numerical method is employed with the DesignBuilder CFD, and this method is referred to as the primitive variable method. This method involves the use of an equation entailing the conservation of heat momentum and heat. This equation is referred to as the Navier Stokes equation. The advantage of using the CFD modelling of DesignBuilder software is that it provides CFD for the internal and external conditions of the model of the building for all considered possible situations.

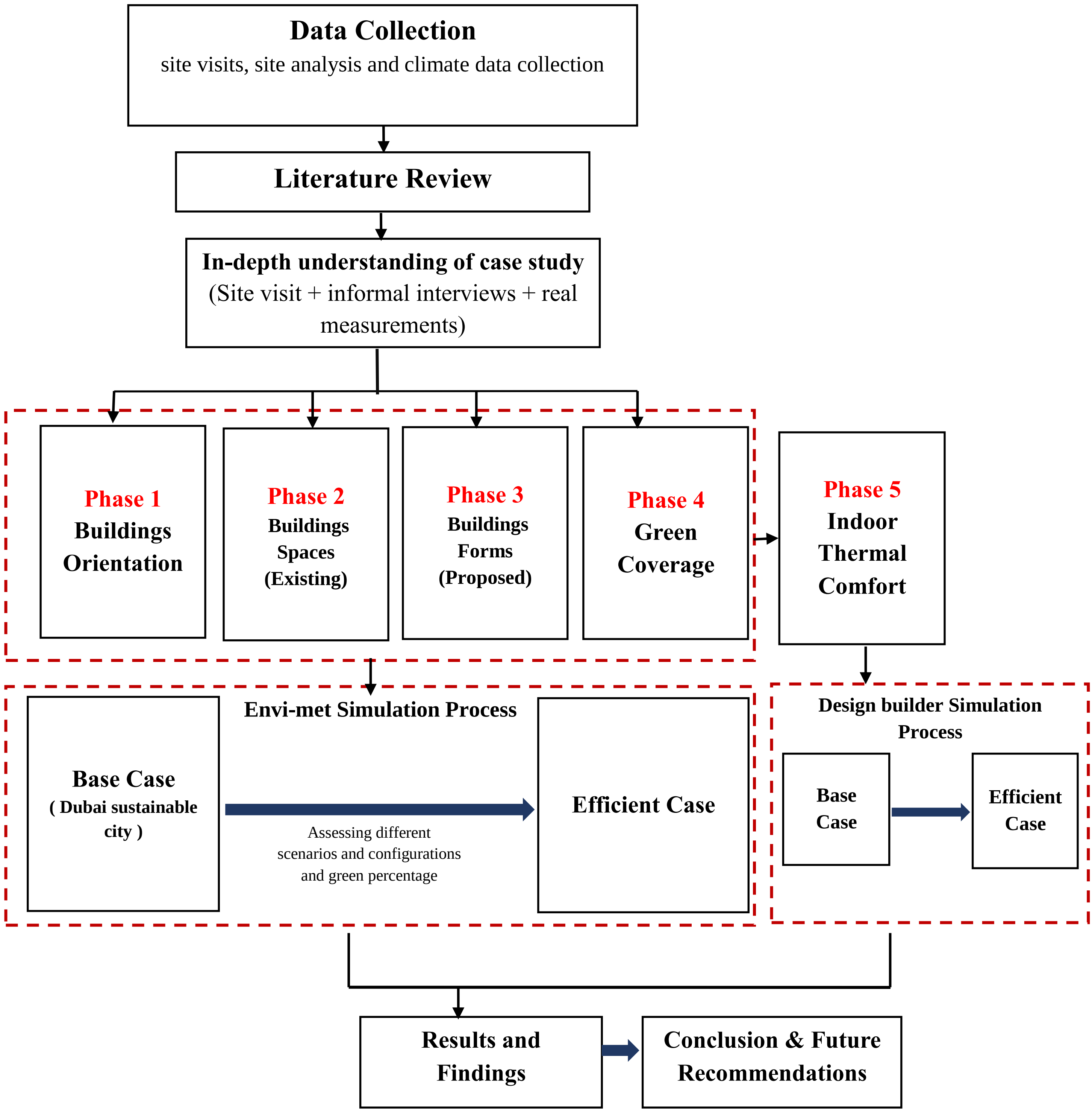
In retrofitted buildings, an insulation solution such as the Vacuum Insulation panel which is high-performance insulation, heat loss is reduced. In Boafo et al. (2015), it was however established that any discontinuity of the material insulation results to thermal bridges. VIP with DesignBuilder is used in the U-value calculations. The U-value refers to the coefficient of the overall heat transfer. The main disadvantages of this VIP are that it is likely to be omitted from the calculations because of numerical calculation difficulties. The three thermal bridges established were VIP material level, Building component, and component VIP level. These were attained due to the differences in thermal conductivity caused by air gaps between VIP and assembly of component VIP. Using the Design-Builder to model the components of the building envelope, a building energy simulation software with the dynamic simulation engine was used Based on BS EN ISO 6946, and the U-value was computed.

There are four PRH building types which were selected in Kwok et al. (2017). These included the Concord, Harmony, Trident, and Slab. These types are differentiated by the building forms they take as well as the building generation where the oldest is the Slab, and the Concord and Harmony are more prevalent. In Kwok et al., (2017), these PRH were simulated with DesignBuilder V5 software.

Building performance data were acquired through the EnergyPlus v8.5 simulation engine. The advantage of these simulations is that they allow the use of the floor only for high rise buildings, therefore, allowing the establishment of average scenario for all building types. The study found out that for Slab and Trident PRH types, the temperatures were higher throughout the study period. During the hottest hours of the day, it was established that the Trident PRH recorded the highest indoor temperatures. This type also was noted to retain a difference in temperatures where the indoor temperature remained higher than the outdoor temperature. However, for the other types of PRH, in at least seven hours, the indoor temperature was found to be lower than the outdoor condition.

Cross Section Ventilation strategy is effective improving thermal and ventilation performance in places with hot and humid climates. In Chung, et al. (2015), the study aimed at validating CFD in DesignBuilder using chimney cross section ventilation to improve the indoor environment performance. The advantage identified for this strategy is that it permits the adjustments of the length of the location of the chimney, therefore, increasing the capacity to attain better results.

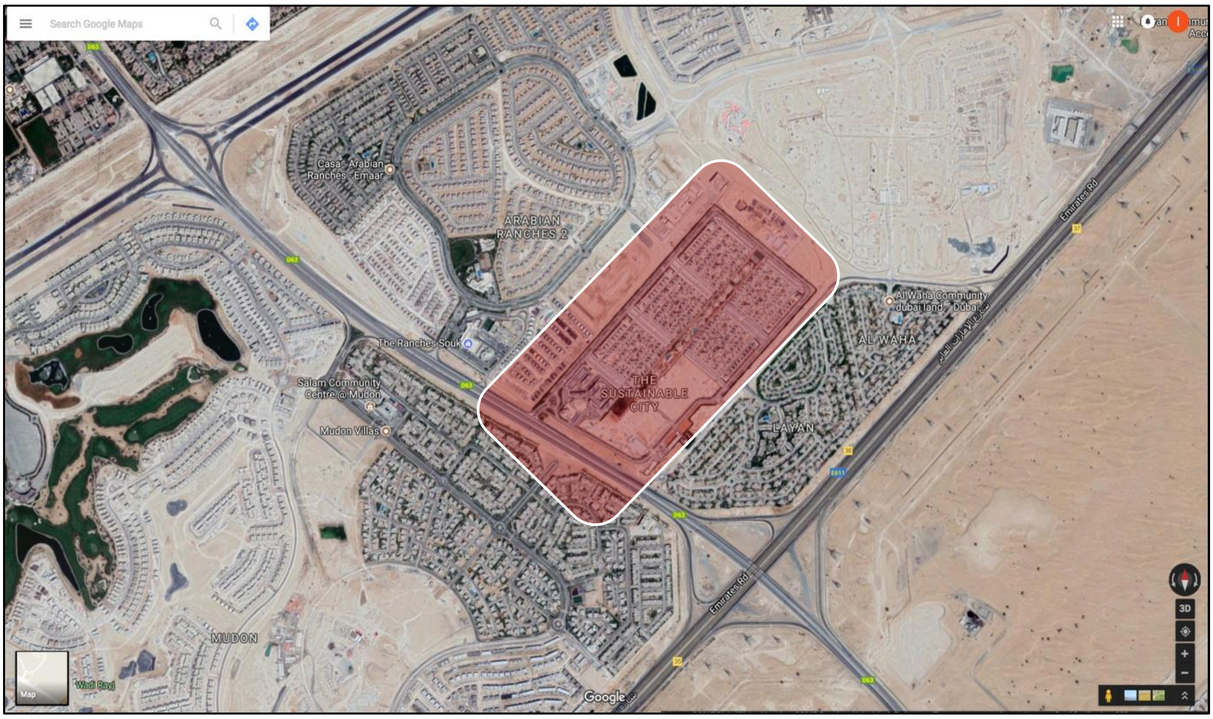
3.5.3 Methodological Map



3.6 Site Selection

Dubai Sustainable city is approximately a 470 thousand square meter site situated in Wadi Al Safa 6, between the two main highways; Emirates Road and Dubai Bypass Road. The site is 4 kilometres far from Emirates Road, and 0.75 Km along Al-Quadra Road which connects the two highways. DSC is located within the Dubai land zone which gives a golden opportunity for its success. This zone is being redeveloped with many new multi-lane expressways normally spaced around the Dubai land area as shown in figure 3.13. This will tolerate easy site access from Dubai as well as the other emirates of the UAE. Dubai land has built a standing as the leader of innovative projects throughout the world. (Abumuaileq & Almulla 2016).

Figure 3.13:Dubai sustainable city aerial view (google map, 2017).



The area gives the residents the feeling of community as it contains communicable areas, lakes, and lush parklands.

Furthermore, it has community centres, shops, and international schools that provide the residents with a self-sustained way of living in the 21st century (Elsheshtawy, 2009). The residential area is in Dubai, near Dubai Sports City. Several other locations exist in the area, such as Motor City Arabian Ranches, Al-Barsha South, and others (Davidson, 2009).

The precinct in existence has a total gross floor area (GFA) of 20,000 square meters and contains several buildings which have been fit to meet the needs of the residents. The percentage of the site coverage is estimated to be 36.9% while the floor area ratio (FAR) has been set to be 1.19 (Elsheshtawy, 2009).

3.7 Case Study: Dubai Sustainable City

Dubai has had a dramatic transformation over the past century. In 1990, the city of Dubai had only 10,000 people, and the city was known as a desert (James, 2014). The city’s current population is 2.1 million, and the current number of visitors to the city is between 8–10 million annually. The city is considered one of the most cosmopolitan cities in the globe (James, 2014). Dubai has encompassed the three key pillars of sustainability: economic, environmental, and social sustainability. There are places in the city that have provided its residents and workers with the lowest environmental footprint and highest quality of life. Dubai becoming a sustainable city is no longer a choice but a necessity. The sustainable city is the first net-zero energy community in Dubai (Bullis, 2016).

Some of the elements and amenities of Dubai Sustainable City are a sustainable training centre, research institute and engineering for sustainable practices, and green school which is nature inspired from kindergarten up to the sixth grade (James, 2014). Tourist attractions in the sustainable city include a grass amphitheatre and a planetarium for hosting events. A variety of leisure and sports activities are available, such as the Equestrian Club, shaded jogging and biking trails in the city, and a community centre, figure 3.14 present Dubai Sustainable City master plan.

Figure 3.14: Master plan of Dubai Sustainable City (Source: Baharash Architecture).

Over 600,000 square feet of solar cells have been used to power Dubai Sustainable City (Bullis, 2016). Many international delegates, such as environmentalists, city officials, and politicians, have visited the ongoing project. The most notable achievement for Dubai Sustainable City was the launch of a new hub whose focus was the provision of insight and education on sustainable development. The hub aims at exploring new strategies and solutions which will facilitate the progression of sustainable thinking in the city of Dubai and ultimately the UAE. Dubai Sustainable City has a residential area of about 500 courtyard villas and townhouses which were primarily inspired by Bastakiya district.

The city relies on 10 MW peak solar production and 11 organic farms, individual garden farms, and bio-dome greenhouses for local food production (James, 2014), figure 3.15 shows an image of DSC in City Scape 2016.

Figure 3.15 :An Image of a model of Dubai Sustainable City (Source: Baharash Architecture).

CHAPTER 4
MODEL SET-UP

4 Computer Model Set-Up

4.1 Introduction

The research to identify the best passive configuration that improves both outdoor and indoor thermal comfort as well as reducing indoor energy consumption is based on the examination of different factors. The first is the site orientation, as Futcher, Kershaw and Mills (2013) noted that special orientation for the architectural units can affect the benefits extracted from exposure to the sun and how solar energy can be collected. In this research, the focus is on the thermal comfort in outdoor spaces that is affected by different aspects such as wind velocity around the units and the shade each building throws on the surrounding spaces, so it is more about blocking the sun's radiation, which is not like the aim of Futcher, Kershaw and Mills (2013) to harness solar energy, which will save the energy needed for cooling indoor spaces

This study is similar to that of Setaih, Hamza and Townshend (2013), who supported Montazeri and Blocken (2013), in setting the fact that wind pressure distribution is affected by many urban factors, including the urban geometry of architectural units as well as the height and density of windbreaker elements. Therefore, this research examines next four layout configurations existing within the same site orientation, where optimal thermal behavior was investigated based on urban forms and configurations. Based on the conclusion of Bruse (2009) and Ahmed and Abu-Hijleh (2016) that thermal comfort parameters are linked to courtyard proportion and building form, the best layout configuration was selected and redesigned to add a courtyard in four different designs. The research then examines the impact of urban green coverage, as Taleb and Taleb (2014) and Thani, Mohamad and Jamaludin (2013) found evidence that green coverage impacts the urban heat island level and enhances the thermal comfort as well as the public interest in and the aesthetic factor of urban spaces. These parameters were addressed earlier in chapter 2 as the factors with the largest effect on the thermal behaviour of urban spaces and open spaces between residential units, as concluded from the literature review (table 2.2). Finally, the research concludes with a final phase that examines the impact of all the above outdoor enhancements on the indoor energy consumption at the residential units.

The research structure depends on a cumulative system where each phase produces the base case for the next phase, while keeping the existing design as our benchmark in terms of the thermal behaviour. This chapter begins with a validation process, where the results of a software model are compared to the results from a site visit, obtained using special equipment, which is elaborated on in detail in section 4.2.

4.2 Trial Validation

In order to validate the software and user capability in addition to the previous readings and reviews that were addressed in chapter 2 and elaborated on in the literature review, ENVI-met4 was recommended and selected for the software model analysis as a simulation methodology. The existing design was simulated at its current status using the Envi-met 4 program, and the outcome results of relative humidity and air temperature were compared with the results collected during the on-site visit using an air quality meter developed by Extech called CO240 (see figure 4.1) on one hand and the national recorded results by the local Ministry of Presidential Affairs - National Centre of Meteorology on the other hand for the same month as the average range shown below in table 4.1.

Figure 4.1: Extech device temperature reading on 23 June 2017 at Dubai's Sustainable City (Author, 2017).

Table 4.1: Average values of humidity, prevailing wind and temperature in the UAE (NCMS, 2016).

	Temperature					Humidity				Wind			
Month	Max	Mean Max	Mean	Mean Min	Min	Mean Max	Mean	Mean Min	Rainfall	Mean	Max	Mean Max	Solar Radiation
January	31.8	24.2	19.3	14.5	7.7	82	65	45	16	12.4	59.3	22	3787.6
February	37.5	25.6	20.4	15.4	7.4	83	64	43	21.7	13.5	53.7	24.2	4648.5
March	41.3	28.5	22.9	17.7	10.1	82	61	38	22.3	13.8	48.2	25	5417.6
April	43.5	33.1	26.9	21.1	12.8	75	54	31	5.3	13.6	72.2	25.8	6172.2
May	47	37.8	31.1	24.9	15.7	71	49	27	0.4	14	40.7	26.1	6770.4
June	47.9	39.7	33.1	27.4	20.7	77	55	30	0	14.1	38.9	25.4	6731.7
July	48.5	41.1	35	30.2	24.1	75	54	32	0.8	14.3	42.6	25.6	6261.1
August	48.8	41.4	35.2	30.5	24	73	53	30	0	14.1	38.9	26	6070
September	45.1	39.1	32.8	27.7	22	80	59	31	0	13	40.7	24.6	5756.9
October	42.4	35.6	29.6	24.2	14.6	81	60	34	1	12.2	42.6	23.5	5047.1
November	38	30.7	25.2	19.9	10.1	79	60	39	4.3	12.2	48.2	22.5	4169
December	33.2	26.3	21.3	16.3	8.2	82	65	45	15.3	12.1	40.7	21.7	3768.3

The site visit was on 23 June 2017, and the test location was Dubai's Sustainable City since it is the project site subject for research and analysis. The photo in figure 4.2. was taken at one of the pathways between the residential units, which are six meters wide. The data collection aims to compare and ensure the accuracy of the software results compared to actual site results considering the small margin of difference that was explained earlier in chapter 3, where Hien et al. (2011) proves that ENVI-met sets an ideal case of a cloudless sky for its simulation settings, yet this simulation is held in summer as the research scope of work focuses on this season in Dubai being the most challenging time of the year, noting that it is proven according to the collected weather data that the Dubai sky is clear with no cloud coverage at this time of the year as per the Ministry of Presidential Affairs - National Centre of Meteorology (see table 4.1), which shows that June has the highest average record of solar radiation over the year, where it reaches 6731.7 wh.m2.

Figure 4.2: Site visit to Dubai's Sustainable City 23/06/2017 (Author, 2017)

4.2.1 Site Visit Records

On the day of the site visit, the data were collected at 12:00 and updated three hours later at 15:00 to compare the results with the results from the software model of ENVI-met 4, as shown in figure 4.3, keeping in consideration that the grid size used in the software model is 3 m x 3 m, which is half the distance between two residential blocks at the site, as the local building regulation indicates that 6 m should be the minimum setback between detached residential blocks, and according to the architectural master plan, this was the space dimension of the walking pedestrian alley between the villas, as shown in figure 4.2. So, to ensure optimum enhancement of thermal comfort, the values were tested twice in shaded spots, once

at each side of the alley, and when a difference of less than 1 C° had accrued, it was neglected, and the highest value was considered as a benchmark to ensure efficiency and seek maximum reduction of temperature using the recommended strategies in this research.

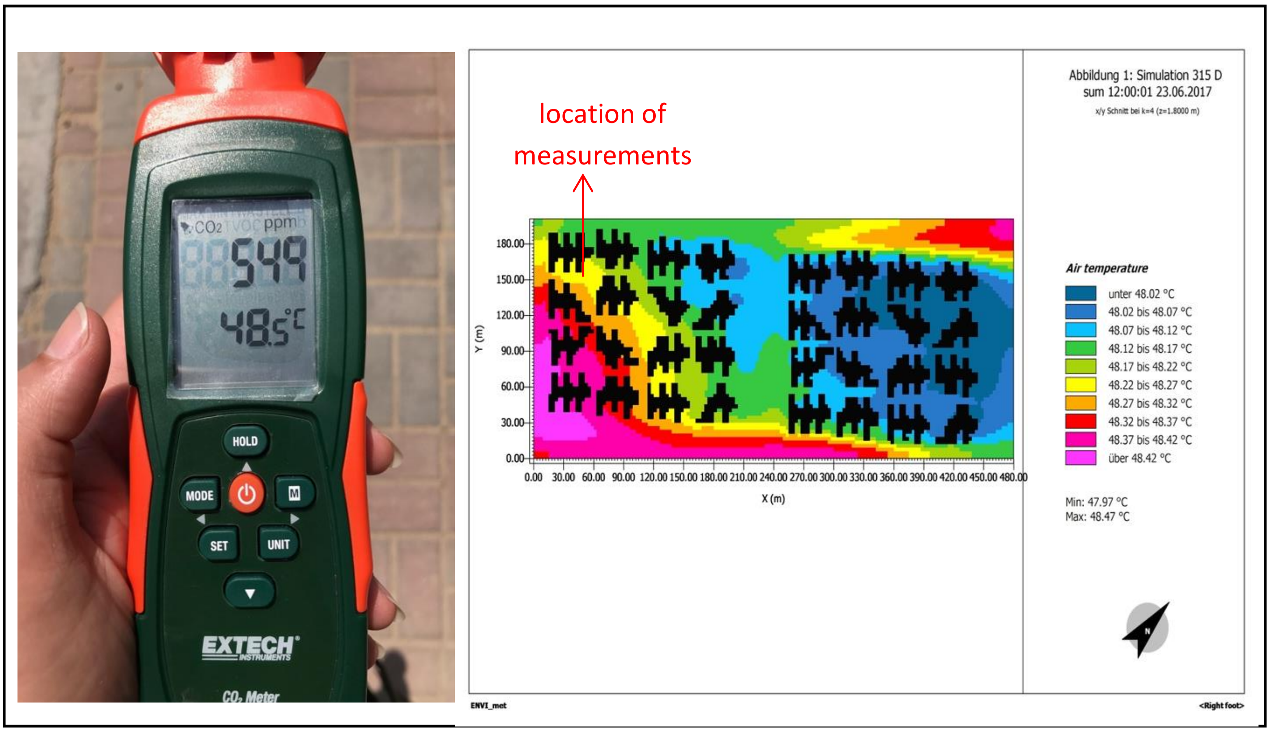
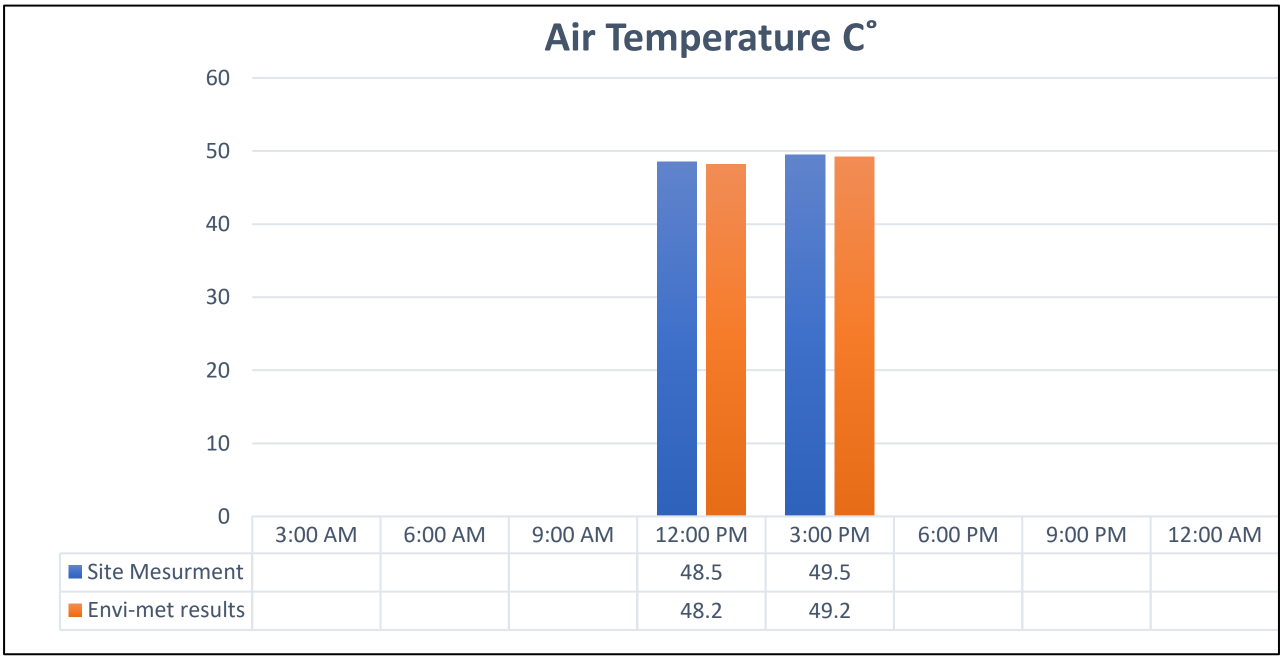


Figure 4.3: Temperature reading comparison between site real measurements and ENVI-met map on 23 June (Author, 2017).

The graph in figure 4.4 displays the site temperature collection data compared to the ENVI-met analysis done to ensure calibration of the software. The reading shown on the device was 48.5 C˚ in building shade at 12:00 (see figure 4.3), while the ENVI-met shows 48.2 C˚ at the same time in the same spot, as shown in figure 4.4.



	3:00 AM	6:00 AM	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM	12:00 AM
Site Mesurment				48.5	49.5			
Envi-met results				48.2	49.2			

Figure 4.4: Calibration between ENVI-met and real measurements in terms of air temperature (Author, 2017).

Three hours later, at 15:00, the air quality meter shows a reading of 49.5 C˚ (see figure 4.5) in building shade in the same spot that was visited earlier, while the simulation software map at the same time shows 49.8 C˚ in the same spot, as shown in figure 4.5.

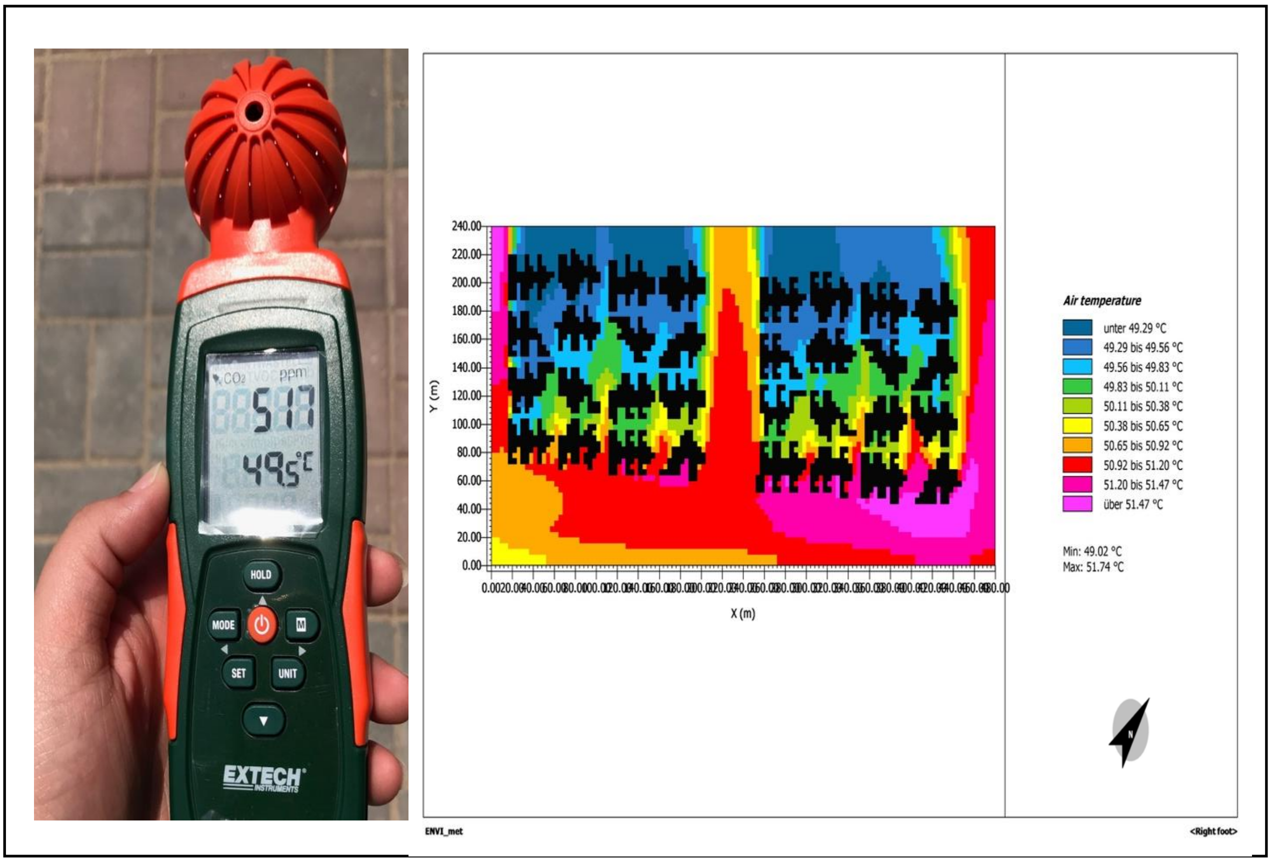


Figure 4.5: Temperature reading comparison between site real measurement and ENVI-met map on 23 June (Author, 2017).

On the other hand, the Extech air quality meter was used for RH, as shown in figure 4.6, where it recorded 32.6% after the first hour of the site visit at the exact location, while the simulation software map shows 32.4% (see figure 4.6) at the same time.

Figure 4.6: Relative humidity reading comparison between site real measurement and ENVI-met map on 23 June (Author, 2017).

Similarly, three hours later, at the next visit, the EXTECH air quality meter shows 31.8 % at the second site visit (refer to graph shown in figure 4.7), and the simulation software map shows 32.2% at the exact same spot, as shown in the graph of figure 4.7.

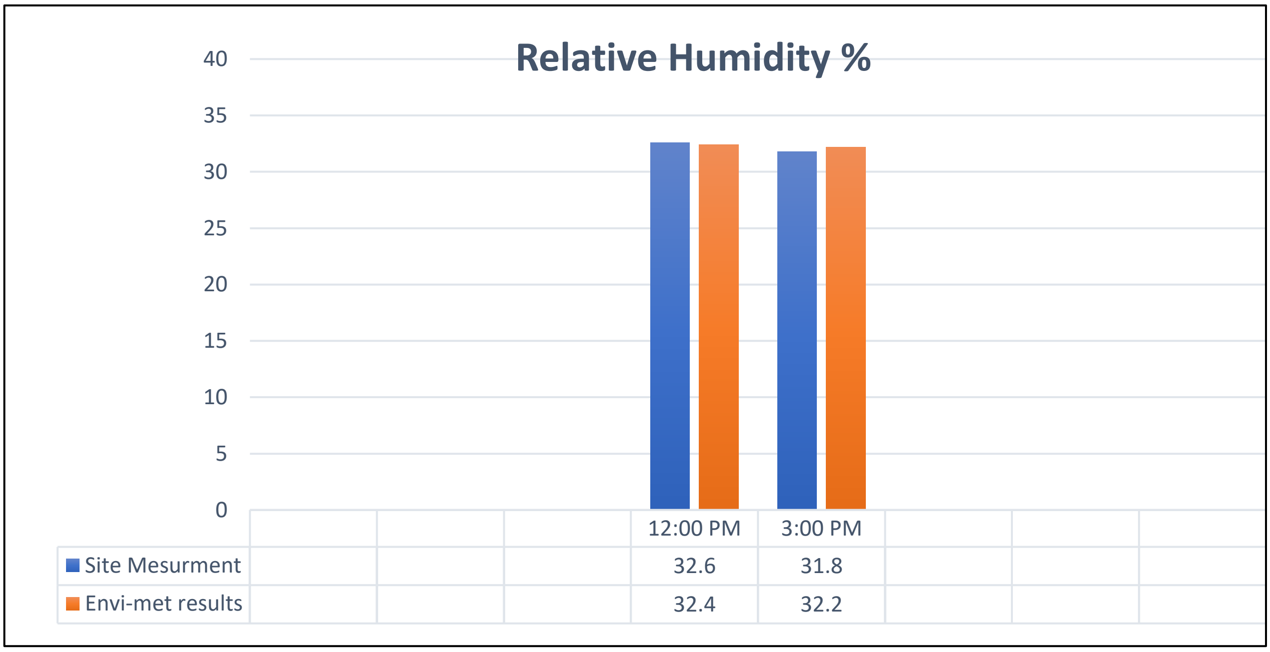


Figure 4.7: Calibration between ENVI-met and real measurements in terms of relative humidity (Author, 2017).

The data collected at the site visit show the reliability of the software results in terms of air temperature and RH, as shown in figures 4.6 and 4.7. The results did not raise any major deviation, which is consistent with the results of Ozkeresteci et al. (2013) and Hien et al. (2011), which were presented earlier in chapter 3, where the software was validated and trusted for the results.

In addition to that, the overall average recorded from the software simulation falls within the average recorded by the Ministry of Presidential Affairs - National Centre of Meteorology for the same month, which supports the analysis results and findings.

Therefore, it was found that ENVI-met 4 is an ideal program for this research and its results are reliable for the scope of work as well as for the efficiency of the user and model builder due to the results of the trial validation test.

4.3 Parametric Analysis Research Matrix

In 1992, a parametric analysis approach was developed by Alder and Monterio, which was related to the geometry of the linear program. This analysis was based on how the changes in the input data affecting the optimal solution of the problem are often essential for the practical effectiveness of the optimisation models. In this research, a parametric analysis was applied to make numerous simulations run on different urban configurations and different vegetation percentages to examine only a single parameter, considering that others are constant.

All the design variables' effects on the outdoor thermal conditions will be examined by running one variable at one time. All other parameters, such as the windows/wall ratio, floor area ratio, buildable area, maximum gross floor area (GFA), site coverage (SC) and building forms and spaces are kept constant. The research framework was built on the determination of the ideal urban configurations and the tree coverage influence on outdoor and indoor thermal comfort, and it argues that various tree percentages and urban configurations proposals regarding climate conditions may result in different outdoor and indoor thermal comfort conditions for each design case.

Phase one examined site orientation at 225D (southwest), 135D (southeast) and 45D (northeast). The evaluation criteria are relative humidity, air temperature, wind speed and PMV values of each case against the relative humidity, air temperature, wind speed and PMV values of the existing base case that is set on 315D (northwest). Previous studies have found evidence that building orientation can play an important role in changing outdoor thermal behaviours, although it is considered one of decisions in the first design stages.

In phase two, the best scenario of phase one is examined for four different layout configurations in terms of building spacing, noting that these configurations all exist within the same site master plan. The reason behind running this phase is the large differences in building configurations among the base case itself. Base case spaces were divided into four different spaces (space 1, space 2, space 3, and space 4) (figure 4.8). During this phase, the evaluation criteria are relative humidity, air temperature, wind speed and PMV.

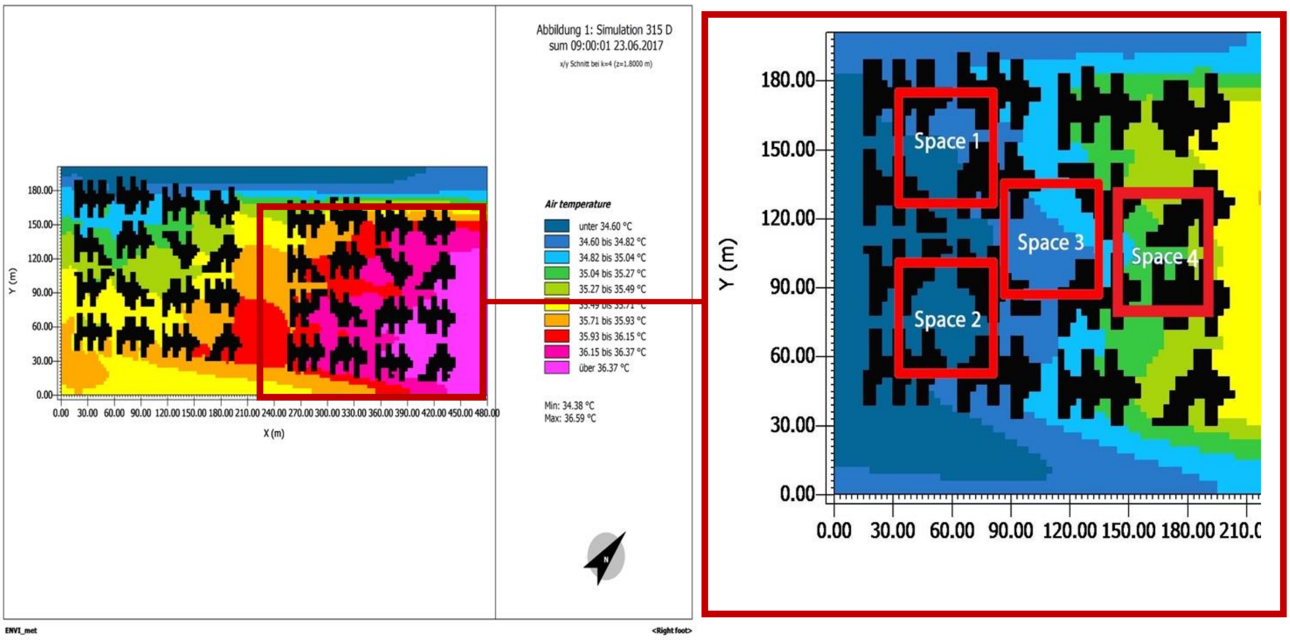


Figure 4.8: ENVI-met map showing the four-different building spacing existing in the base case.

Phase three is based on the outcome of the previous stage. The best layout configuration in terms of building spacing from the base case is redesigned to include a courtyard in four different forms, as per the recommendations from the previous studies in the literature review. Figure 4.9 presents the courtyard arrangement in the base case, which represents the variety of shapes and open direction used in the courtyard design.

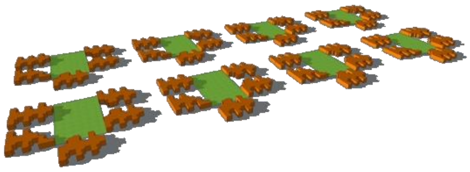
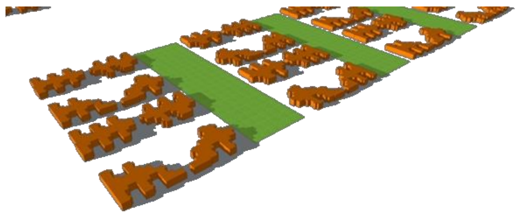
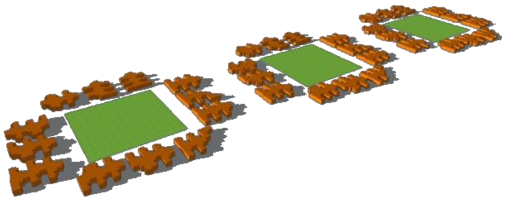
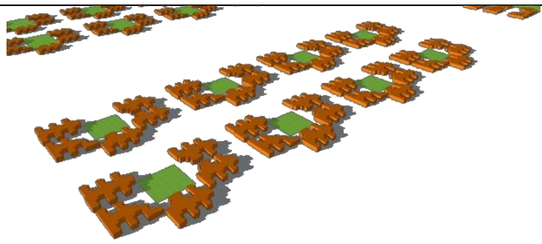
For this phase, the same evaluation criteria are used as in phase two to maintain professional evaluation; therefore, relative humidity, air temperature, wind speed and PMV are collected for each of the four courtyards designs. The selected building configurations were recommended by the literature review, as per table 2.3 at the end of chapter 2, and they are listed in table 4.2.

ZONE PA07	LANDUSE	PLOT-NO	AREA sq.m
	RESIDENTIAL	10	5152
	OPEN SPACES & SIKKA & ENTRANCE	1	1288
TOTAL		11	6440

ZONE PA08	LANDUSE	PLOT-NO	AREA sq.m	PARKING SPACE NO.
	RESIDENTIAL	90	18495	20*
	PARKING	2	5757	200**
	OPEN SPACES & SIKKA & ENTRANCE	1	12515	
TOTAL		93	36767	220

Figure 4.9: Courtyard arrangement and location in the base case (Adapted from Dubai Sustainable City report, 2016).

Table 4.2: The four proposals of different courtyard configuration (Author, 2017).

Space Code	Configurations description	Illustration	Courtyard length to width proportion
Space A	Proposed U shape buildings form and Rectangular courtyard .		28:14 = 2:1
Space B	Existing linear buildings form with rectangular courtyard.		56:14 = 4:1
Space C	Developed Central buildings form with square courtyard.		35: 35= 1:1
Space D	Proposed U shape buildings with square courtyard.		28:28 = 1.1

Phase four focuses on the plantation and green cover percentage of the site, as four different percentages of green cover will be tested using the same software, and the results are based on the same variables to maintain continuity of evaluation method and judgment factors. From a holistic view of the previous studies in the literature review (table 2.3) and in most of the research conducted in this field, vegetation and green surfaces are considered one of the most effective ways to decrease the urban heat effect and improve the outdoor thermal comfort. The previous four parameters investigated the outdoor thermal comfort using simulation runs achieved in four phases using the ENVI-met software.

Phase five is the last phase, and it will be the only phase focusing on the effect of outdoor thermal comfort on the indoor energy consumption. Phase five uses the best results acquired at the end of the previous four phases and applies the simulation using DesignBuilder software to investigate the changes in energy consumption. The two examined cases are the base case of Dubai's Sustainable City and the optimal case.

This chapter presents the parameters and variables of this research and goes into explaining the software modeling using ENVI-met 4 for the outdoor level and DesignBuilder for the indoor level application, which was discussed earlier in chapter 3 as per Bruse (2009) and Hien et al. (2011). A validation experiment is conducted, and the results are presented as well to validate the user capability and validate the results for this site on the selected date. Table 4.3 summarises the five phases in terms of parameter and variable scenarios.

Table 4.3: Selected parameters and variable optimisations (Author, 2017).

Parameters	Base case	Variable Scenarios
1- Building Orientation	According to the existing	-45D (north-east) * -225D (southwest) -135D (southeast) -315D (northwest)
2- Building Spacing * (Existing base case)		-Space 1 -Space 2 -Space 3 -Space 4
3- Courtyard Layout		- Proposed u-shaped buildings formed with rectangular courtyard -Existing linear buildings formed with rectangular courtyard -Developed central buildings formed with square courtyard -Proposed u-shaped buildings with square courtyard
4- Green Cover Percentages		- 0%* - 15 % - 30% - 40%
5- Indoor Energy Analysis		-Base case -Optimal case

*Base Case existing variable

4.4 Microclimate Variables

The mathematical definition for the term “parameters” as per the Oxford Dictionary is the quantity whose value is selected for circumstances and in relation to which other variables’ quantities may be expressed. In this research, the parameters are divided into fixed parameters and changing parameters. Each parameter consists of the number of variables that impact the overall experiment. Therefore, to limit the analysis to the specific research scope of the work, the changing parameters were selected as per previous research papers and case studies that meet the objectives of this research discussed earlier in section 1.8.

Similar to the research of Tsitoura, Michailidou and Tsoutsos (2016) that analyzed selected parameters related to Mediterranean climate after classifying parameters into two groups, this research uses three groups of fixed parameters that are standardised overall simulation phases in order to eliminate their impact on the final results, as it was seen through the literature review that these variables have an impact on the research topic yet their impact is out of the research scope of this work, as discussed in previous chapters.

The first fixed parameter is the architectural parameter, which includes different variables such as the typography at the selected site, the location of the case study project, building form and height, facade openings and elevation materials. These variables were fixed throughout all phases of the study, as studying them does not comply with the research objectives and aim.

The second fixed parameter is time, as all analyses were conducted during the summer, on 23 June, for a full 24 hours. Accordingly, the initial input weather data for all simulations, as air temperature and RH at 2 m height, wind speed measured at 10 m height, solar radiation and initial soil condition in terms of soil wetness and temperature, were fixed as initial inputs for all simulations, as measurements were all taken on the same day. Note that the winter season is not included as it was concluded in the earlier literature review that Dubai is facing design challenges for outdoor areas in the summer season, not the winter season (Setaih, Hamza & Townshend, 2013; Thani, Mohamad & Jamaludin, 2013). Therefore, this research focuses on the summer session, taking June as an example for the case study in terms of site visits and model simulation.

The third fixed parameter is the software modelling settings that were used to build a base model the first time, which was kept it in use for all further phases of the simulation. These settings are related to the main model area grid, which is X-grid =160, Y-grid = 67 and Z-grid = 20, while the size of the grid cell is 3 m on X, Y and Z, as shown below in figure 4.10.

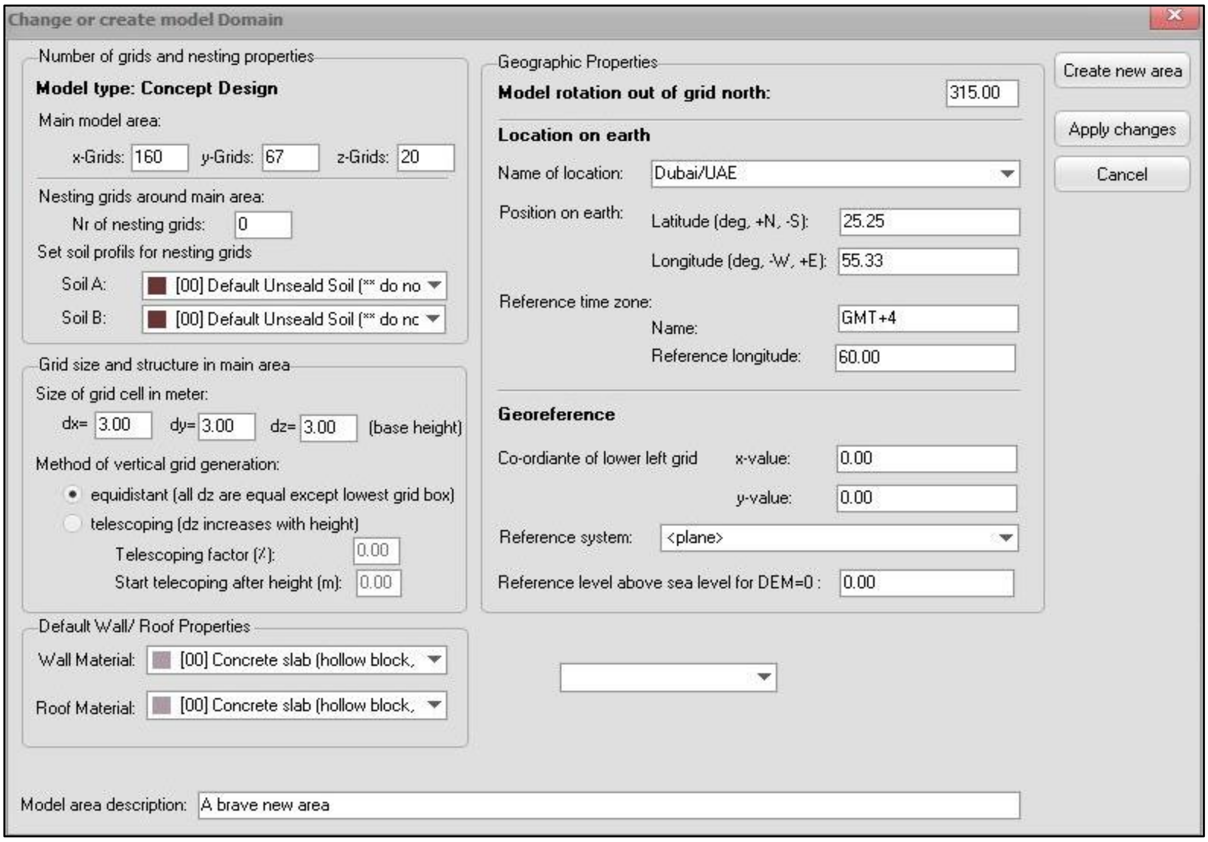


Figure 4.10: Main model area grid X-grid, Y-grid and Z-grid (ENVI-met software, 2017).

Table 4.4 shows the fixed parameters as explained earlier, with the initial input numerical value wherever it is needed.

Table 4.4: Simulation fixed parameters (ENVI-met software, 2017).

Fixed Parameters (Figure 4:10)	Architecture Parameter	Site typography	
		Site location	
		Building form	
		Building height	Height is G + 1(5.4 m)
		Facade materials	Concrete block
		Facade openings	Double glazed
	Time and Date Parameter	Day of analysis	23 June
		Time of analysis	24 hours
		Initial input of weather data (air temperature, RH, wind speed, solar radiation)	Air temp. (48 C°) RH (50 %) Wind speed (7.5 m/s) Wind direction (233)
		Initial condition for soil	Soil wetness (60%)
	Software Modelling Settings	Model domain details	Main model area X-grid = 160, Y-grid = 67 and Z-grid = 20
			Size of grid cell in meters: 3 x 3 x 3

As shown in figure 4.11, the fixed input data related to the main model is the initial wind speed measured at 10 m height and the initial temperature atmosphere.

On the other hand, there are the changing parameters that are divided into two groups: First, the variables subject to examination, referred to as research subject variables, are the research core that forms the scope of this work, as it is the changing factor that is required to be studied and examined. some of which Setaih, Hamza and Townshend (2013) referred to as microclimate enhancement methods for thermal comfort. In this research, these are known as research subject variables. Second, the evaluation variables that change based on the changes in the previous variables and the results of these variables are used to determine the conclusion of the research and how to select a preferable scenario.

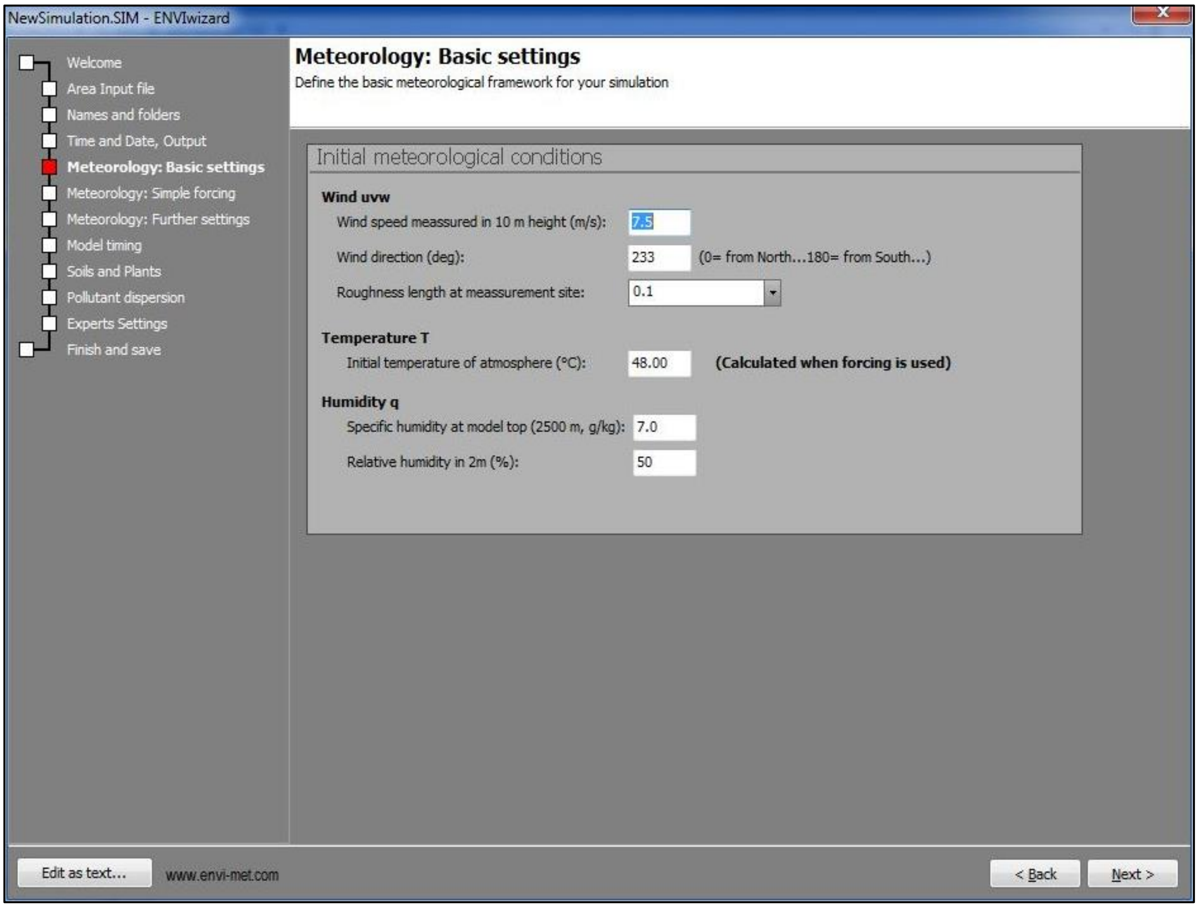


Figure 4.11: The fixed input data related to the main model (ENVI-met software, 2017).

Table 4.5 shows the changing parameters discussed earlier and the different variables listed into two categories: first, the research subject variables and second, the evaluation variables.

Table 4.5:Simulation phases changing parameters and variables (Author, 2017).

Changing Parameters	Research Subject variables	Project Layout Orientation
		Urban Configuration
		Urban Courtyard
		Green Coverage
	Evaluation variables	PMV
		Relative Humidity
		Air Temperature
		Wind Speed

The research subject variables are examined in phases, and each is evaluated using the same evaluation variables that were explained and discussed earlier in chapter two for being the most relevant variables to this case study, which is in Dubai and facing the challenge of designing for summer outdoor urban areas.

4.5 Urban Texture Variables

As explained earlier in section 4.4 microclimate variables, the architectural variable in this research is considered a fixed parameter, including all its related variables, as presented in table 4.5. For example, the villa form that is known to be a townhouse villa of 16 m x 13.5 m type one and 15 m x 13 m type two, with a total number of 98 villas in the selected cluster, as shown in figure 4.12.

Figure 4.12: Dubai Sustainable City Typologies Plan (Dubai Sustainable City Annual Report, 2016).

Yet, this research deals with the spacing between the residential units being considered as one of the strategies used in phase two. In the currently existing design, this spacing is referred to as the primary pedestrian path with a 7-m width, as per figure 4.13. This does not include the 40% open area excluded from the total plot area, where 60% is used for the built-up area and 40% is dedicated for frontcourt and private open spaces to meet building code regulations.

In this analysis, as explained earlier in section 4.3, on the parametric analysis research matrix, the dimensions of the spacing between the plots will be changed while proposing different building configurations, as suggested by Setaih, Hamza and Townshend (2013), who found that building configuration has an impact on thermal comfort around the building.

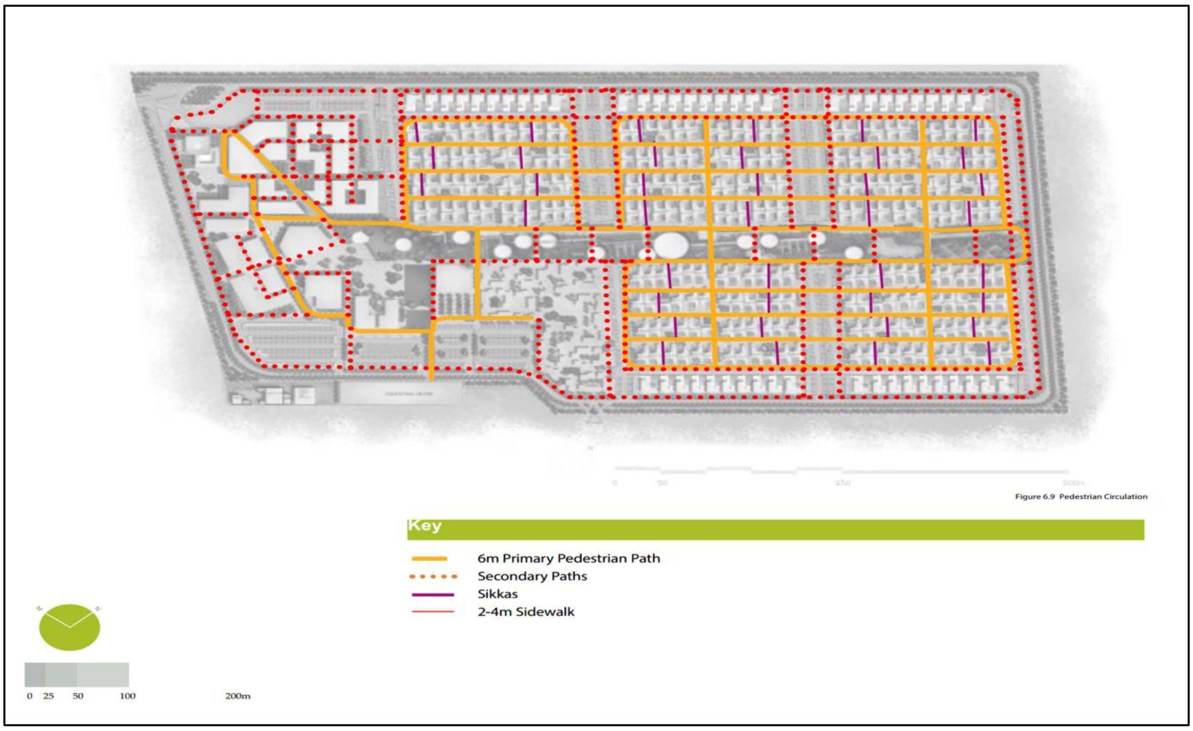


Figure 4.13 : Dubai Sustainable City pedestrian circulation (Dubai Sustainable City Annual Report, 2016).

Yet the private open space in each plot is not changed in any of the proposed scenarios of phase three, as all proposals comply with the Dubai Municipality building regulation code, where the minimum setback required is 3 m for detached units with three sides, and 6 m from the front side.

In addition to that, the existing residential units at the site are designed to the maximum allowed height as per the Dubai Municipality building code (table 4.6), and the front elevation of each residential unit is set back 6 m from the front pedestrian line, while the maximum height accepted by the building code for the fence that separates the private property land from the public pedestrian walkway is 1.8 m.

PLOT DETAILS					DEVELOPMENT PROFILE				
ZONE NO	PLOT NO	LANDUSE	AREA sq.m	BUILDING TYPE	F.A.R	COVERAGE	G.F.A sq.m	BUILDING HEIGHT	SET BACKS
pa07	pa0701	Residential	672	Villa			414.63	G+1	As Dm Standards
	pa0702	Residential	476	Town House			315	G+1	As Dm Standards
	pa0703	Residential	476	Town House			315	G+1	As Dm Standards
	pa0704	Residential	476	Town House			315	G+1	As Dm Standards
	pa0705	Residential	476	Town House			315	G+1	As Dm Standards
	pa0706	Residential	476	Town House			315	G+1	As Dm Standards
	pa0707	Residential	476	Town House			315	G+1	As Dm Standards
	pa0708	Residential	476	Town House			315	G+1	As Dm Standards
	pa0709	Residential	476	Town House			315	G+1	As Dm Standards
	pa0710	Residential	672	Villa			414.63	G+1	As Dm Standards
	pa0711	Landscape /Sikka Enterance	1288						As Dm Standards
	TOTAL		6440				3349.26		

Table 4.6: Dubai Municipality maximum building height and setbacks allowed in residential villas (Dubai Sustainable City annual report, 2016).

Therefore, in order to propose a shading element that covers the public pedestrian walkway and enhances the surrounding microclimate, special approval will first be needed from Dubai Municipality and project developers in order to review the master layout design regulations and increase the height of the fence to add the shading element above the pedestrian walkways, known as the primary pedestrian path in the existing design. This will not look interesting from an aesthetic point of view and will have an impact on the architectural characteristics of the site, as well as adding complexity of maintenance over the management for this structure. Figure 4.14 presents the cross-section of the existing design of the villas' setback and pedestrian pathway.

Therefore, a different approach was found that complies with both parties' regulations and enhances the aesthetic experience of different users without compromising on the need to improve the microclimate aspects of the site in response to the research objectives.

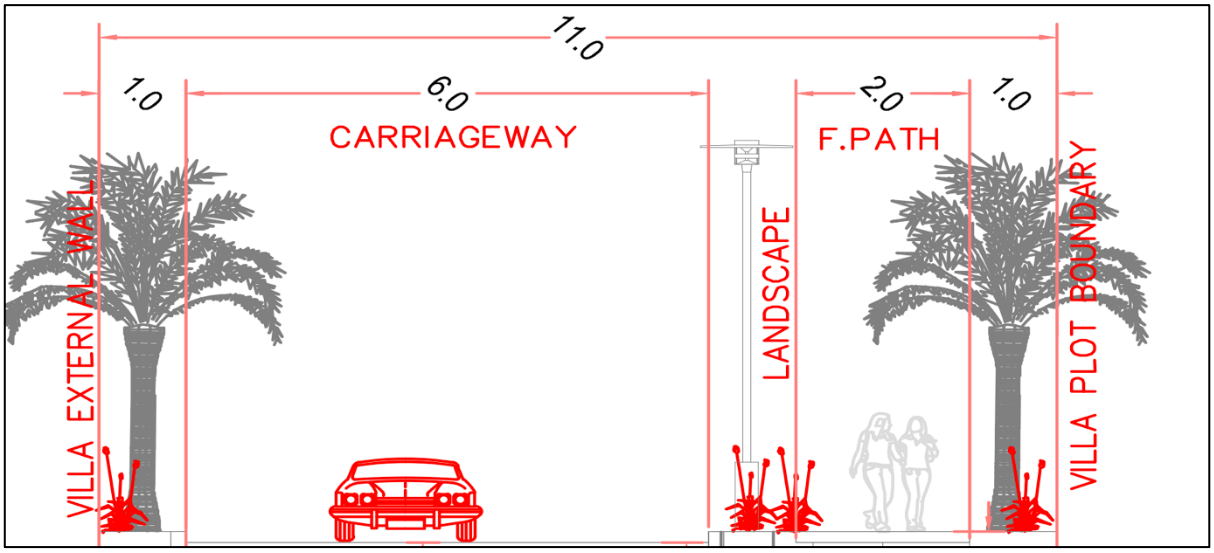
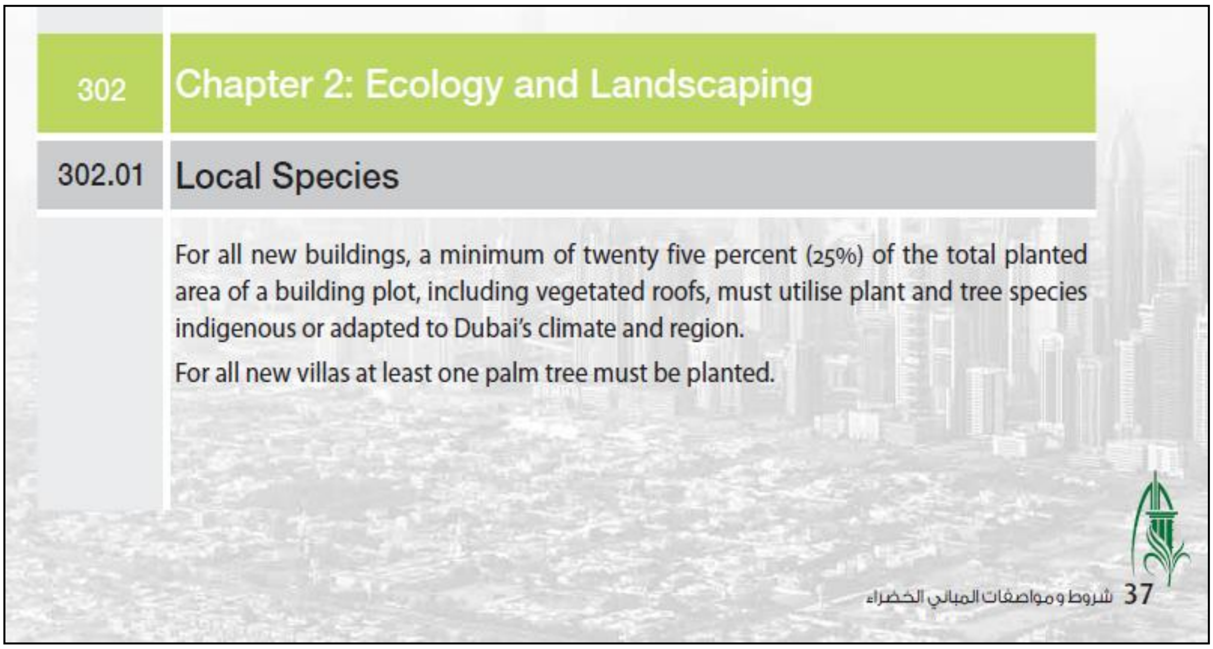


Figure 4.14: Dubai Sustainable City residential unit cross-section showing the villa setback and pedestrian pathway (Author, 2017).

The decision was made to propose a percentage of greenery coverage for the site during phase four of this analysis, as Thani, Mohamad and Jamaludin, (2013) concluded that urban landscaping has an impact on air temperature, relative humidity and wind speed and recommend using green cover as a cooling strategy when designing urban spaces.

Since the existing base case has 0% green surfaces, three scenarios of green coverage percentage will be examined: 15%, 30% and 45%. The proposed vegetation will include local plants that are recommended for local use due to their ability to adapt to the outdoor climate in this region throughout the year, so it complies with the sustainability standards emphasised by both the project developers as well as Dubai Municipality green code regulations section three, chapter two, 302.01, local species (see figure 4.15).



302	Chapter 2: Ecology and Landscaping
302.01	Local Species
	For all new buildings, a minimum of twenty five percent (25%) of the total planted area of a building plot, including vegetated roofs, must utilise plant and tree species indigenous or adapted to Dubai's climate and region. For all new villas at least one palm tree must be planted.

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Figure 4.15: Local species green guild lines (Dubai Municipality green code regulation book, 2015).

4.6 Model Set-Up Simulation (Phase One): Building Orientation

During phase one, the simulation runs to investigate the impact of layout orientation. Futcher, Kershaw and Mills, (2013) and Huynh and Eckert, (2012) found evidence that orientation can enhance the sustainability features of a site by allowing the units to harness solar energy by directing the main openings and solar panels toward maximum solar radiation. This project aims to use the same method but to avoid sun radiation in the outdoor spaces and between architecture units as well as harnessing wind to reduce relative humidity, as Huynh and Eckert (2012) suggested in their case study of Ho Chi Minh City. This will impact the thermal comfort of users, which is evaluated and judged by the PMV results, similar to the method used by Bruse (2009), in addition to other evaluating variables, such as air temperature, relative humidity and wind speed. The results for the newly proposed orientation are tested against the existing case that is the benchmark in this phase and that is referred to as the existing-base case to distinguish it from further base cases in each phase.

The current design is found to be oriented at an angle of 45 degrees, known as the northeast, where north is considered zero and east is 90 degrees, as shown below in figure 4.16.

The site components were maintained exactly the same while rotating the site at an angle of 225 degrees, known as southwest, 135 degrees, known as southeast and 315 degrees, known as northwest. In each scenario, the simulation runs on 23 June, representing the summer session, for 24 hours.

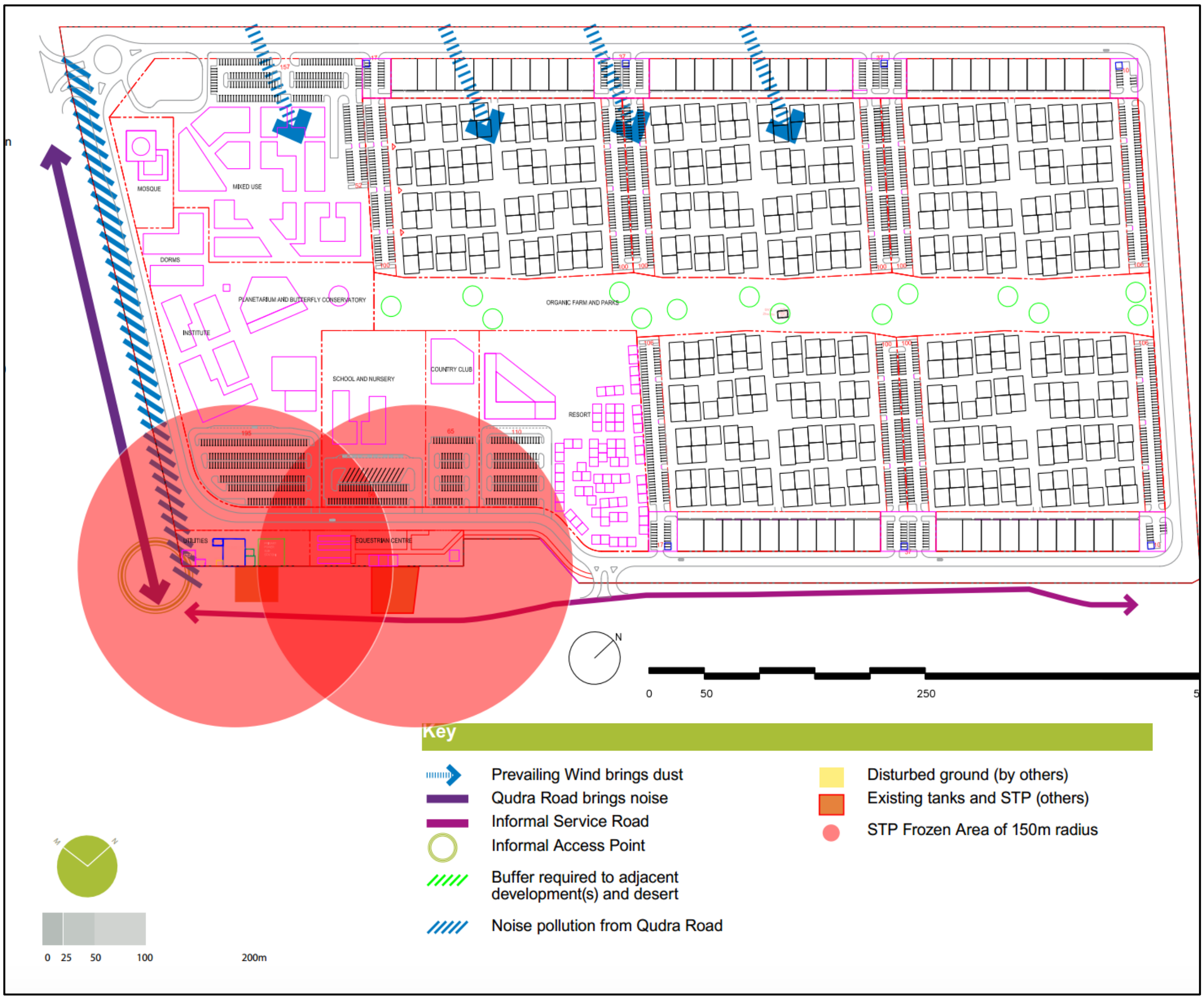

Figure 4.16: DSC site analysis showing the prevailing wind direction and other site analysis elements (Dubai Sustainable City annual report, 2016).

The decision of having PMV as one of the evaluation methods was made based on previous studies, such as Bruse (2009), that were elaborated on previously in chapter 3. This thermal scale runs from -4, which represents a cold environment, to +4, which indicates a hot environment, and the middle zero point represents ultimate comfort, as developed earlier by Fanger and adopted recently by the international standard ISO 7730:2015. The ASHRAE 55 sets the comfort zone between -0.5 and +0.5 for interior spaces, as shown below in table 4.7.

Table 4.7: ASHRAE 55 comfort zone index (Adapted from Huynh & Eckert, 2012).

Sensation	Extreme cold	Cold	Cool	Slightly cool	**Neutral**	Slightly warm	Warm	Hot	Extreme hot
Value	-4	-3	-2	-1	**0**	+1	+2	+3	+4

In order to standardise the experiment and eliminate any impact from any other factor on the results, the model was built once, and all weather data and surface materials as well as architectural elements were designed once and maintained the same overall scenarios. This keeps all fixed parameters neutral in their impact on the result, which means that the only difference between one scenario and another was the rotation angle, which was controlled using the north angle input (model rotation out of the grid to the north) in the model geographical properties under the model domain figure 4.17.

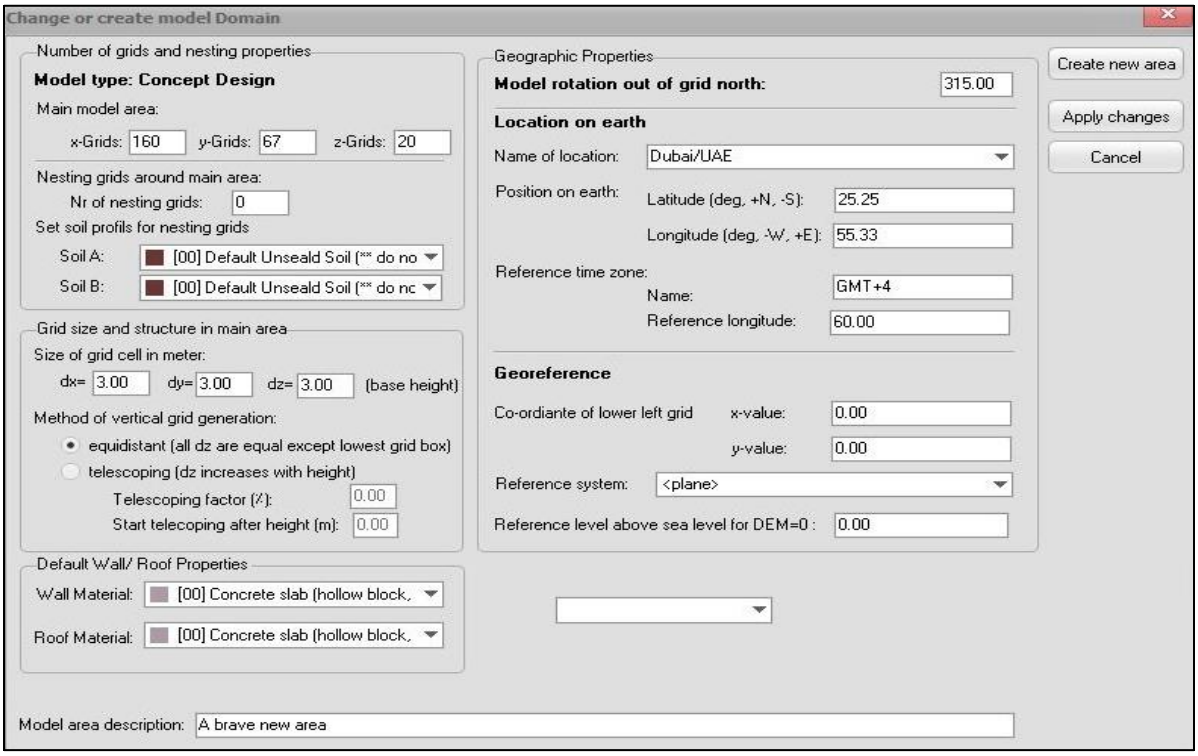

Figure 4.17 : ENVI-met model domain interface (ENVI-met software, 2017).

4.6.1 Layout Orientation Simulation of Existing-Base Case

In order to analyse the existing-base case urban layout at its current orientation using ENVI-met 4, as discussed earlier, the model was built using the fixed parameters as discussed in section 4.4, where the townhouse dimensions were 13.5 m x 16 m and 15 m x 13 m, while the height of the residential unites is G + 1, as per Dubai Municipality standards, which specify 10 m maximum.

The size of the grid cell is 3 x 3 x 3 m, as explained earlier in table 4.4 section 4.4, while the main model area X-grid = 160, Y-grid = 67 and Z-grid = 20. The research aims at this phase to explore which orientation is best for outdoor spaces in terms of the best results from the record of the evaluation variable discussed earlier in section 4.4.

Like Huynh and Eckert (2012), who studied air temperature reduction when reorienting building blocks to allow deeper penetration of wind flow, in this research, air temperature is used as an evaluation variable beside relative humidity and wind speed as well as PMV records. Yet, the initial data of air temperature, RH and wind speed must be registered each time the simulation runs. Therefore, it is recorded as presented in the following table 4.8. On the other hand, some variables are considered fixed parameters, and to eliminate their impact on the results, their values were also recorded in table 4.8, to repeat the same input during each model simulation run. In addition to these parameters, the time and date of the simulation are also fixed, as all simulations run on 23 June for 24 hours, representing the summer session, as explained earlier.

Table 4.8: Initial weather data input (Adapted from ENVI-met software 2017).

Wind Speed m/s	Wind Direction	Initial Average Temp. C°	R.H in 2 m Height %	Adjustment Factor for Solar Radiation	Soil Layer Wetness from 0 cm to 50 cm Below	CO2 Background Level (ppm)
7.5	315°	48	50%	1.0	60 %	549

The simulation of the existing-base case aims to extract the benchmark values for the evaluation variables listed before, as Thani, Mohamad and Jamaludin (2013) refer to the primary physical parameters that help people set a range for their thermal tolerance for both indoor and outdoor spaces. Toudert (2015) agreed that air temperature is an essential parameter that should be tested in both hot and cold climatic zones. Following Monteiro (2010), relative humidity and wind velocity were added to the evaluation parameters beside air temperature and PMV value in this research.

4.6.2 Layout Orientation Simulation for Four Proposed Scenarios

The analysis was built using the same ENVI-met 4 file from the previous simulation to ensure consistency of data that are not under the research scope of this work, as explained previously in section 4.6. Only this time, the whole model was rotated into three different angles by giving a rotation value to the model domain settings explained earlier in figure 4.17. Then, the simulation runs three different times over a period of 24 hours on 23 June.

The first angle is 225 degrees, known as the southwest direction, the second is 135 degrees, known as the southeast direction and the last one is 355 degrees, known as the northwest direction, keeping in consideration that the existing-base case is at 45 degrees, known as the northeast direction, which is the predominant wind direction in Dubai.

Note that this research covers zone Pa07-Pa08 shown in figure 4.18, where wind flow is interrupted by other clusters and architectural blocks. Yet the model built for this research does not include the other clusters and is limited only to the highlighted zone, as it represents the research scope of this work.

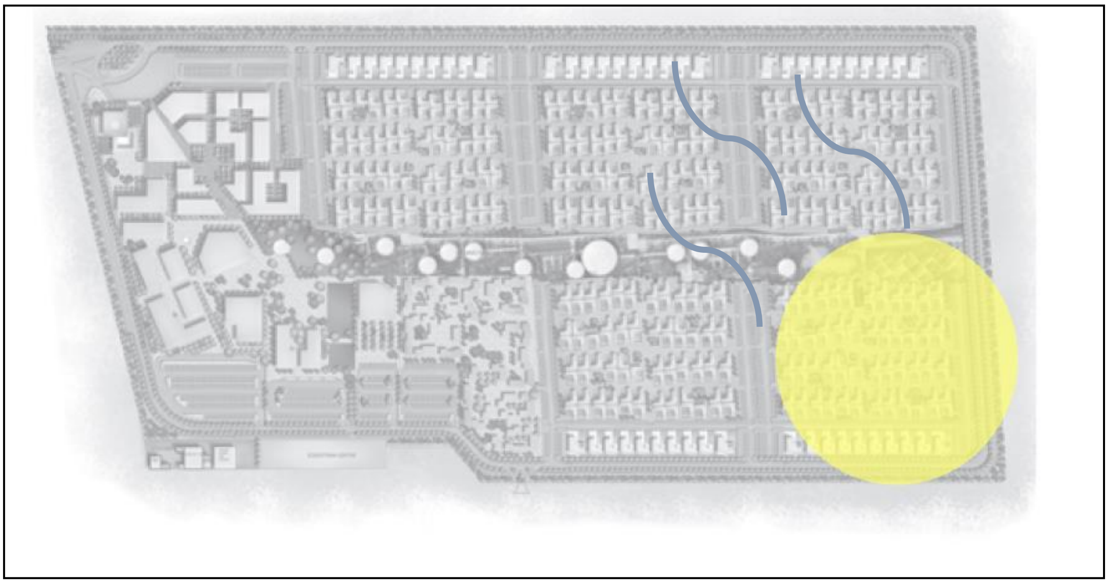

Figure 4.18:DSC site plan showing the investigated cluster (Dubai Sustainble City annual report 2016).

The results of the simulation variables for each rotation angle were recorded and listed in a comparison table with the previous benchmark analysis. Detailed elaboration and discussion will be carried out in chapter 5. The best scenario among all four scenarios is selected and carried ahead for the next phase of this research, keeping the same fixed parameters as well as the angle of rotation. This will help collect and optimize strategies and features overall in the phases ahead.

4.7 Model Set-Up for Urban Configuration Simulation (Phase Two): Building Spacing

During phase two, the simulation aims to examine the impact of urban configuration since many researchers refer to urban configuration as one of the vital factors in urban thermal comfort (Taleb & Taleb 2012), as the overall unit configuration in this project does not follow a standard arrangement that ends up having a different impact on the thermal behaviour of the urban space between each group of semidetached residential units in this project.

Taleghani, Kleerekoper, Tenpierik and Dobbelsteen (2014) and Taleb and Taleb (2012) indicate that building configuration impacts the thermal comfort in the urban spaces, which will have an impact on the interior spaces in advance. This phase investigates four spaces out of the existing layout design that was selected, as each one has a different array around the central open space, as shown in figure 4.19.

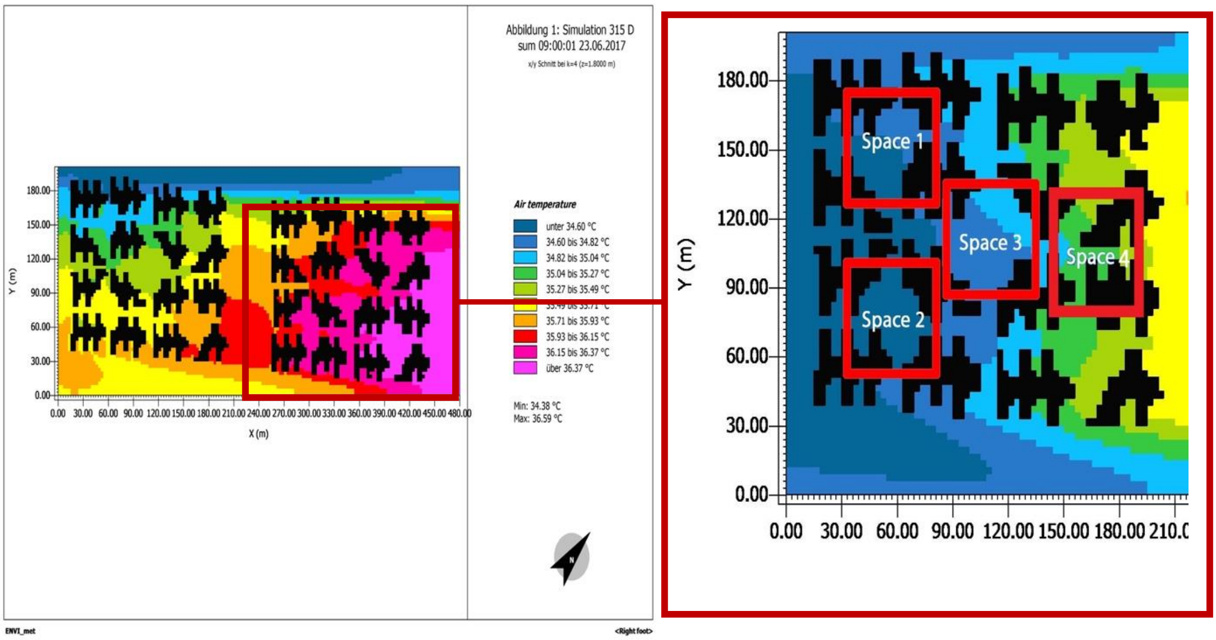

Figure 4.19: Four spaces out of the existing layout design that were selected for this research (adapted from ENVI-met).

This simulation used the same evaluation variables summarised by Thani, Mohamad and Jamaludin (2013) as primary physical parameters when the analysis is based on the relative humidity, air temperature and wind speed. This is consistent with the variables used by Toudert (2015). In addition to that, the PMV value was added as changing parameters at each space, as discussed in section 4.4 and elaborated on in chapter 2, where Setaih, Hamza and Townshend (2013) and Thani, Mohamad and Jamaludin (2013) concluded that these parameters have the most impact on thermal behaviour and user comfort.

On the other hand, Thani, Mohamad and Jamaludin (2013) found evidence that Dubai's greatest urban design challenge is relative humidity and air temperature, which impact the outdoor activities for users and limit the efficiency of open urban spaces such as green parks and community gardens as well as front and back yards for private residential units.

The outcome results of this phase are compared against each other without reference to a benchmark since all four space configurations exist and the preferable selection shall be considered based on the best thermal behaviour among the four options when the layout is oriented to the optimum scenario from phase one.

This simulation is also carried using ENVI-met 4, as discussed earlier in chapter 3, while keeping the same file with the existing-base case model to maintain the consistency of the fixed parameters as well as limit the changes in the initial weather data input that is required to build the model and run the simulation (see table 4.8), as discussed earlier in section 4.6.1 of this chapter. In addition to the individual outcome of each simulation at this phase, the discussion and overall comparison of the results and evaluation variables recorded will be discussed later in chapter 5.

4.8 Model Set-Up for Urban Configuration Simulation (Phase Three): Courtyard Layout.

During phase three, the simulation targets the optimum space configuration of phase two and sets it for a redesign to add the concept of a courtyard, as discussed earlier in chapter 2, where Svedin (2015) indicates that this urban space enhances the social sustainability of the design and impacts public behaviour toward the project. On the other hand, the idea of courtyards is traced back to the traditional architectural forms in this region, as it responds to the climatic challenges and is considered a tool for passive sustainable design, as per Soflaei, Shokouhian and Shemirani (2016). In addition to that, Taleghani, Kleerekoper, Tenpierik and Dobbelsteen (2014) concluded that the courtyard protects the microclimate and reduces the exposure to solar radiation, which will impact the microclimate around the architecture unit.

The courtyard shape and layout impact the thermal characteristics of the urban space by improving the evaluation variables that were discussed earlier in section 4.4.

Microclimate variables the overall experience of using the space by different users will be improved and eventually impact the environment in the interior spaces (Taleb and Taleb, 2014). To examine the impact of courtyards in this case study, four designs of open urban courtyards were implemented in the selected urban space configuration, which is considered the optimal case of the previous phase based on its records with the evaluation variables, which will be explained and listed in chapter 5. The software model used the same fixed variables, which helps neutralise their impact on the final results. The simulation runs for 24 hours on the same day selected for this research simulation, the 23th of June, like the two phases explained earlier in section 4.4, to maintain the same fixed parameters (see table 4.8).

4.9 Model Set-Up (Phase Four): Green Cover

The research aims to enhance the public comfort experience in the outdoor urban spaces by focusing on passive solutions, such as the layout orientation that was studied in phase one and the building configuration that was studied at phase two beside the courtyard design, which was examined in phase three. During this phase, the research targets the vegetation and greenery cover of the urban spaces, as climatologists and urban designers through various studies have proven that greenery and plantation impact outdoor thermal comfort, as Kenawy, Afifi and Mahmoud (2010) and Taleb and Taleb (2014) concluded that vegetation is a primary tool that can be used in order to enhance outdoor thermal comfort, as discussed by Bruse and Skinner (1999).

Following the same guidelines in this research, phase four focuses on investigating the impact of different percentages of green cover and compares the results of the evaluation variables against the optimal selected courtyard design results from phase three that were presented earlier in section 4.8.5 using the ENVI-met 4 as the standard software program for this research, as discussed earlier in chapter 3. The simulation analysis is based on the fact that the current status on site has 0% green cover. This is considered the benchmark for this simulation. Since Rajabi and Abu-Hijleh. (2014) concluded that green grass does not comply with the aim of heat island reduction, as it was found that a collection of greenery trees will have a greater impact on the microclimate and higher contribution to the urban heat island mitigation at city centres compared to green grass surface only.

Therefore, this simulation focuses on using a combination of a palm tree with shrubs in order to maximize the shading effect over pedestrian walkways as well as enhance thermal comfort in urban public spaces. The simulation runs for 24 hours, similar to previous phases, on the exact same day, on four different options, starting with option one, which represents the current status at the site, where the urban spaces between the residential blocks do not include any greenery coverage, only pavement material for sidewalks, while the plantation is limited to the private courtyard of each villa's compliance with the Dubai Green Building Regulation that insists on having at least one palm tree in all residential villas. The second option suggests 15% greenery coverage. The third option suggests 30% green coverage. The final option is 45% coverage. The green coverage includes a flower box of 3 x 3 m, where a palm tree is located and surrounded by 60 cm tall shrubs. This unit is repeated in a different location to cover the required percentage at each scenario.

4.10 Model Set-Up for Indoor Energy Consumption Analysis (Phase Five)

This study is in cooperation with the international effort to reduce GHG emissions and combat the international global warming threat since it is the 13th goal of the United Nation Sustainable Development Goals titled as Climate Change, which indicates the need for urgent action to face the increase in the global temperature, as records are showing that from 1880 to

2012, the average temperature around the world increased by 0.85C° and is expected to reach up to 1.5C (*UN climate change report* 2016).

Therefore, since the UAE is a vital participant in international environmental agreements, such as Paris agreement COP21 signed in 2015, it was essential to meet the UAE 2021 vision and work on implementing the Dubai Green Building Regulation code, where a 20% reduction in average energy consumption is required. Therefore, this phase investigates the impact of the previous four phases that were targeting the outdoor thermal comfort and examines the impact of this enhancement on the indoor energy consumption of the residential units at the area subject to the research analysis.

Since Kwok et al. (2017) noted a linear relationship between the indoor and outdoor temperatures while studying the urban dense areas in Hong Kong, this is consistent with Abdullah (2015), who found that building cooling loads are reduced in buildings where the design is considered responsive to the climate, where designers established weather and site analysis to comply with the surrounding features and environmental requirements of the site. In addition to that, Feng, Ming and Ruey (2015) also investigated the relationship between microclimate conditions of the site and the indoor energy consumption, using computer simulation software for modelling a unified design flat and collecting the weather data from weather stations that were distributed among different locations in Taiwan, as the study runs over three months to validate the collected information recorded by the weather stations as well as use this data to feed the software simulation model. The results also indicate the variation between different urban areas in terms of energy consumption, where the most vegetated site recorded the lowest indoor air temperature compared to all other sites.

Therefore, this phase used DesignBuilder as a simulation software to build a virtual model for one of the residential blocks that surrounds the urban space that was subject to the study in this research. This was done by using the weather file built into the programme and feeding the model with construction and weather data collected from the site for the existing-base case analysis, while the construction and architectural design data were extracted from the developer's brochure that describes the project and its areas as well as present floor plans for the interiors of the residential units, in addition to the site visit and AutoCAD software master plan that was used to build the site plan in the first phase (figure 4.20).

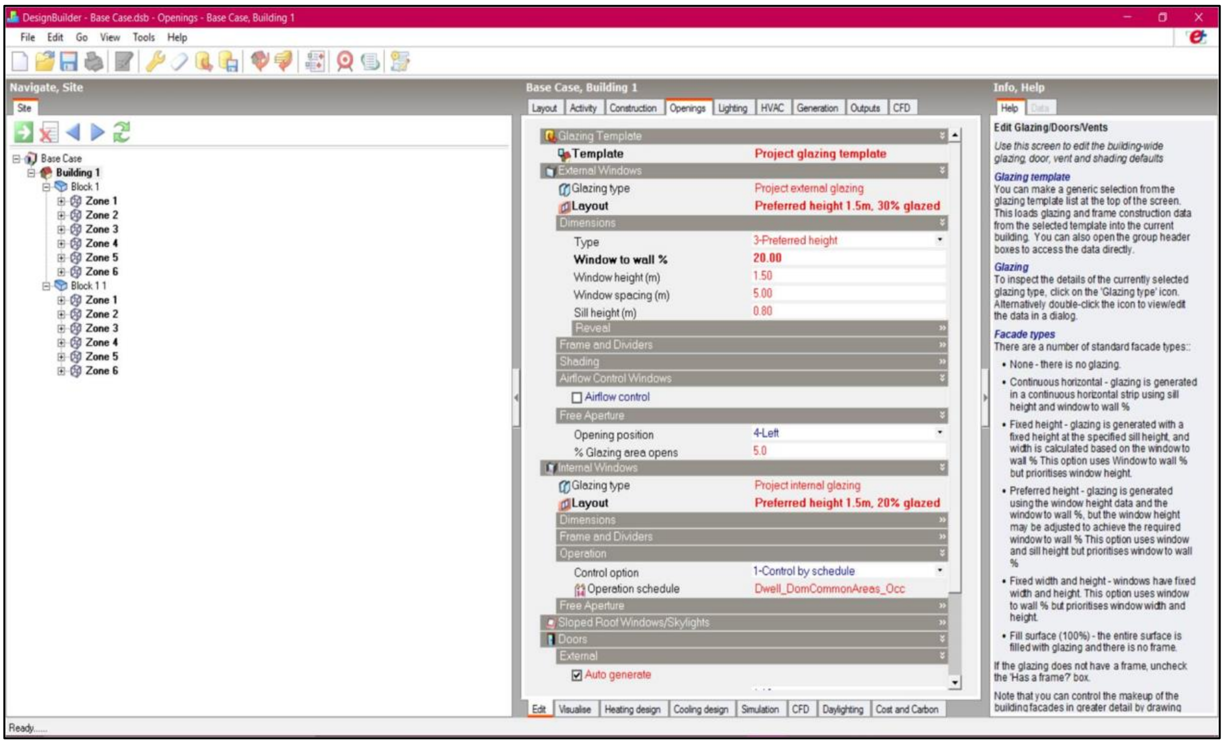

Figure 4.20: DesignBuilder interface showing the construction and architect data entry screen (DesignBuilder software 2017).

Figure 4.21 shows the input data windows in the Design-Builder programme that was needed to build the virtual model for the six residential units as per the existing design on site to run the simulation process where the energy load is measured.

Figure 4.21 shows the input data related to the activity level of indoor spaces and other personal parameters that are essential to determine the thermal comfort threshold level for users, since each space has different parameters based on many aspects, such as user number, type of activity and equipment and machinery pieces used in the area.

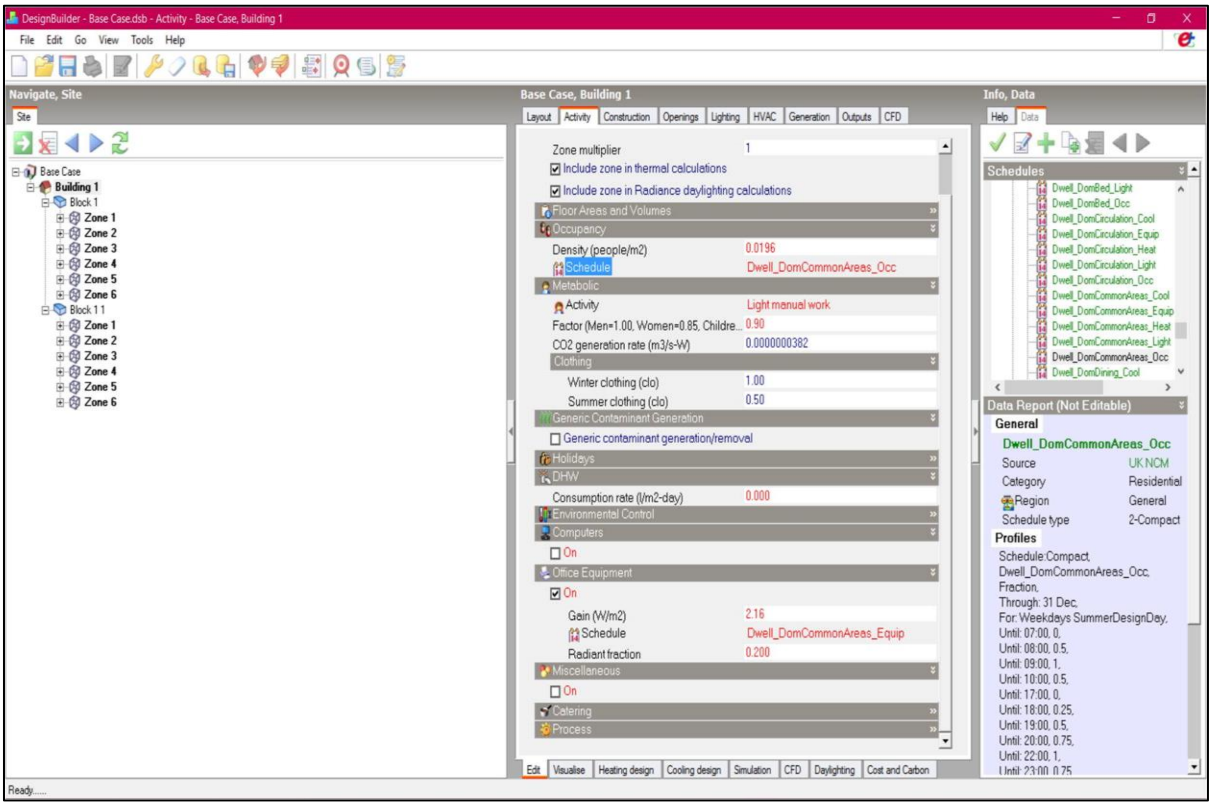

Figure 4.21:DesignBuilder interface showing the indoor activity level data entry screen (DesignBuilder software, 2017).

Figure 4.22 is a screenshot for the model building process, showing the construction data input with the architectural features of walls, ceiling and partition areas and locations.

After running the simulation for the base case using the weather data used in phase one at the beginning of the simulation analysis, the second simulation will be run using the same model but after changing the outdoor air temperature, relative humidity and wind speed variables to meet the final optimal result selected from phase four earlier in order to compare both cases after applying the enhancement that resulted from the previous strategies since the target of the previous four phases is to enhance the outdoor thermal comfort of the urban spaces around the residential units.

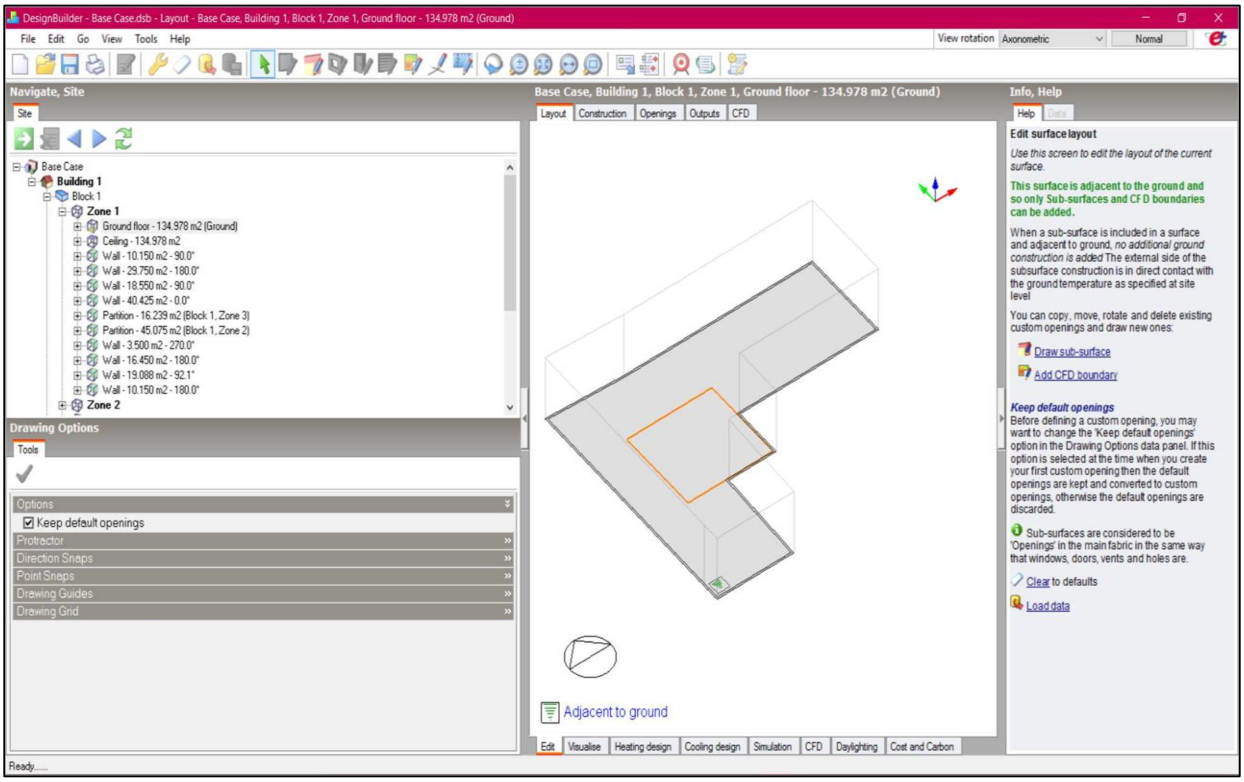

Figure 4.22:DesignBuilder interface showing the model construction process (DesignBuilder software 2017).

CHAPTER 5
RESULTS AND FINDINGS

5 Result and Findings

5.1 Chapter Preface

By the end of the computer simulation analysis, the results were collected using LEONARDO 2014 software that is designed by ENVI-Met 4, to bring the simulation results into graphical readable maps with numerical and colour range legend on the side. It is the same software Huttner, Bruse, Dostal (2010) and Huynh, Eckert (2012) as well as Tsitoura, Michailidou, and Tsoutsos (2016) used it recently in their simulation-based researches.

At this chapter, the values of the evaluating variables of each phase of the five phases presented earlier in chapter four, while the results and findings are discussed, analyzed and compared to the previous results and findings of other research papers that were discussed and elaborated earlier in the literature review.

After concluding with the final optimal design through four phases of passive urban design strategies to enhance the outdoor thermal comfort examined using ENVI-met 4, the DesignBuilder software is used to evaluate the impact of these enhancements on the indoor energy consumption of the residential units that were surrounding the urban space subject of this study.

This chapter aims on responding to the research question listed earlier at chapter two section 2.7 and spot the similarity as well as differences between Dubai sustainable city as a case study of this research and the previous similar research topics, in order to conclude with recommendations and guidelines for urban designers and other parties involved in achieving thermal comfort at outdoor and indoor spaces through Urban passive design configurations and landscaping.

The structure of this chapter follows the simulation process see figure 5.1, that started by phase one was the optimal orientation is investigated by setting the current existing orientation of the project into examination to evaluate the thermal behaviour using the evaluation variables selected and listed earlier in chapter four.

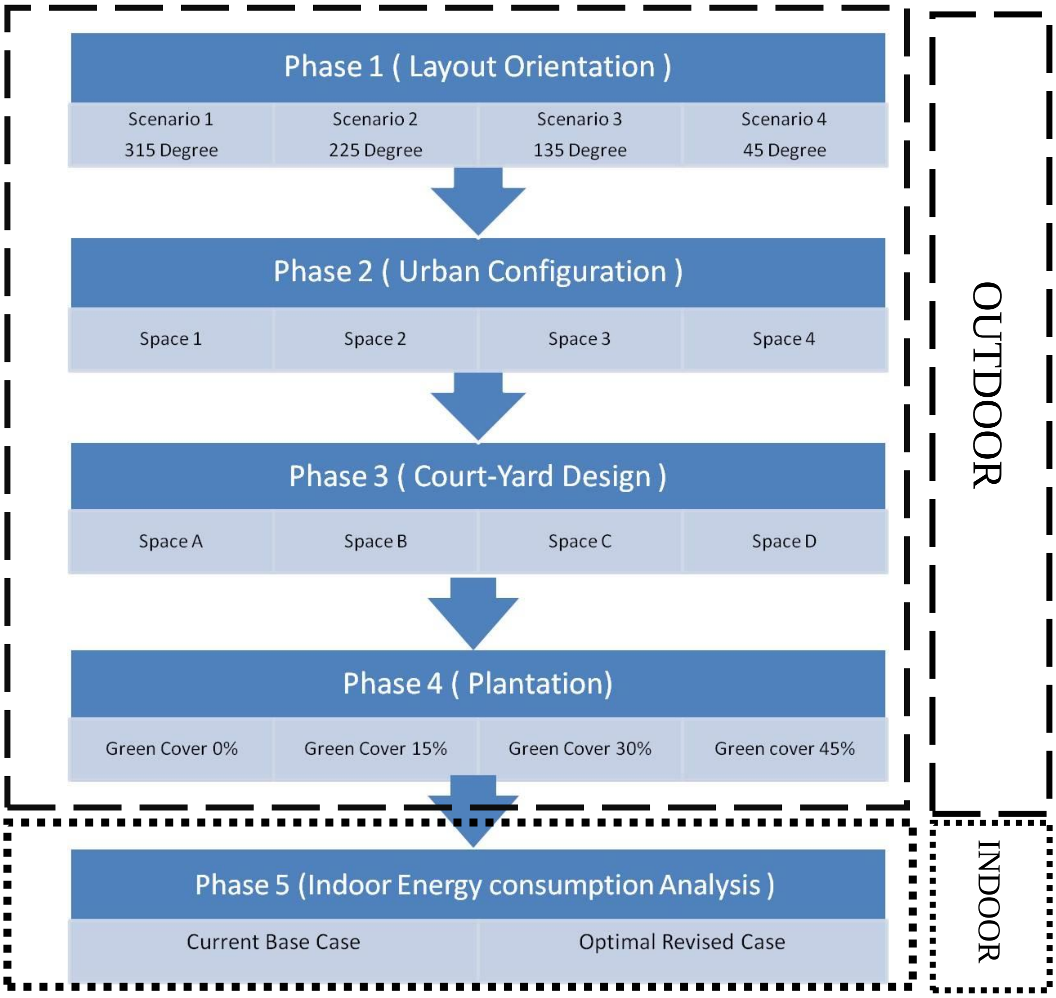

Figure 5.1: Simulation phases hierarchy.

Then compare the results to three other suggested layout orientations to specify the best scenario and use it as the base case for the next phase. The second phase aims to study the optimal urban configuration out of four different space configuration found at the existing design of the case study as shown figure 5.2, this phase also used the same evaluation variables described earlier at chapter four as concluded by (Setaih, Hamza, & Townshend, 2013) and (Montazeri and Blocken 2013), as well as (Futcher, Kershaw, & Mills, 2013) ,who agreed that

Orientation and urban configuration impacts necessary weather parameters such as air temperature and wind speed as well as relative humidity, therefore, these parameters are used to evaluate and judge the previous design strategies in term of thermal comfort enhancement in the second phase too.

Figure 5.2: Dubai Sustainable city master plan showing the location of the four different spaces in phase 2 (Adapted from Dubai Sustainable City annual report, 2016)

The orientation and building configuration are tested previously, in addition to the greenery cover impact that was examined by (Thani, Mohamad &Jamaludin, 2013), and Taleb & Taleb (2014) side by side with courtyard proportion and design that was tested by Ahmed and Abu-Hijleh (2016). This was analysed in phase three after selecting optimal case of phase two to be the base case while studying four suggested courtyards designs as recommended by the conclusion of Zhao, Liu, & Zhou. (2016), as well as Ahmed and Abu-Hijleh (2016) for its impact over outdoor microclimate.

The impact of four different courtyard designs on the open urban space is examined using the same evaluation variables that were used to investigate phase one and two earlier. The outcome result of this phase will be the recommended courtyard design that improves the thermal comfort parameters and will be taken to phase four as a base case and benchmark for further analysis and enhancements.

The fourth phase of this research investigates the impact of landscaping and greenery coverage over outdoor urban spaces, by proposing three different green coverage percentage into the optimal result of the previous phase, considering that the current existing case has zero green coverage, therefore, the simulation compares four various options using the same evaluating variables used earlier in this research.

The result of the four previous phases will be an urban space designed with a specific configuration that includes a courtyard designed with the recommended percentage of greenery, which optimizes the thermal comfort evaluation variables used through all different phases which are relative humidity, wind speed, air temperature and PMV value. This result will be tested for its impact on the indoor energy consumption at the residential units, by comparing the current existing design using Design-Builder Software that was used earlier by Torre, Yousif (2014) and Boafo, Ahn, Kim, and Kim (2015), as well as Kwok, Lau, Lai. etc. (2017) elaborated earlier in chapter two and three. This aims to evaluate the impact of the outdoor thermal comfort enhancements over indoor energy consumption using layout orientation, urban configuration, courtyard design, and landscaping.

Finally, this chapter will end up with an elaborated discussion and analysis over the topic and findings, as a reply to the research question to fulfill the research aim.

5.2 Phase One Introduction

Phase one started by building the software model using ENVI-met 4 regarding the AutoCAD software drawings of the master plan, where one cluster was selected for the research scope of work see figure 5.3, and examined its thermal comfort basic parameters by building at its current - existing orientation, first as explained earlier chapter four section 4.6, in order to extract the microclimate data as a base case then compare it with further suggested scenarios.

Figure 5.3: Dubai Sustainable city selected cluster for this study PO7-P08(Adapted from DSC annual report, 2016)

While evaluation and best scenario selection are based on its recorded result for the evaluation variables described earlier chapter four section 4.4, and presented below in figure 5.4.

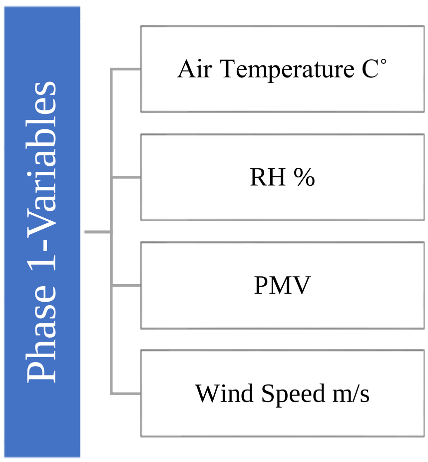

Figure 5.4:Phase 1 evaluation variables.

5.2.1 Result and Findings of Existing – Base Case (45 Degrees)

The existing base case north direction is oriented 45 degrees clockwise. This orientation was selected by developers based on wind direction analysis to increase wind velocity within the site that will drive ambient temperate down as per the client (April 2013) see figure 5.5.

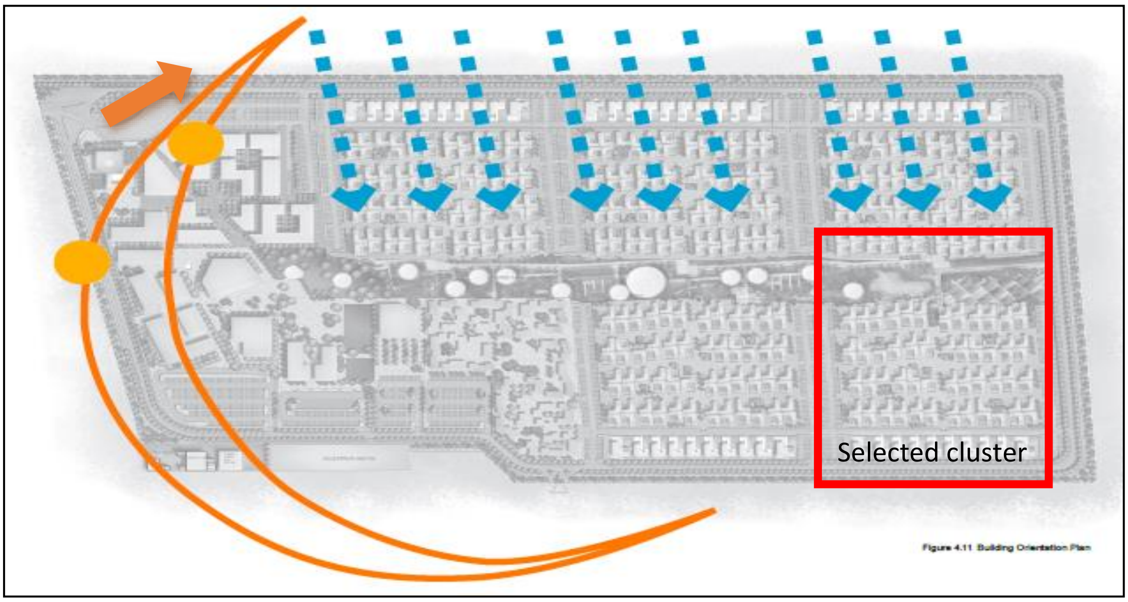

Figure 5.5: Dubai Sustainable city site analysis showing the prevailing wind direction and sun direction in the base case (Adapted from Dubai Sustainable City annual report, 2016)

The analysis of the selected cluster for this research as per the Existing - base case urban layout in its current orientation using ENVI-met 4, shows relative humidity reaches its peak at 03:00 as it goes above 86.70%, while drops below 19.25% at 15:00 with an average of 56.27 % during the day on 23rd of June. While the wind speed records it highest values as it reaches 3.54 m/s at 01:00, but its lowest records were 2.68 m/s at 00:00, see table 5.1. The average recorded over the day is 2.55 m/s. On the other hand, the air temperature is hitting peak point at 15:00, where it records 57.05 C˚ and reaches its lowest point at 06.00, where it marks 29.94 C˚ setting an average of 41.02C˚.

In addition to the above parameters, the PMV values were tested over the day and noted that the highest value was recorded at 15:00, where it hits (10.04) while its lowest values were recorded at 06.00 as it drops to 1.43 meeting the air temperature time for pack, as well as lowest point and setting an average of 5.10 over the day, see table 5.1.

Table 5.1: Summary of numerical data extracted in Phase 1- (45 Degree) on June 23, 2017, for 24 hours.

Base case (45 Degree)	R.H %	Wind Speed m/s	Air Temp. C°	PMV
1:00	64.35	3.54 ↑	36.64	3.89
2:00	72.55	3.32	33.3	2.78
3:00	86.76 ↑	3.23	29.95	1.58
4:00	84.81	3.13	29.72	1.51
5:00	83.84	3.08	29.61	1.47
6:00	82.86	3.03	29.49 ↓	1.43 ↓
7:00	82.5	3.00	32.56	2.65
8:00	81.34	2.95	33.53	3.62
9:00	80.17	2.89	35.63	4.81
10:00	74.33	2.865	36.65	5.25
11:00	72.23	2.86	42.33	6.12
12:00	68.49	2.84	44.3	6.98
13:00	45.55	2.85	48	7.86
14:00	32.4	2.91	52.53	8.94
15:00	19.25 ↓	2.97	57.05 ↑	10.04 ↑
16:00	20.04	2.98	55.55	9.64
17:00	20.43	2.96	53.83	8.45
18:00	20.82	2.98	52.1	7.30
19:00	29.32	2.90	46.9	5.81
20:00	33.33	2.85	43.64	5.11
21:00	37.81	2.72	41.7	4.32
22:00	51.08	2.70	40.38	4.25
23:00	64.35	2.69	40.1	4.32
00:00	41.93	2.68 ↓	39.05	4.32
Average	**56.27**	**2.955**	**41.02**	**5.1018**

The simulation analysis as seen from the maps in figure 5.6 presented using LEONARDO Beta and the numerical data that were extracted as listed above in table 5.1, shows a link between Air temperature and PMV value as both are reaching a maximum point and minimum point simultaneously at the same time of the day.

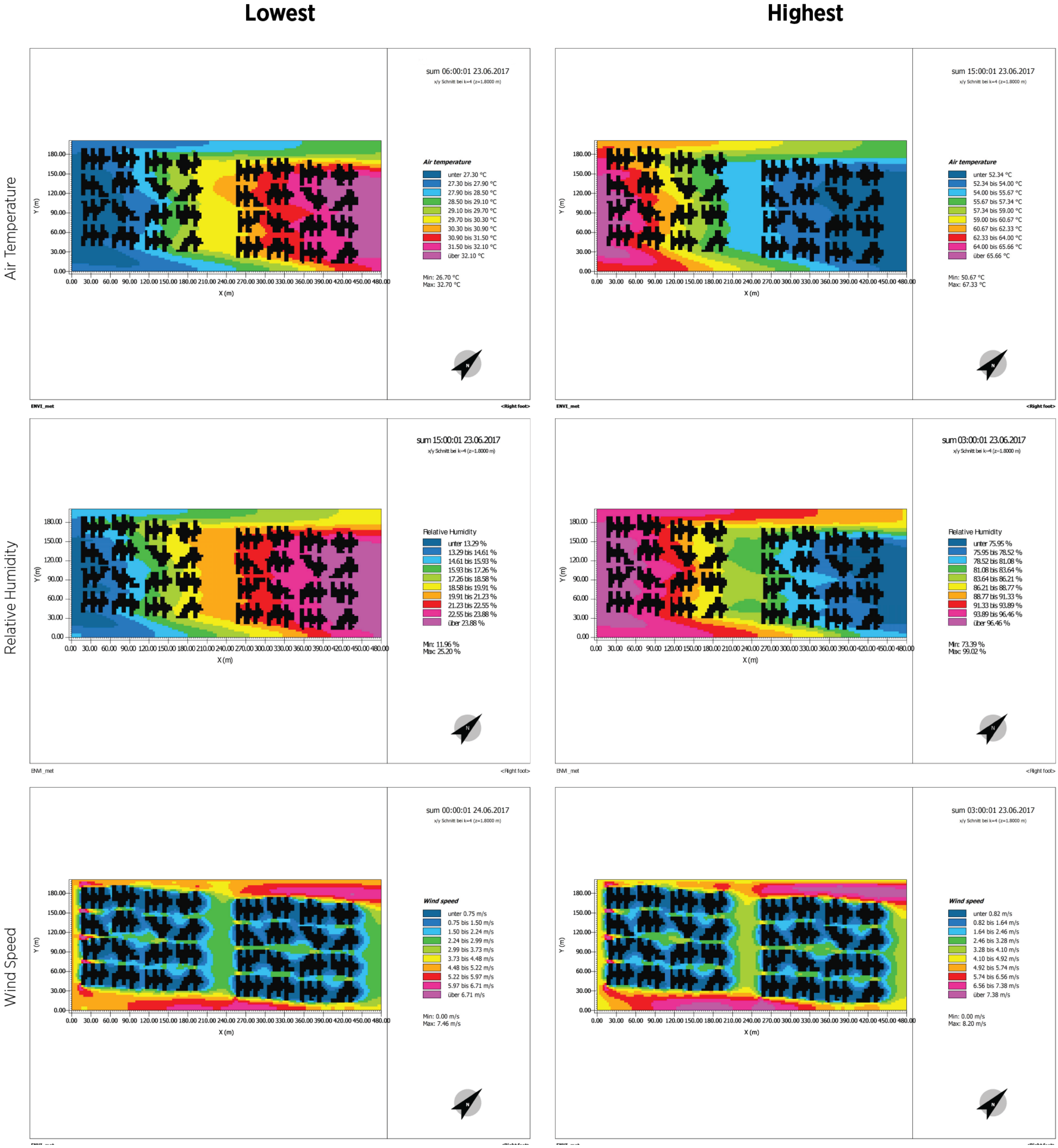

Figure 5.6: Envi-met maps are showing the highest and lowest readings for air temperature, RH, wind speed, and PMV -45 Degree. (For all 24 hours' maps refer to Appendix 1)

This is expected since PMV equation designed by Fanger (1972) has air temperature as the primary variable aside with wind speed and other factors that were taken as fixed parameters when establishing the model for this research. Figure 5.7 indicates the personal parameters used for Biomet analysis required for PMV calculation.

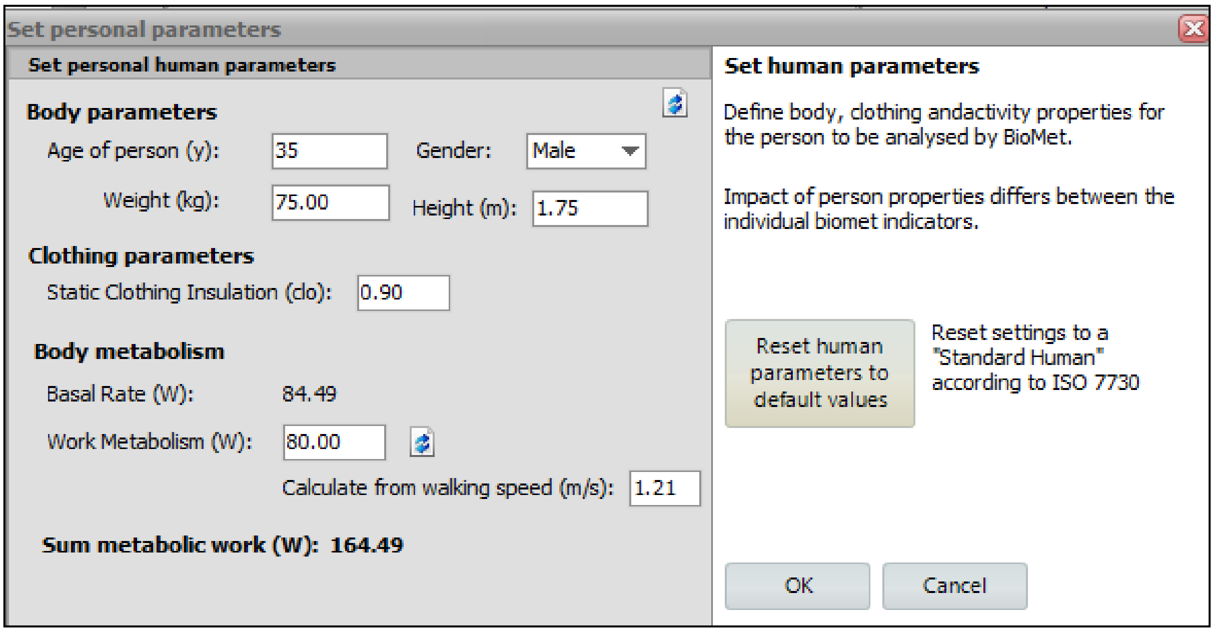

Figure 5.7: Biomet analysis personal parameters used for PMV calculation (ENVI-met software, 2017).

As shown the average age of the analysis is considered 35 years, gender subject for the study is a male who weight 75 kg, with a height of 1.75m and Clo=0.90. This input was assigned as per (standard Human) about ISO 7730 as noted by Envi-Met itself.

5.2.2 Layout Orientation Simulation of Scenario 1 (135 Degrees)

The analysis was built using the same file from the previous simulation to ensure consistency of data that is not under research scope of work as explained previously at section 4.6. Only this time the north arrow was indicated at 135 degrees by giving this value at the model domain settings illustrated chapter four, see figure 5.8 that represent the new north arrow.

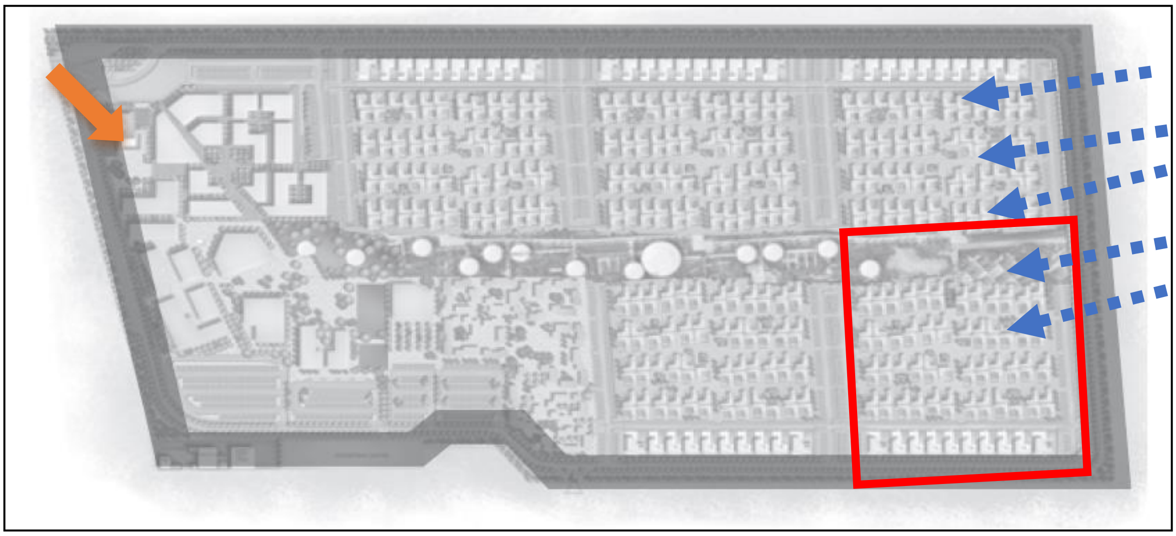

Figure 5.8: Dubai Sustainable city master plan showing the prevailing wind direction and sun direction in 135 scenarios (Adapted from DCS annual report, 2016)

Unlike the previous case, the wind is crossing the site at the shorter side of the site plan, with a longer path to penetrate which might create a lot of wind barriers that stop or reduce the air velocity remarkably. Since the selected cluster is forming almost a square, this impact might not be noticed, yet the analysis shows that R.H reaches its peak at 03:00, as it goes above 80.9% while drops to 19.46% at 15:00, with an average of 46.63 % during the day, that is higher than the previous case.

Simultaneously, the wind speed records it highest values that were 3.2 m/s, at the same time 15:00 am but, its lowest records were 2.79 m/s at 22:00, see table 5.2 below were the average recorded over the day is 2.98 m/s, that is 0.33m/s less than the previous case. On the other hand, the air temperature is hitting peak point at 15:00 where it records 53.51 C˚, and reaches its lowest point at 06.00, where it records 33.77 C˚ setting an average of 41.76 C˚ that is 0.57 C˚ less than the previous case. Additionally, the PMV values were tested over the day and noted that the highest value was recorded at 15:00, where it hits (9.25) while its lowest values were at 06.00 and 05:00 were it drops to 1.92 setting an average of 5.08 over the day that is 0.26 less than base case, see table 5.2.

Table 5.2: Summary of numerical data extracted in Phase 1- (135 Degree) on June 23, 2017, for 24 hours.

Scenario 1 (135 Degree)	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	53.51	2.98	35.5	3.52
2:00	66.98	3.00	33.75	2.85
3:00	80.9 ↑	3.15	32	2.04
4:00	78	3.07	31.89	1.98
5:00	76.55	3.03	31.83	1.95 ↓
6:00	75.1	2.99	31.77 ↓	1.92 ↓
7:00	72	2.97	33.36	2.80
8:00	69.86	2.93	33.97	3.59
9:00	67.71	2.89	34.95	4.60
10:00	54.71	2.92	39.22	5.82
11:00	48.65	2.92	44.6	6.41
12:00	41.7	2.95	46.18	6.99
13:00	34.58	2.99	49.98	7.94
14:00	27.02	3.08	51.75	9.03
15:00	19.46 ↓	3.2 ↑	53.51 ↑	9.25↑
16:00	19.79	3.18	51.99	8.85
17:00	19.95	3.16	50.73	7.98
18:00	20.11	3.14	49.47	6.70
19:00	23.01	3.00	46.8	5.70
20:00	24.41	2.96	45.15	4.00
21:00	25.9	2.81	44.13	4.70
22:00	39.71	2.79 ↓	43.51	4.58
23:00	53.51	2.8	43.31	4.44
00:00	26.12	2.8	42.88	4.36
Average	**46.63**	**2.988**	**41.76**	**5.0833**

The simulation of scenario as presented in figure 5.9, were the maps indicates north direction at 135 degree shows a decrease of wind speed average as expected since the airflow is hitting the site from the shorter side without tunnelling through the paths between the residential blocks.

On the other hand, the link between the different weather variables as the lowest R.H percentage is recorded at the same time with the highest wind speed, air temperature, and PMV values. While the link is stronger between air temperature and PMV as both records lowest values at the same time, see table 5.2 and figure 5.9. The difference between highest R.H. percentage and lowest PMV value is 0.09 while the difference between highest R.H percentage and lowest Air temperature is 0.23C°.

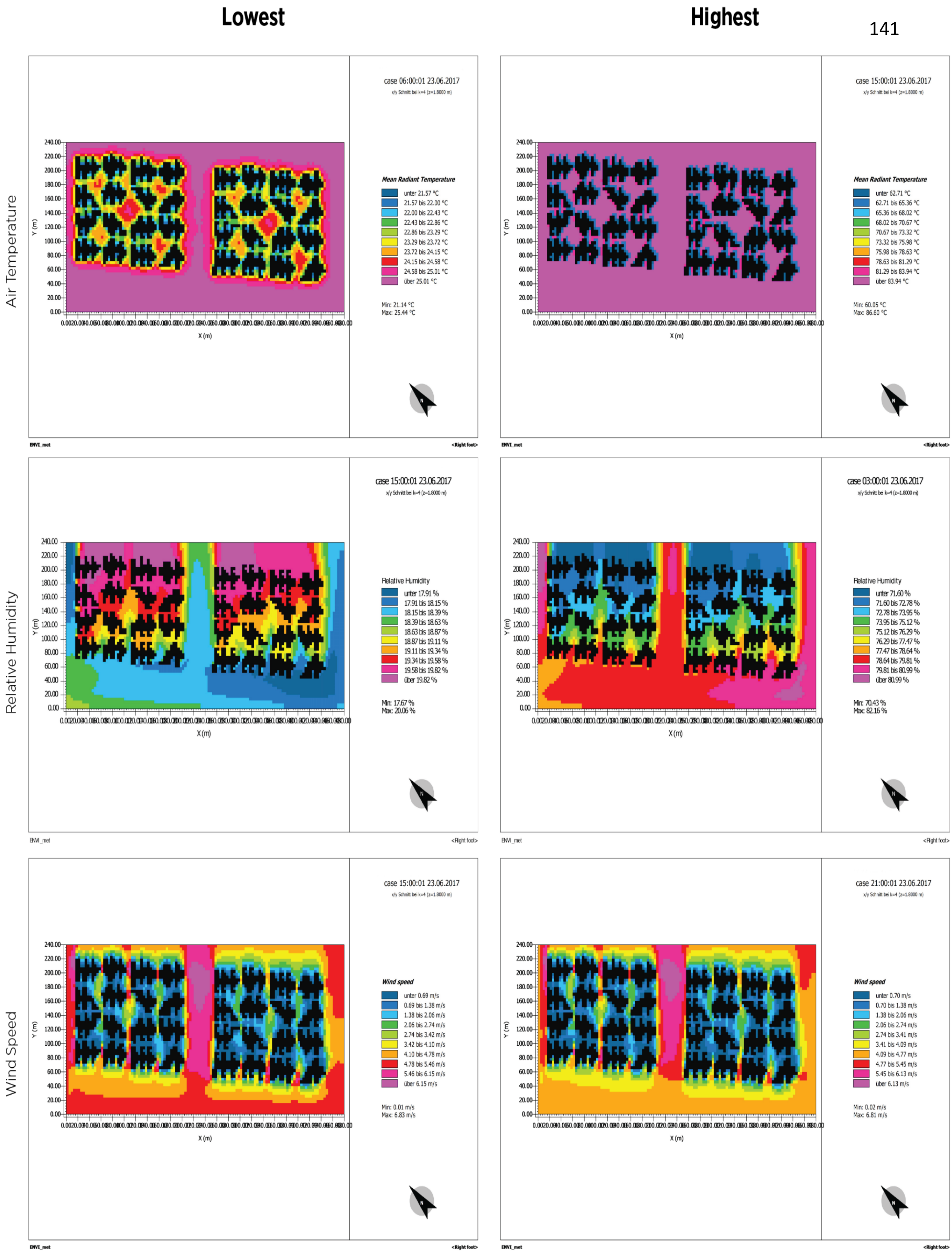

Figure 5.9: Envi-met maps are showing the highest and lowest readings for air temperature, RH, wind speed, and PMV -135 Degree. (For all 24 hours' maps refer to Appendix 1)

5.2.3 Layout Orientation Simulation of Scenario 2 (225 Degree)

The same file from the previous simulation was used once again to maintain consistency of fixed parameters. After changing the rotation degree to 225 known as south-west for this scenario at the model domain settings as explained earlier, where wind direction is rotated as illustrated in figure 5.10 below.

Figure 5.10: Dubai Sustainable city site plan is showing the prevailing wind direction in 225 Degree scenario (Adapted from DCS annual report, 2016).

Similar to the base case the wind is crossing the site at a longer side of the site plan, with a shorter path to penetrate between the units. The analysis shows that R.H reaches its peak at 03:00 as it goes above 73.90% while drops to 19.67% at 18:00 with an average of 40.02% during the day, that is less than the previous case. Simultaneously, the wind speed records it highest values at the same time where it records 3.63 m/s, but its lowest records were 3.2 m/s at 22:00, see table 5.3 where the average is 3.418 m/s, over the day that is 0.43m/s higher than the previous case, and 0.1m/s higher than base case.

On the other hand, the Air temperature is hitting peak point at 15:00 where it records 49.73C˚ and reaches its lowest point at 03.00, where it records 33.66 C˚ setting an average of 42.05C˚ that is 0.29 C˚ less than the previous case, and 0.28C˚ lower than base case.

Table 5.3: Summary of numerical data extracted in Phase 1- (225 Degree) on June 23, 2017, for 24 hours.

Scenario 2 (225 Degree)	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	47.05	3.45	38.21	4.00
2:00	59.98	3.56	35.94	3.65
3:00	73.94 ↑	3.63 ↑	33.66 ↓	2.40
4:00	70	3.55	33.7	2.37
5:00	68.03	3.51	33.72	2.36
6:00	66.06	3.47	33.74	2.34 ↓
7:00	63.15	3.36	35.33	3.10
8:00	58.65	3.37	35.81	3.98
9:00	54.14	3.36	36.92	4.91
10:00	41.2	3.405	39.91	5.98
11:00	36.1	3.44	43.52	6.52
12:00	28.25	3.45	46.68	7.05
13:00	27.02	3.45	47.12	7.45
14:00	23.66	3.50	48.43	7.99
15:00	20.3	3.55	49.73 ↑	8.32 ↑
16:00	19.99	3.50	48.21	7.72
17:00	19.83	3.45	48.06	7.15
18:00	19.67 ↓	3.41	47.91	6.36
19:00	20.35	3.40	46.62	5.66
20:00	20.98	3.32	45.84	5.12
21:00	21.03	3.23	45.33	4.96
22:00	34.04	3.20 ↓	45.06	4.96
23:00	47.05	3.24	45	4.85
00:00	20.15	3.23	44.79	4.80
Average	**40.02**	**3.418**	**42.05**	**5.1665**

Additionally, the PMV values were tested over the day and noted that the highest value was recorded at 15:00, where it hits (8.32), while its lowest values was at 06.00, were it drops to 2.34 setting an average of 5.16 over the day that is 0.08 more than the previous case while it is 0.174 less than base case, see table 5.3.

The simulation of this scenario as presented in figure 5.11 were the maps indicates north direction at 225 degree shows an increase of wind speed average compared to scenario one, and base case. Since the air flow is penetrating the site from the long side, while the selected cluster is facing fewer windbreakers and blocks compared to the base case. Additionally, the numerical data show a link between the maximum wind speed and maximum R.H. that is against previous scenarios were high R.H is linked to low wind speed, as well as the lower air temperature is recorded at the same hour of the day with a slight difference of 0.06 from the lowest PMV value recorded on the same day.

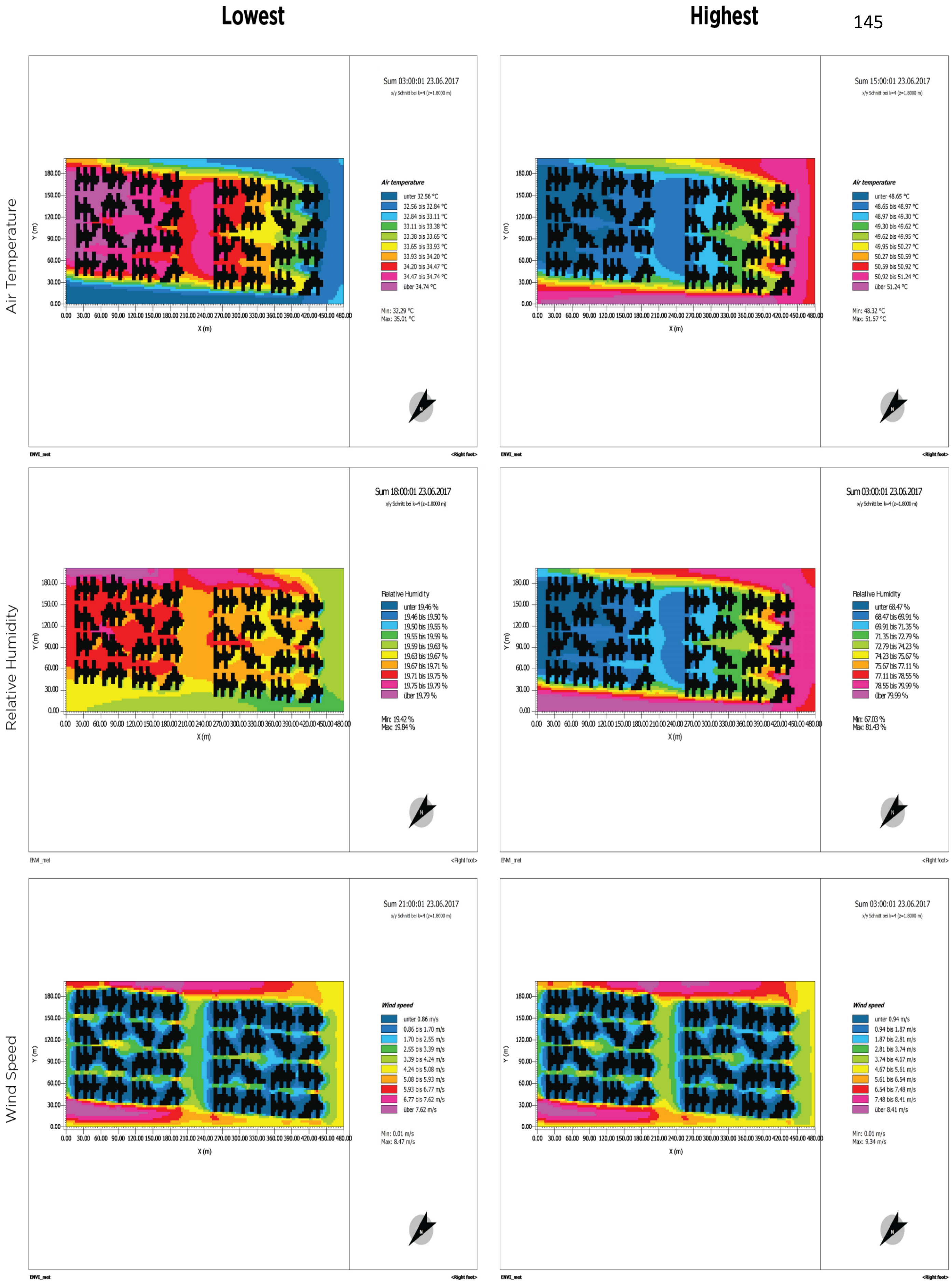

Figure 5.11: Envi-met maps were showing the highest and lowest readings for air temperature, RH, wind speed, and PMV - 225 Degree. (For all 24 hours' maps refer to Appendix 1)

5.2.4 Layout Orientation simulation of scenario 3 (315Degrees)

For the final scenario, again the same model was used once again to ensure keeping the fixed parameters neutral over the final result. After changing the rotation angle to 315 Degree known as north-west at the model domain settings for this scenario, as shown in figure 5.12, the wind direction found to be crossing the site from the shorter side again like scenario one.

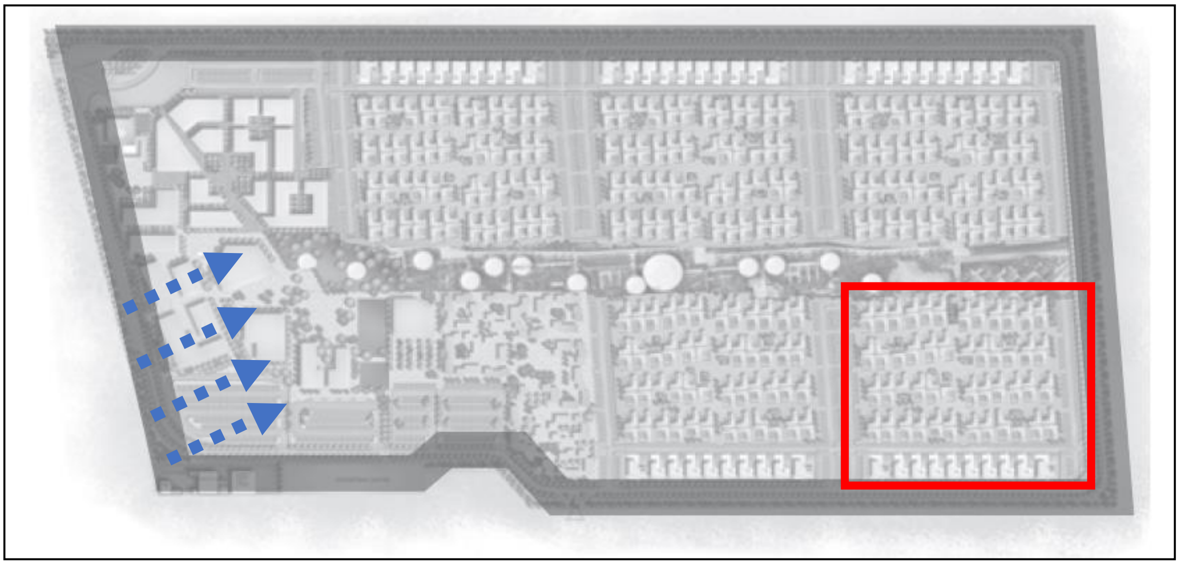

Figure 5.12: Dubai Sustainable city site plan is showing the prevailing wind direction in 315 Degree scenario (Adapted from DCS annual report, 2016).

The analysis shows that R.H reaches its peak at 03:00 like all previous scenarios, as it up to 76.71% while drops to 18.74% at 17:00 and 18:00 with an average of 39.95% during the day, that that is the lowest among all previous scenarios. As for wind speed, the highest values are recorded at 16:00 were it was 3.5 m/s but, its lowest records were 3.2 m/s at 02:00, see table 5.4 where the average is 3.318 m/s over the day, that is lower than the previous case that is scenario two by 0.1m/s yet higher than scenario one and base case. On the other hand, the air temperature is hitting peak point again at 15:00, where it records 50.46C˚ and reaches its lowest point at 03.00 where it records 33.19C˚ setting an average of 42.33C˚, that is the highest among all scenarios. Additionally, the PMV values indicate the highest value at 15:00, where it hits (8.49), while its lowest values were at 06.00 where it drops to 2.30 setting an average of 5.34 over the day, that is the highest among all scenarios. See table 5.4.

Table 5.4: Summary of numerical data extracted in Phase 1- (315 Degree) on June 23, 2017, for 24 hours.

Scenario 3 (315 Degree)	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	47.79	3.25	40.21	4.23
2:00	58.31	3.2 ↓	36.7	3.84
3:00	76.71 ↑	3.33	33.19 ↓	2.35
4:00	72.98	3.3	33.22	2.33
5:00	71.12	3.285	33.24	2.31
6:00	69.25	3.27	33.25	2.30 ↓
7:00	62.75	3.27	34.79	3.05
8:00	60.29	3.33	35	4.15
9:00	57.82	3.23	36.33	4.93
10:00	42.05	3.265	38.87	6.04
11:00	34.51	3.28	43.56	6.71
12:00	26.28	3.3	47.27	7.38
13:00	23.35	3.4	48.25	7.76
14:00	21.05	3.39	49.36	8.00
15:00	18.75	3.48	50.46 ↑	8.49 ↑
16:00	18.75	3.5 ↑	50.5	8.09
17:00	18.74 ↓	3.44	49.34	7.83
18:00	18.74 ↓	3.42	48.17	6.94
19:00	19.38	3.38	46.84	6.00
20:00	19.5	3.27	46.09	5.64
21:00	20.02	3.23	45.51	5.06
22:00	33.91	3.34	45.33	5.01
23:00	47.79	3.21	45.3	4.97
00:00	18.87	3.25	45.15	4.93
Average	**39.95**	**3.318**	**42.33**	**5.3474**

The simulation of the last scenario as presented in figure 5.13 and the maps that indicates north direction at 315 degree known as north-west direction, shows the lowest R.H percentage among all previous scenarios, concurrently with the highest air temperature record compared to all previous scenarios side by side with the highest PMV value, while wind speed was second highest record among all scenarios, as unlike the past scenario, the highest R.H percentage was connected to the lowest wind speed records with 0.13m/s difference only as shown table 5.4.

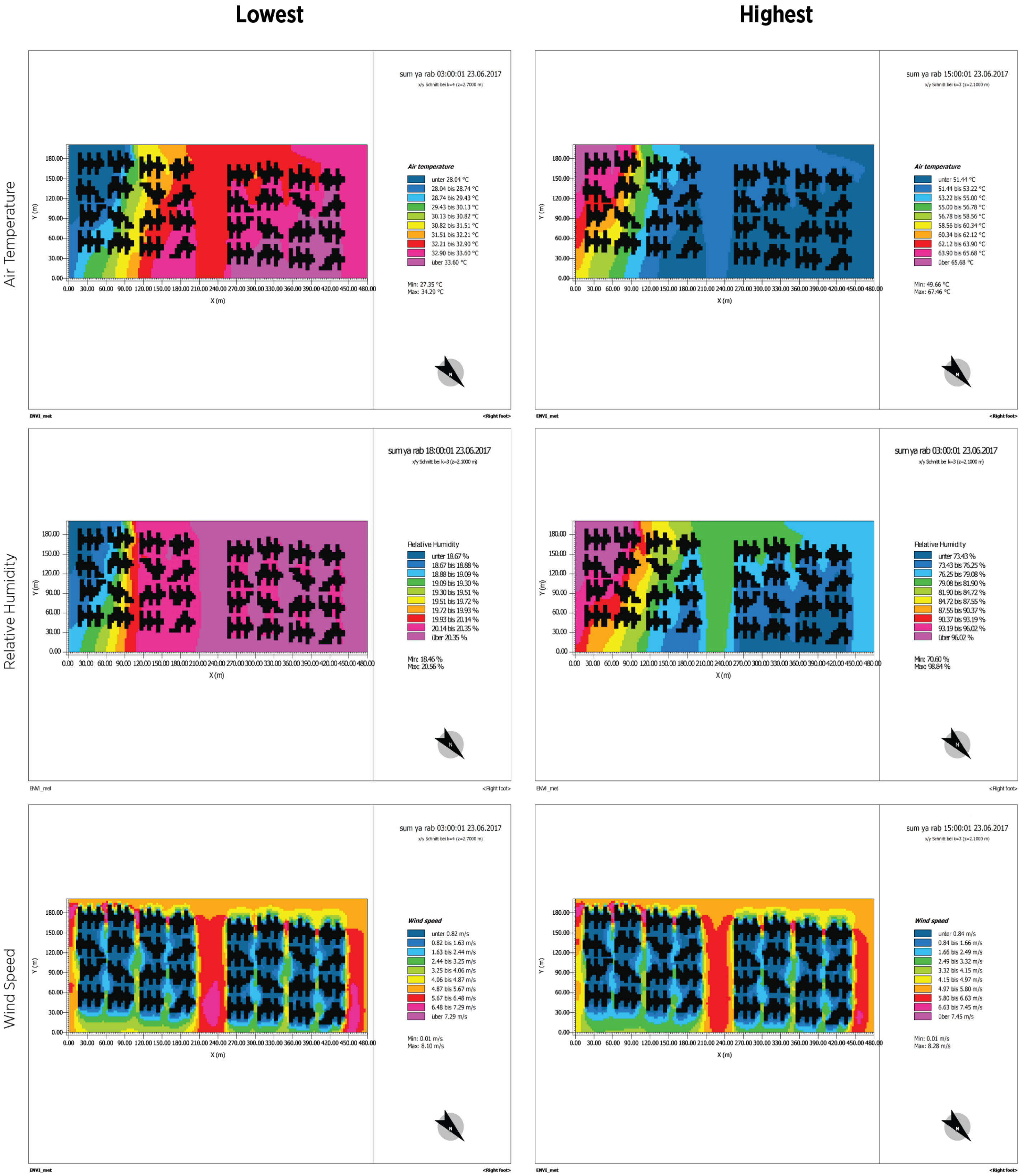

Figure 5.13: Envi-met maps were showing the highest and lowest readings for air temperature, RH, wind speed, and PMV - 315 Degree. (For all 24 hours' maps refer to Appendix 1)

5.2.5 Layout Orientation summary and discussion

Phase one of this simulation analysis aims to investigate the optimal orientation for Dubai Sustainable city, where the project is announced an advertised as being a first sustainable city in the region. In term of orientation, the project developers clearly stated that the orientation allows maximum wind velocity to cross the site through the urban layout, that creates wind tunnels between the residential blocks to enhance wind speed through different clusters, yet the analysis for the selected cluster shows that rotating the site at 315 degrees or in another way mirror the plot will be more effective in term of wind speed, this is related to the fact that at the existing case wind crosses the cluster above the selected cluster: first which creates windbreakers and obstacles that reduces the speed, unlike the case if the wind hits the selected cluster first as it is the case in scenario 3, this will allow the selected cluster to harness higher speed at first before the wind hits any obstacles as seen figure 5.14, were wind direction are illustrated in both scenarios showing the location of the selected cluster.

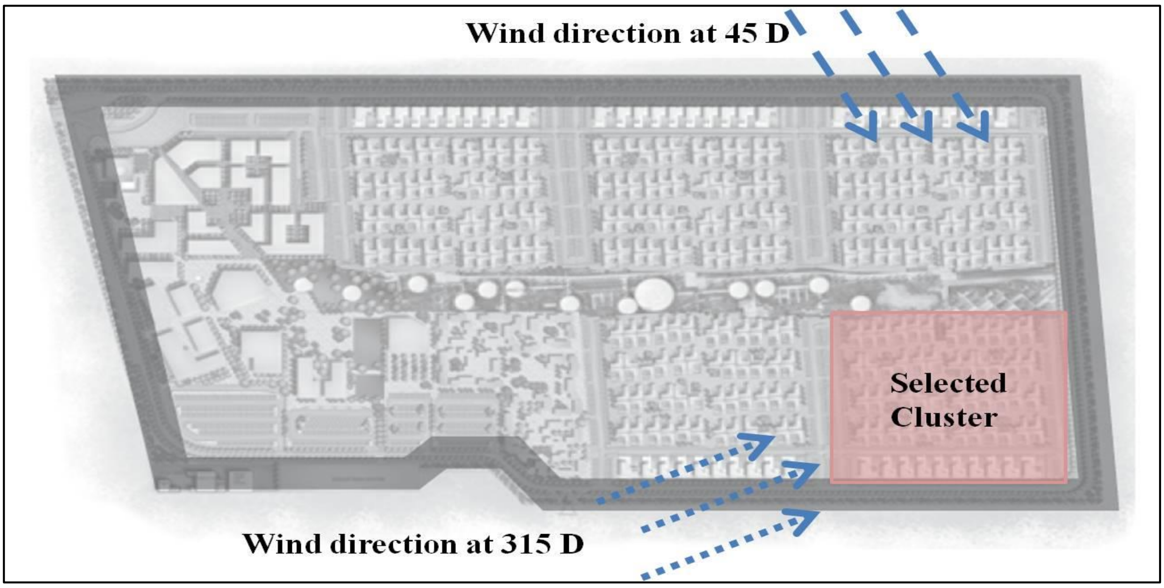

Figure 5.14: Dubai Sustainable city site plan is showing the prevailing wind direction of 45 D and 315 D (Adapted from DCS annual report, 2016).

Even though wind speed is recorded higher in scenario three than in the base case as shown in table 5.5, the air temperature is also higher with a 1.31C° difference, which was also reflected in the PMV value that was 0.24 higher in scenario three than the base case. While as expected the R.H is setting the lowest percentage among all other simulation since scenario three has the most top wind speed as shown in table 5.5 below.

Table 5.5: Phase one scenarios variables average summery.

Phase 1 Average	Base Case (45 Degree)	Scenario 1 (135 Degree)	Scenario 2 (225 Degree)	Scenario 3 (315 Degree)
R.H	**56.27**	**46.63**	**40.02**	**39.95**
Wind Speed	**2.955**	**2.988**	**3.418**	**3.318**
Air Temp	**41.02**	**41.76**	**42.05**	**42.33**
PMV	**5.1018**	**5.0833**	**5.1665**	**5.3474**

The results are showing consistency in a pattern of behaviour between air temperature and PMV as shown in the figure 5.15 below, for example, were the existing-base case orientation indicating that air temperature is recording increase and decrease in consistency with PMV values over the day.

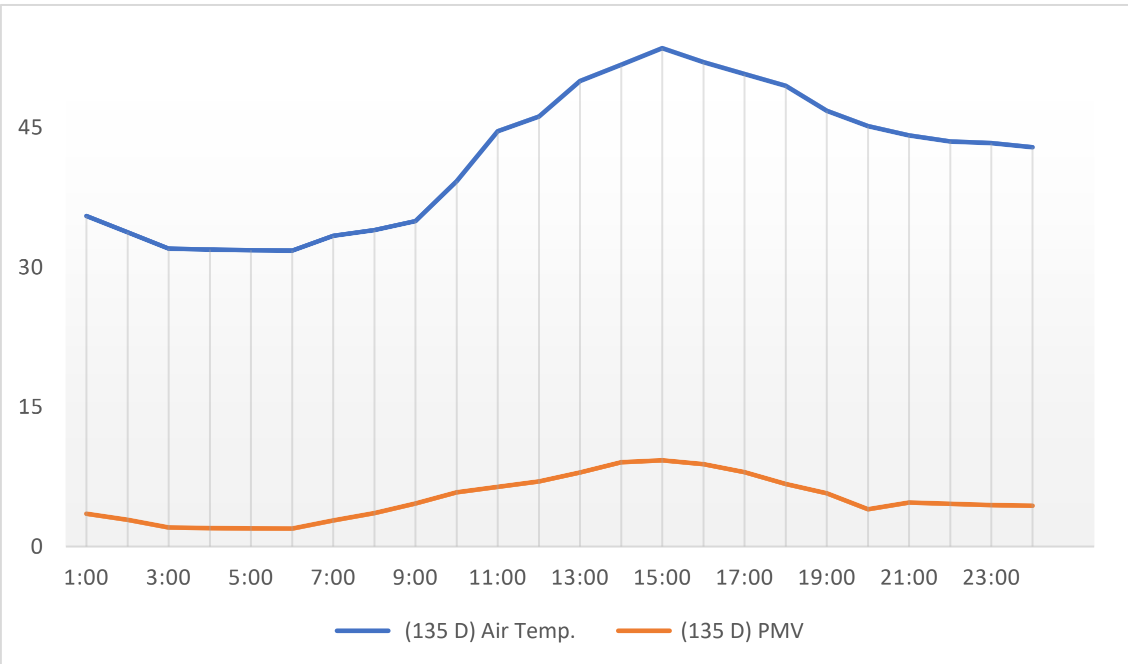

Figure 5.15: Pattern of behaviour between air temperature and PMV in phase 1-135 D.

Another example is scenario three were the north arrow is at 135 degrees similarly both parameters are recording consistency in value changing over the day. The same pattern of behaviour was recorded for the other two scenarios which meets (Sugiono and Hardiningtyas, 2014) results, while investigating the thermal comfort using PMV and CFD simulation analysis taking the University of Brawijaya as a case study in Malang-Indonesia, where they found that the increase in air temperature is reflected as an increase in PMV value similarly with the reduction in air temperature as seen in figure 5.16 were 24C° recorded the optimal value for PMV, were it was close to zero in co-ordinance with ASHRAE standard 55/2010.

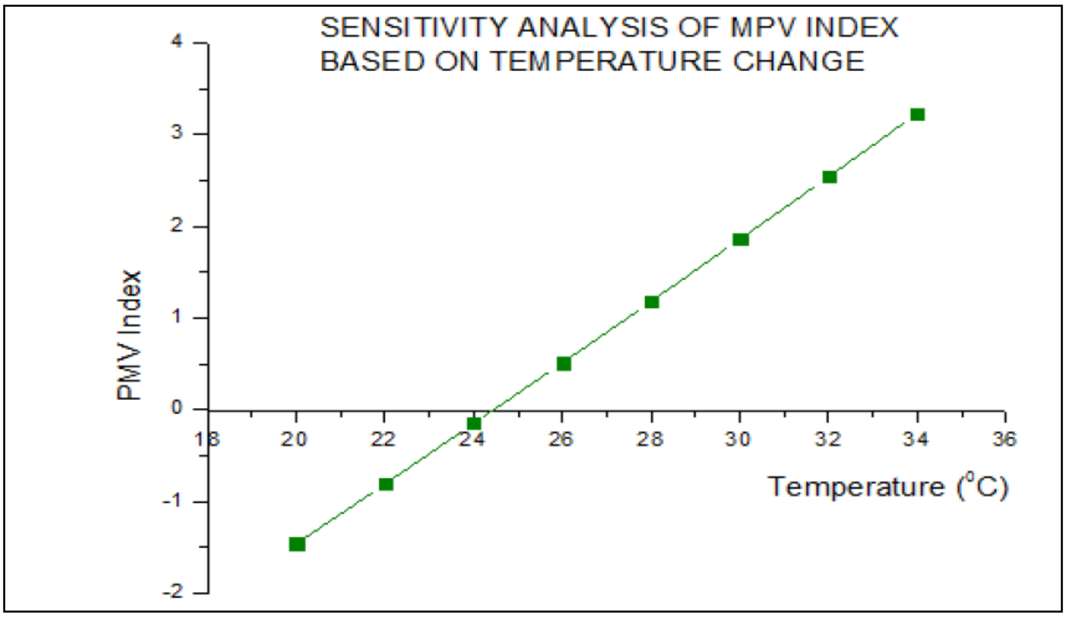

Figure 5.16: Sensitivity analysis of MPV index based on temperature change (Sugiono and Hardiningtyas, 2014).

As Bruse (2009), concluded that software simulation models do not only provide summarised information, but it helps also assess the new data and finds lead to different calculation methods. Therefore, it was noticed while studying the relation between average levels listed below table 5.6, that air temperature recordings were not affected by the change in wind speed in comparison to the changes recorded in R.H percentage.

Table 5.6: Phase, one scenarios variables, average summery showing best scenario.

Phase 1 Average	Base Case (45 Degree)	Scenario 1 (135 Degree)	Scenario 2 (225 Degree)	Scenario 3 (315 Degree)
R.H	**56.27**	**46.63**	**40.02**	**39.95**
Wind Speed	**2.955**	**2.988**	**3.418**	**3.318**
Air Temp	**41.02**	**41.76**	**42.05**	**42.33**
PMV	**5.1018**	**5.0833**	**5.1665**	**5.3474**

Figure 5.17 illustrates the change in R.H percentage at the four simulations and indicates the low percentage for R.H in scenario 2 and three while recording the highest wind speed values.

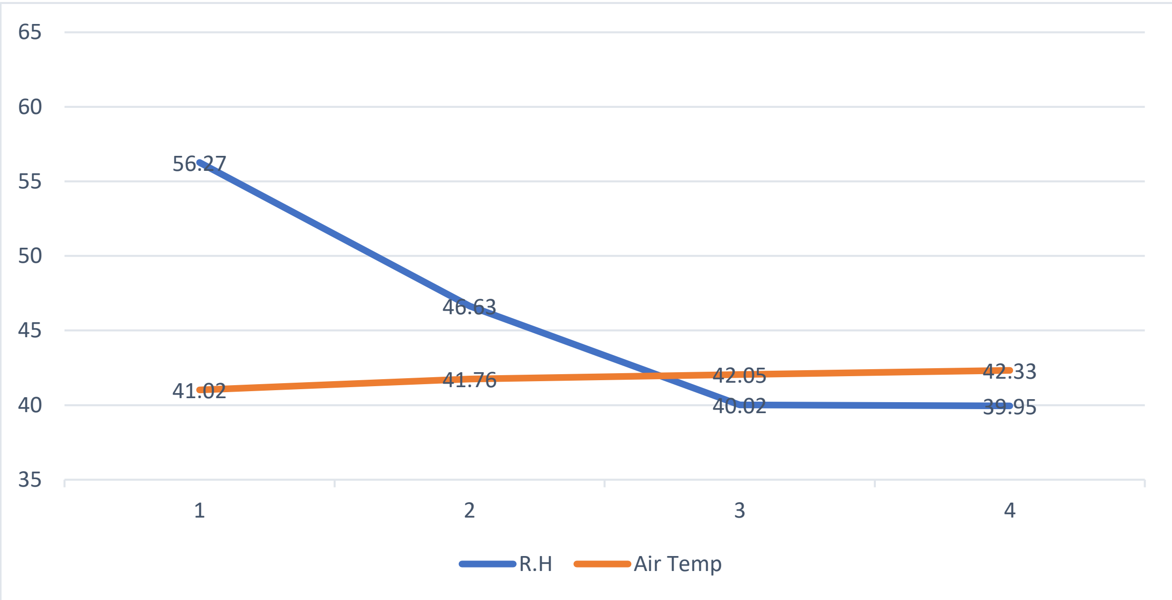

Figure 5.17: The change in R.H percentage at the four simulations.

When considering all previous remarks and evaluation variables average for the four simulations that are listed in table 5.6, it was seen that the base case has the lowest air temperature, yet records the highest R.H percentage, while keeping close average in PMV value with Scenario 2 and wind speed average of scenario 1. On the other hand, scenario, 3 records the highest PMV value as well as air temperature while it has the lowest R.H value among all scenarios even though wind speed records are close to scenario 2 with 0.07 C° difference in air temperature between both scenarios. Eventually, the existing base case was found to be the best case since it records the lowest air temperature while its PMV value records are close to the lowest recorded value among all examined cases. Even though the R.H percentage is the maximum, yet it is considered within the comfort limit, and further passive design strategies will focus on reducing the R.H as well as air temperature and PMV value.

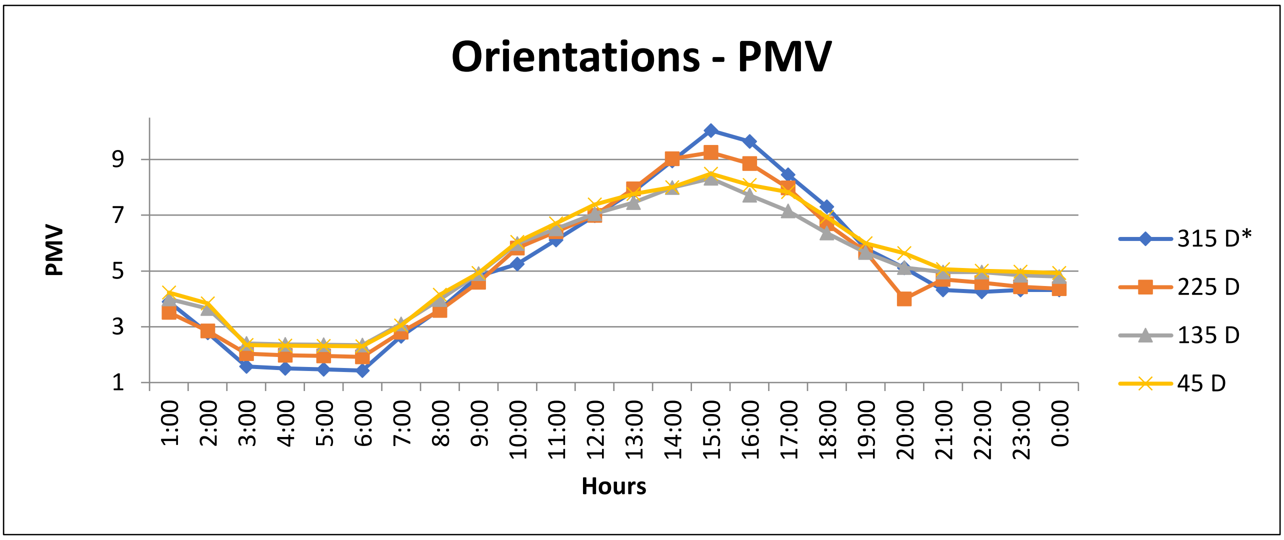

Figure 5.18: The four orientation PMV value for 24 hours.

5.3 Phase Two Introductions

Taleb, Taleb, (2012) pointed that researchers are setting a great connection between outdoor thermal comfort on one hand and urban configuration of that same outdoor space on the other hand. Since this research aims to achieve thermal comfort in urban spaces using passive strategies, studying the urban configuration was essential as Taleb and Taleb, (2012) concluded that Urban configuration impacts Urban Heat Island mitigation therefore, it is essential to investigate the best space configuration using the same evaluation variables that were used earlier, since (Monterio. 2010) and (Thani et al. 2013), both used basic climate parameters such as relative humidity, air speed and temperature for passive design plans evaluation at their investigations, this research is using the same parameters for selecting best proposals. The optimal layout orientation selected by the end of phase one as presented at previous section were moved to this phase and considered the base case, were four different urban configurations were selected out of the layout as shown below figure 5.19 and were examined to select the best configuration.

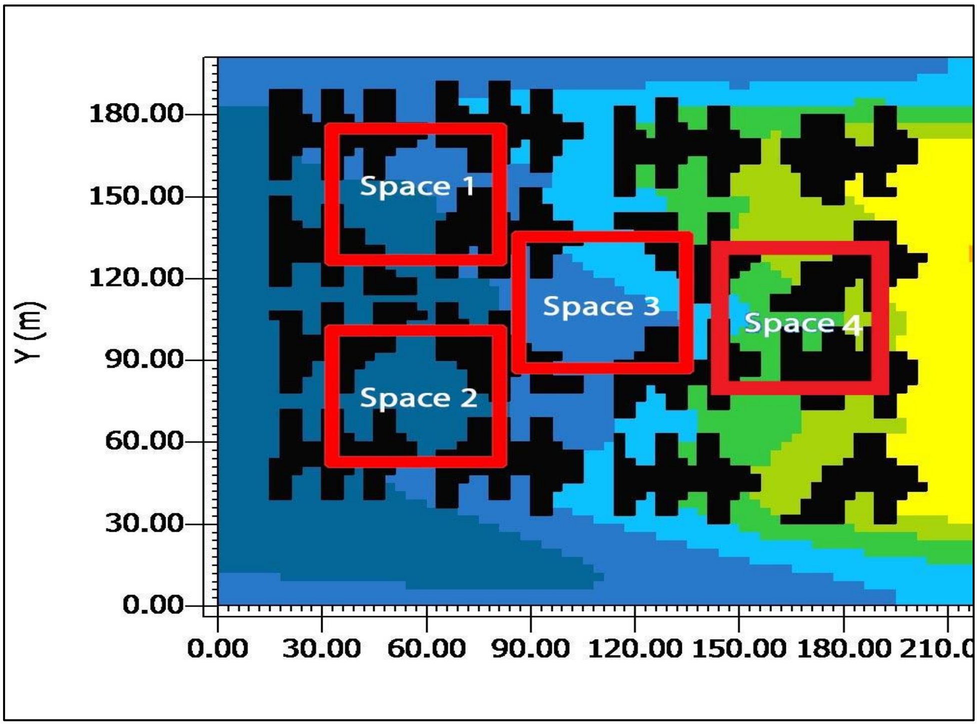

Figure 5.19: Phase 2 spaces position on the base case master plan (Envi-met, 2017).

5.3.1 Urban Configuration Simulation of Space One

Space is located between four residential units. The space is blocked from north side by the residential unite as well as south, east and west side while the access to the inner space is at the four secondary directions; north- east , north-west, south-east and south-west as per the selected optimum orientation from phase one as shown in the illustration in figure 5.20, where the arrows represent the access path to the central open space with two different line type, referring to the dimension and width of each path as the straight direct arrow indicates the narrower path and the other arrows indicates wider path while the oval, hatched shape is representing the open urban space that is subject to research.

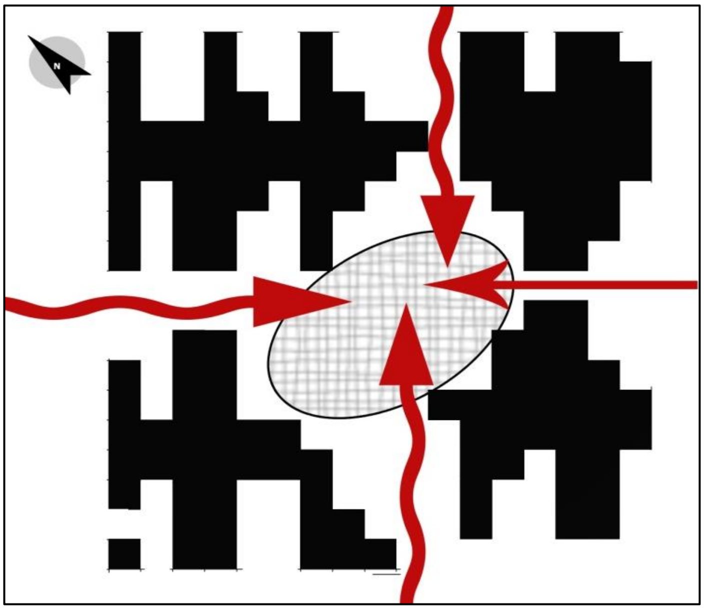

Figure 5.20: Phase 2, space one illustration diagram showing the path to the central open space. (Author, 2017).

The simulation results for space one as presented below table 5.7 shows that relative humidity reaches its peak at 03:00 as it goes above 72.00 % while drops below 18.8% at 18:00, and 19:00 with an average of 38.69 % during the day on 23rd of June. Simultaneously the wind speed records it highest values at the same time of the day where it reaches 3.28 m/s at 03.00, but its lowest records were 2.83 m/s at 21:00. It maintains the range from 2.85 to 2.88 over 15 hours of the day starting from 06:00 up to 22:00 refer to table 5.7, were the average recorded over the day is 2.94 m/s.On the other hand the air temperature is hitting peak point at 15:00 where it records 49.36 C˚, and reaches its lowest point at 02.00 where it records 34.00 C˚ on the same day, see table 5.7 and figure 5.21, where all simulations are running on 23 June that represents summer session with an average of 41.58 C˚ over the day.

Table 5.7: Summary of numerical data extracted in Phase 2- (space 1) on June 23, 2017, for 24 hours.

SPACE 1	**R.H %**	**Wind Speed m/s**	**Air Temp. C˚**	**PMV**
1:00	53.85	3.25	36.5	4.22
2:00	62.945	3.26	34 ↓	3.68
3:00	72.04 ↑	3.28 ↑	34.12	2.36 ↓
4:00	67.875	3.06	34.275	2.37
5:00	65.7925	2.96	34.36	2.375
6:00	63.71	2.85	34.43	2.38
7:00	60.68	2.85	35.74	2.85
8:00	56.83	2.86	36.395	3.66
9:00	52.98	2.86	37.05	4.91
10:00	40.75	2.85	41.375	5.71
11:00	33.85	2.86	43.5375	6.365
12:00	28.52	2.86	45.7	7.02
13:00	24.14	2.86	47.53	7.53
14:00	21.95	2.88	48.445	7.77
15:00	19.76	2.89	49.36 ↑	8.04 ↑
16:00	19.23	2.88	48.74	6.975
17:00	18.87	2.88	48.43	6.65
18:00	18.7 ↓	2.88	48.12	5.91
19:00	18.7 ↓	2.86	46.985	5.55
20:00	19.115	2.84	46.4175	5.19
21:00	19.53	2.83 ↓	45.85	4.83
22:00	22.53	2.88	42.88	4.62
23:00	30.59	2.9	40.03	4.685
00:00	35.66	3.18	37.7	4.75
Average	**38.69156**	**2.94**	**41.58208**	**5.016667**

In addition to the above parameters, the PMV values were tested over the day, and noted that the highest value was recorded at 15:00 where it hits (8.04), while its lowest values were recorded at 03.00 as it drops to 2.36, as shown table 5.7 and figure 5.21, setting an average of 5.016 over the day.

Keeping in mind that for PMV value the closer the result was to zero the more comfortable it is as zero indicates the optimal comfort balance between extreme hot where it is +3 and extreme cold was it is -3 as per ANSI / ASHRAE Standard 55-2010 presented earlier chapter two section2.7 and chapter four section 4.5.

The previous data shows a connection between higher R.H % and wind speed on one hand and the decrees in air temperature and better PMV values on the other hand, even though R.H. is considered high as shown at 03:00 am, the PMV value is considered relatively better compared to the highest value at 15:00 figure 5.21, the same day for the 24-hour simulation of space one. This result links the PMV value to the air temperature record and shows that PMV reaches the highest value simultaneously at the same time with air temperature reaching highest degree.

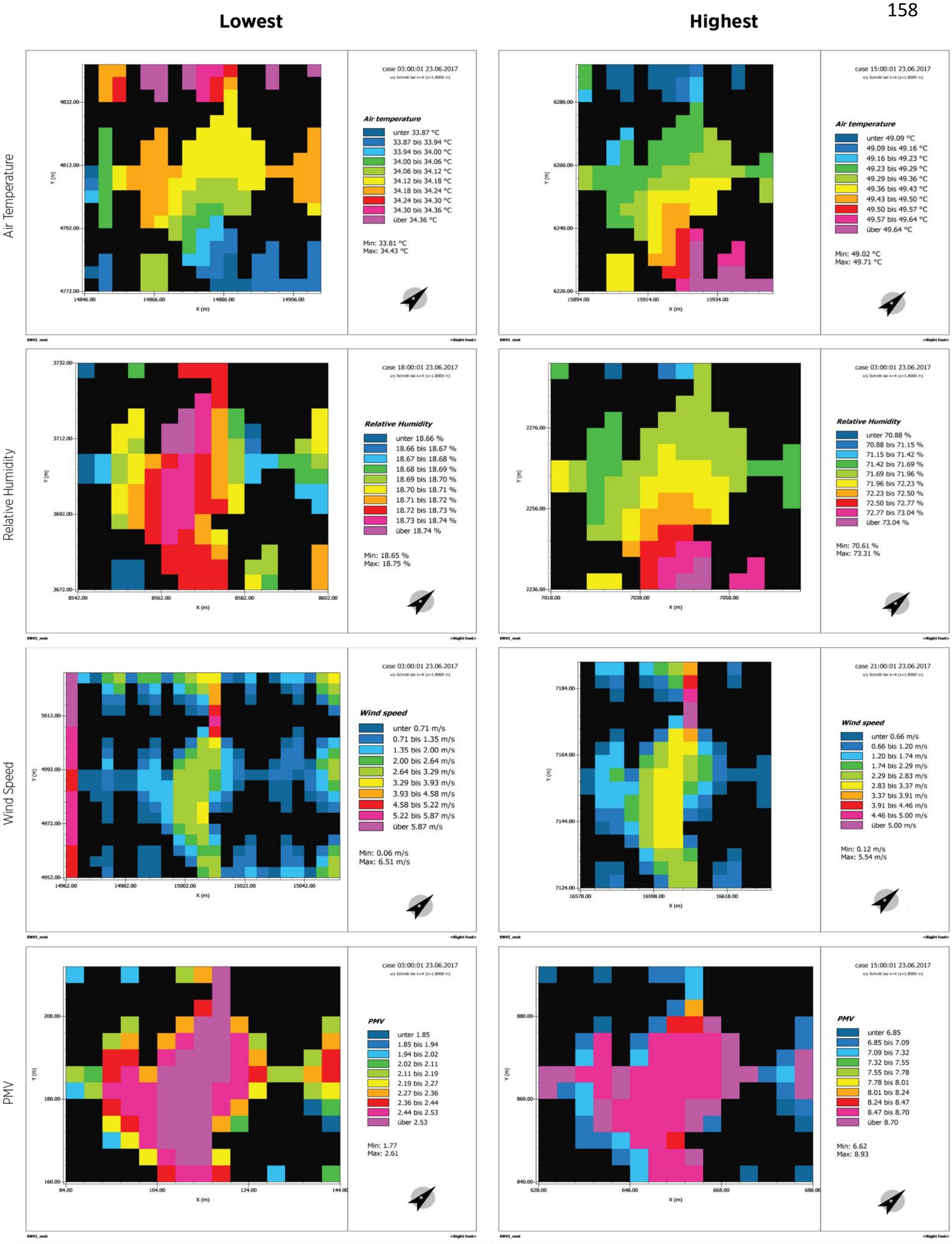

Figure 5.21: Envi-met maps are showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space 1. (For all 24 hours' maps refer to Appendix 2).

5.3.2 *Urban Configuration Simulation of Space Two.*

Space is also located between four residential units. Similar to the previous case space is blocked on the north side by the residential unite as well as south, east and west side similarly to space one condition while the access to inner urban space is at the four secondary directions; north- east, north-west, south-east, and south-west. The access paths to the inner space are all equal in dimension and constructing a continues path in addition to that it is considered much narrower when compared to Space one. See figure 5.22 below.

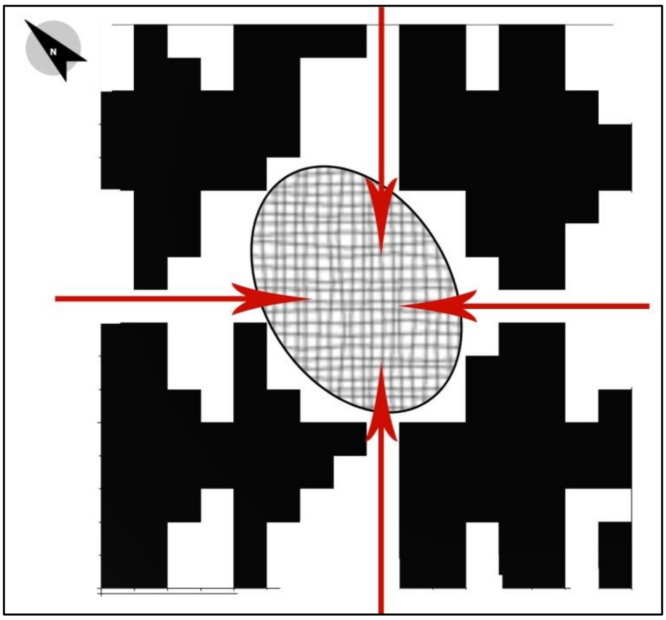

Figure 5.22: Phase 2, space two illustration diagram showing the path to the central open space (Author, 2017).

The simulation analysis of space two as presented table 5.8, shows that relative humidity reaches its peak at 03:00 am, as it goes above 75.60 % while drops to 18.54% at 17:00 pm, with an average of 39.90 % over the day that is more than space one. Simultaneously the wind speed records it highest values at 15.00pm refer to figure 5.23, as it reaches 3.03 m/s while its lowest records were 2.5 m/s at 01:00 am setting an average of 2.76 m/s over the day that is 0.18m/s less than space one.

On the other hand, the air temperature hits its peak point again at 15:00 pm as shown in table 5.8, where it records 50.24 C° almost one degree higher than space one.

Table 5.8: Summary of numerical data extracted in Phase 2- (space 2) on June 23, 2017, for 24 hours.

SPACE 2	R.H %	Wind Speed m/s	Air Temp. C°	PMV
1:00	56.885	2.5 ↓	38.88	3.99
2:00	66.2875	2.6	35.67	3.583
3:00	75.69 ↑	2.6	33.35 ↓	2.13
4:00	71.35	2.62	33.425	2.12
5:00	69.18	2.63	33.456	2.115
6:00	67.01	2.65	33.5	2.11 ↓
7:00	59.95	2.65	34.95	2.73
8:00	58.03	2.68	35.675	3.33
9:00	56.11	2.7	36.4	4.88
10:00	41.795	2.73	41.72	5.12
11:00	34.4	2.76	44.38	6.195
12:00	27.48	2.8	47.04	7.27
13:00	23.295	2.84	48.64	7.71
14:00	21.2025	2.86	49.44	7.83
15:00	19.11	3.03 ↑	50.24 ↑	8.15 ↑
16:00	18.92	3	49.22	6.91
17:00	18.54 ↓	2.98	48.71	5.93
18:00	18.73	2.96	48.2	5.67
19:00	18.98	2.85	46.89	5.31
20:00	19.41	2.77	46.235	4.96
21:00	19.84	2.78	45.58	4.61
22:00	23.68	2.8	43.33	4.59
23:00	33.69	2.77	42.9	4.505
00:00	38.08	2.7	40.08	4.42
Average	**39.90188**	**2.760833**	**41.99629**	**4.840333**

While it reaches its lowest point at 03.00 am see figure 5.23, where it records 33.35 C˚ also one degree less than space one while the average over the day is 41.99 C˚ considering that the simulation was running on the same day the difference in the average result is 0.41 C˚. The PMV values were also tested over the day and noted that the highest value was recorded at 15:00 see figure 5.23, similar to space one where it hits 8.15 with an increase of 0.11 compared to space one. While its lowest values were recorded at 06.00, as it drops to 2.1 see setting an average of 4.84 over the day that 0.17 less compared to space one presented earlier.

Table 5.8 shows a connection between maximum values of wind speed, air temperature and PMV value as all three variables reaches peak point at 15:00 pm, see figure 5.23. This result keeps the link between PMV value and air temperature that was found at space one simulation earlier, and additionally sets a close values between the minimum air temperature at 03:00, and the minimum PMV value at 06:00 were the difference is 0.03 from lowest PMV value recorded at 0.3:00 am, yet the link between R.H and wind speed does not exist in this case unlike the previous simulation nevertheless space one has a link between lowest R.H percentage and lowest wind speed as the difference is 0.1m/s from lowest wind speed to Lowest R.H as shown table 5.8.

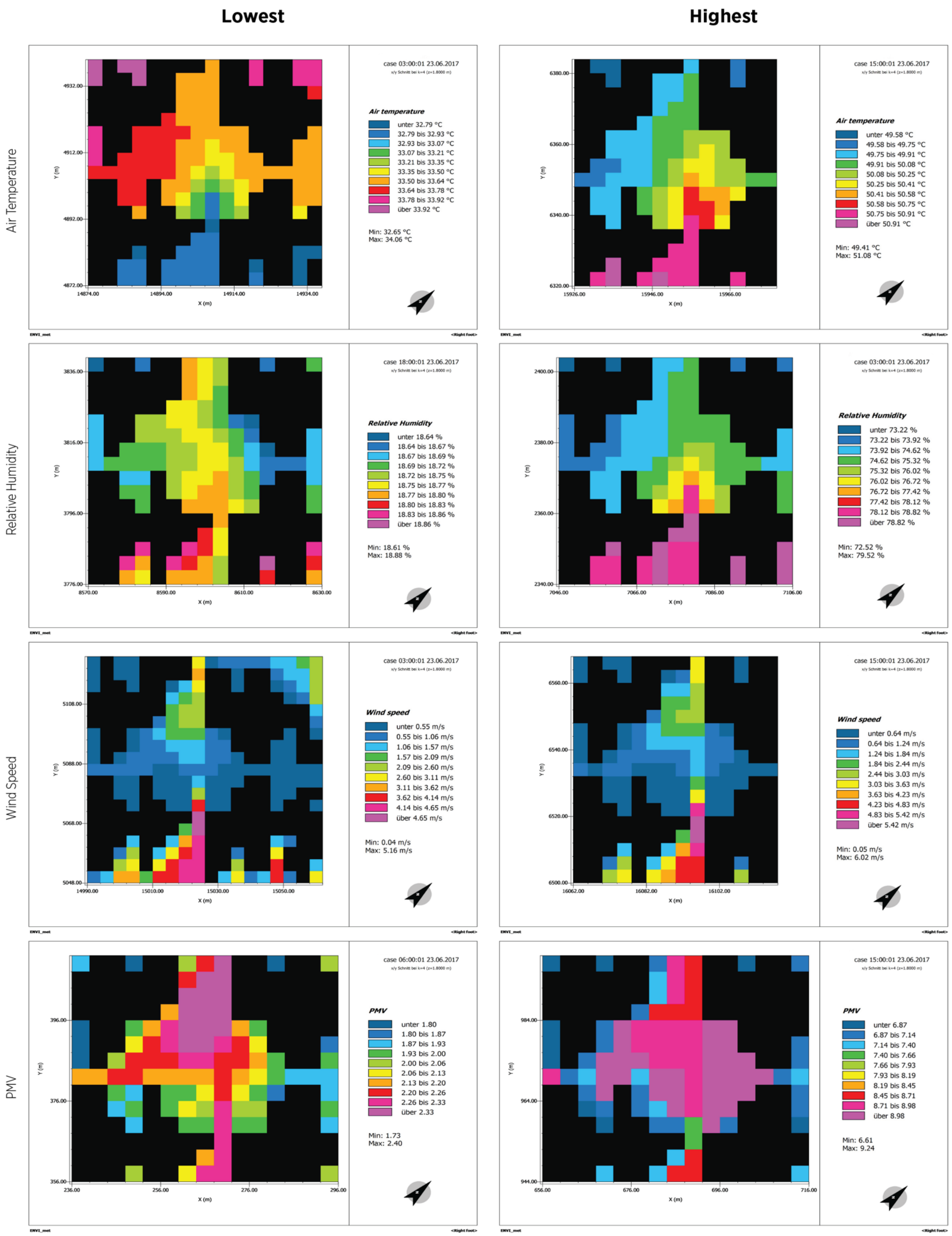

Figure 5.23: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space 2 (For all 24 hours' maps refer to Appendix 2).

5.3.3 Urban Configuration Simulation of Space Three

The third space selected is also surrounded by residential units as this represents the standard unified design in this project were every four to six residential units forms an open urban space that can be utilized and used for outdoor activities. The space is also blocked from north side by the residential unite see figure 5.24, as well as south, east and west side while the access to the inner space is at the four secondary directions similar to the previous two configurations; north- east, north-west, south-east, and south-west, yet the access path to the inner space is much wider than space one and two where it forms a continues, direct circulation between all units.

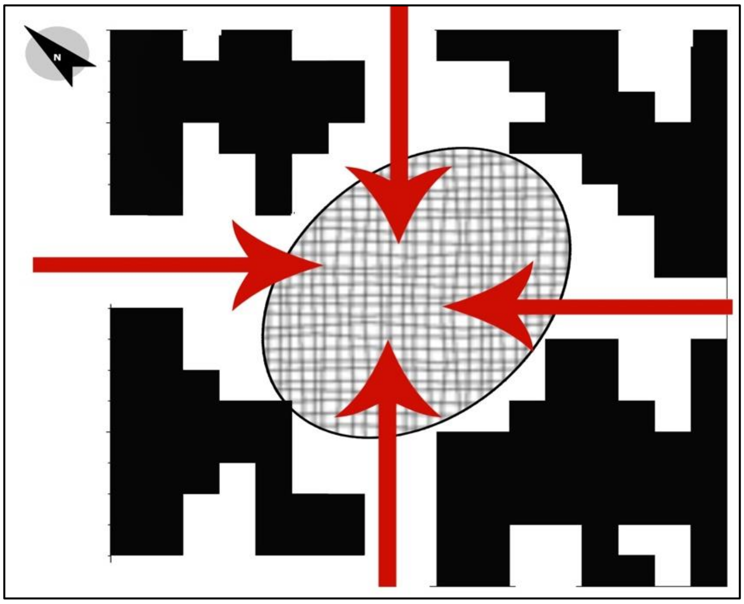

Figure 5.24: Phase 2, space three illustration diagram showing the path to the central open space (Author, 2017).

The simulation of this space shows that relative humidity reaches its peak at 03:00 as it goes above 74.10 % while drops to 18.40% at 17:00 as presented below table 0.00 setting an average of 39.82 % over the day that is close to space two yet more than space one. On the other hand, wind speed records its highest values at 15.00 as it reaches 2.77 m/s while its lowest records were 2.63 m/s at 01:00 am. as shown below in table 5.9 with an average of 2.69 m/s over the day that is less than space one and two.

Table 5.9: Summary of numerical data extracted in Phase 2- (space 3) on June 23, 2017, for 24 hours.

SPACE 3	R.H %	Wind Speed m/s	Air Temp. C°	PMV
1:00	56.445	2.63 ↓	39.1	4.022
2:00	65.2825	2.64	36.88	3.753
3:00	74.12 ↑	2.66	33.57 ↓	2.53
4:00	70.1	2.66	33.67	2.41
5:00	68.09	2.68	33.73	2.35
6:00	66.08	2.68	33.77	2.29 ↓
7:00	62.12	2.68	35.185	2.77
8:00	58.645	2.68	35.8925	3.95
9:00	55.17	2.68	36.6	5.01
10:00	41.375	2.69	41.55	5.63
11:00	35.87	2.69	44.025	6.415
12:00	27.58	2.7	46.5	7.2
13:00	23.405	2.73	48.24	7.755
14:00	21.3175	2.75	49.11	8.15
15:00	19.23	2.77 ↑	49.98 ↑	8.31 ↑
16:00	18.965	2.76	49.075	7.225
17:00	18.4 ↓	2.76	48.6225	6.8
18:00	18.7	2.75	48.17	6.14
19:00	18.77	2.73	46.905	5.86
20:00	19.265	2.7	46.2725	5.36
21:00	19.76	2.68	45.64	4.86
22:00	23.85	2.68	44	4.77
23:00	34.52	2.67	42.522	4.755
00:00	38.77	2.64	39.99	4.74
Average	**39.82625**	**2.695417**	**42.04165**	**5.127292**

Simultaneously the Air temperature hits its peak point on the same day also at 15:00 where it records 49.98 C° while it reaches its lowest point also at 03.00am recording 33.57 C° as shown in table 5.9 below. Setting an average of 42.04C° over the day on 23rd June similar to the average of space two and higher than space one by 0.54C°. This PMV values also were tested over the day and it was noted that the highest value recorded was at 15:00 pm where it hits

(8.31) while the lowest values were recorded at 06.00am, as it drops to (2.29) with an average of (5.12) that is higher than space one and two presented earlier.

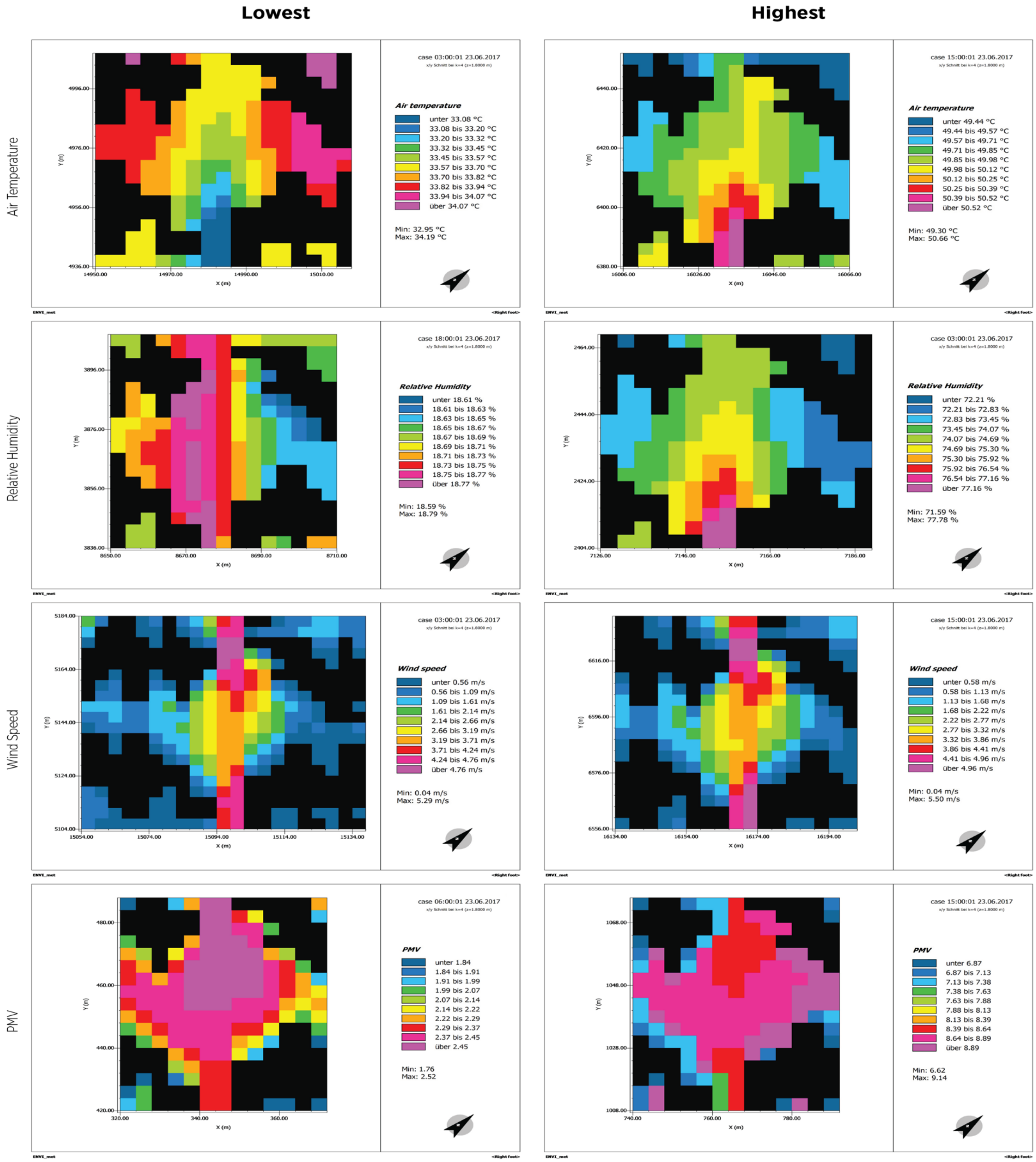

Figure 5.25: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space 3(For all 24 hours' maps refer to Appendix 2)

This simulation shows a similarity at the peak point for wind speed, air temperature, and PMV value as all three variables hit peak points at 15:00 figure 5.25, keeping the same pattern of behavior of space two presented earlier with the same time of the day.

It was noted from table 5.9, that the difference between lower air temperature and lower wind speed is only 0.03 m/s that is considered a minor difference at the same time were R.H at its peak point. Yet PMV is higher in this simulation even though air temperature at the same time of the day is lower than space one yet PMV in space one is 0.16 less than space two, keeping in mind that the closer the value to zero the better and more comfortable it is according to ASHRAE standard 55/2010.

5.3.4 Urban configuration simulation of space four

Space four is located close to space three. It has a slightly different configuration of the residential units around the urban space where the main access to the urban space between the units is through east direction, and secondary access is the north-west side. However, the south-west and south-east are very narrow, and the units are close to each other as shown in figure 5.26.

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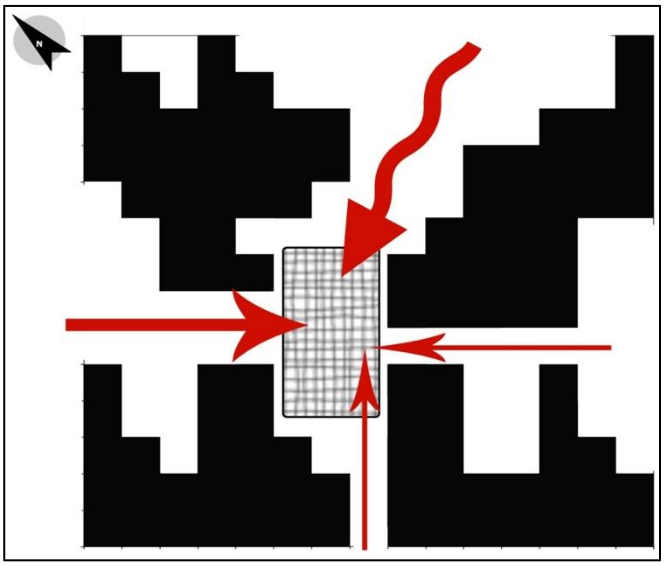


Figure 5.26: Phase 2, space four illustration diagram showing the path to the central open space (Author, 2017).

The simulation results of space four show that relative humidity reaches its peak point at 03:00 am see figure 5.27, as it goes above 73.10 % while drops to 18.7% at 18:00 pm with an average of 39.56 % over the day that is less than space two and three yet higher than space one. In case of wind speed, it records the highest values at 15.00pm as shown in table 5.10, where it reaches 1.95 m/s while the lowest record was 1.69 m/s at 00:00 am setting an average of 1.78 m/s over the day, noted to be the lowest among all previous spaces.

Table 5.10: Summary of numerical data extracted in Phase 2- (space 4) on June 23, 2017, for 24 hours.

SPACE 4	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	56.095	1.7	35.35	3.84
2:00	64.6425	1.76	34.78	2.75
3:00	73.19 ↑	1.8	33.76 ↓	2.19
4:00	69.29	1.79	33.84	2.175
5:00	67.34	1.76	33.88	2.1675
6:00	65.39	1.74	33.92	2.16 ↓
7:00	61.13	1.75	35.325	2.83
8:00	58.05	1.73	36.0275	3.48
9:00	54.97	1.725	36.73	4.89
10:00	41.435	1.73	41.4375	5.55
11:00	34.25	1.79	43.79125	6.335
12:00	27.9	1.815	46.145	7.12
13:00	23.625	1.83	47.9575	7.55
14:00	21.4875	1.87	48.86375	7.84
15:00	19.35	1.95 ↑	49.77 ↑	7.98 ↑
16:00	19.025	1.94	48.965	6.795
17:00	18.36	1.92	48.5625	6.1
18:00	18.7 ↓	1.895	48.16	5.61
19:00	18.72	1.85	46.9175	5.23
20:00	19.2	1.77	46.29625	4.91
21:00	19.68	1.695	45.675	4.59
22:00	25.45	1.7	42.28	4.59
23:00	33.21	1.72	40.11	4.495
00:00	39	1.69 ↓	38.61	4.4
Average	**39.56208**	**1.788333**	**41.54807**	**4.815729**

Air temperature reaches peak point at 15:00 pm recording 49.77 C˚, while it reaches the lowest point at 03.00am recording 33.76 C˚ as shown in table 5.10 and figures 5.27. Setting an average of 41.54C˚ over the day on 23rd June that is less than average result of space three by 0.5 C˚ and less than space one by 0.04C˚ and less than space two by 0.45 C˚.On the other hand the PMV values over the day records the highest value at 15:00pm where it hits (7.98) while its lowest value was at 06.00am as it drops to (2.16) with an average of (4.93) that is the lowest among all simulations which are like to zero that is considered the optimal comfort point as explained earlier, see table 5.10.

This simulation shows a similarity at the peak point for wind speed, temperature and PMV value as all three variables hits peak points at 15:00 see figure 5.27, keeping the same pattern of behavior of space two and three presented earlier with the same time of the day. The same link can be drawn at this simulation between the lowest Air temperature and lowest PMV as the difference in PMV value is 0.03 only from 03:00 that indicates lowest Air temperature to 06:00 that indicates lowest PMV value as shown table 5.10.

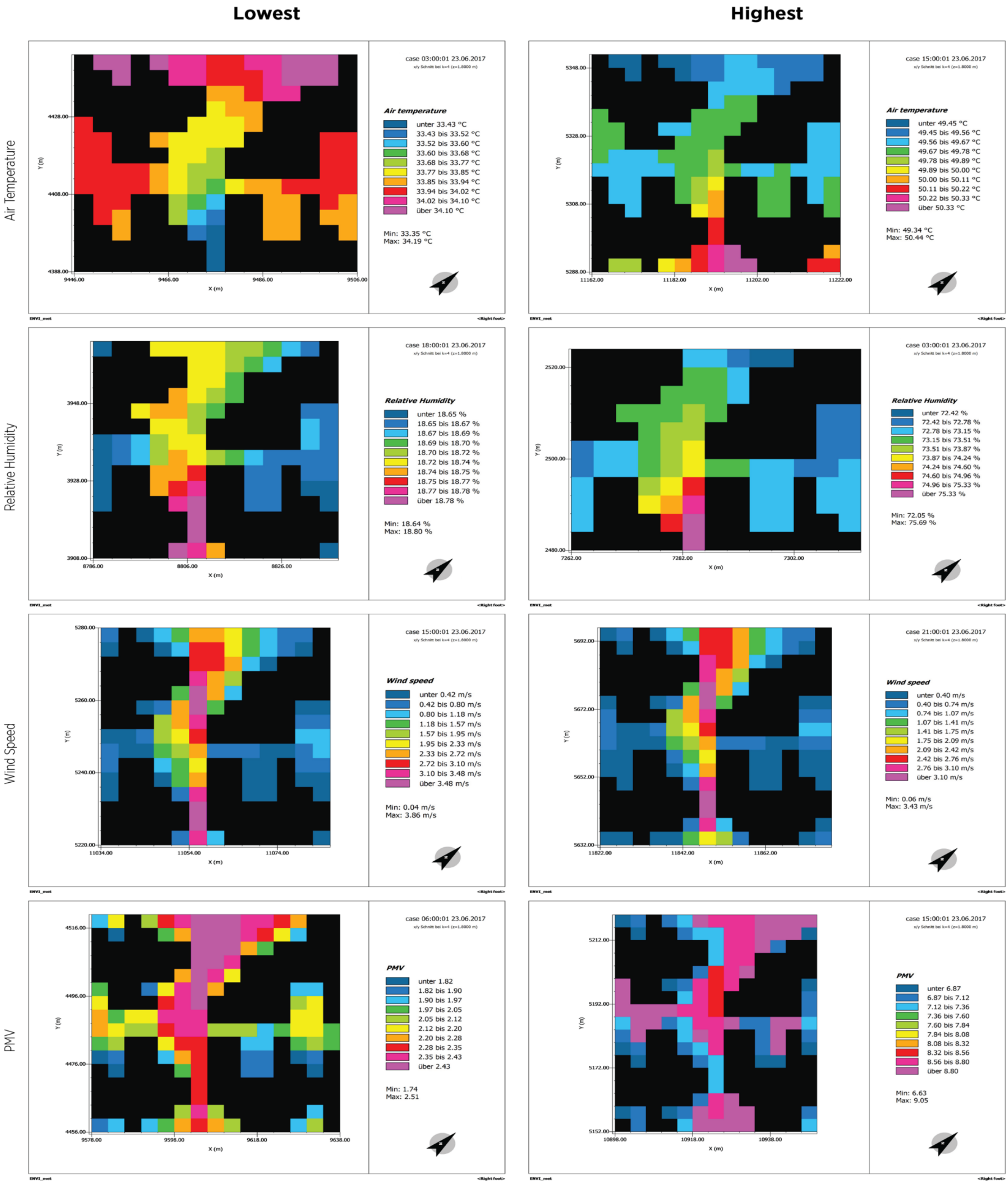


Figure 5.27: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space 4 (For all 24 hours' maps refer to Appendix 2)

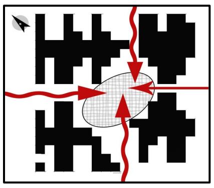
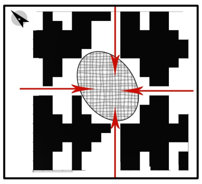
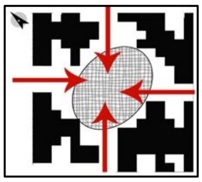
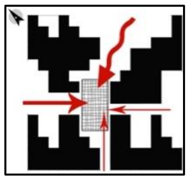
5.3.5 Urban Configuration Summary and Discussion.

By using ENVI-met and LEONARDO for model simulation and maps extraction, the evaluation variables were collected and compared against each other. This phase used some of the evaluating parameters that were used by Monteiro (2010) and Thani et al.(2013) for their research withby Dubai Weather and urban specification.

Monteiro (2010) concentrated on passive design systems therefore for L.Hasa project the examination variables were solar radiation, relative humidity, air velocity while Thani et al.(2013) added ambient temperature and mean radiant temperature to the previous list of variables. This research used absolute air temperature as a reliable value that can be easily linked and understood by space users as well as its impact on PMV value is undeniable as found in previous simulations. In addition to air temperature, the research used relative humidity, wind speed, and PMV Values to examine each space through the four phases.

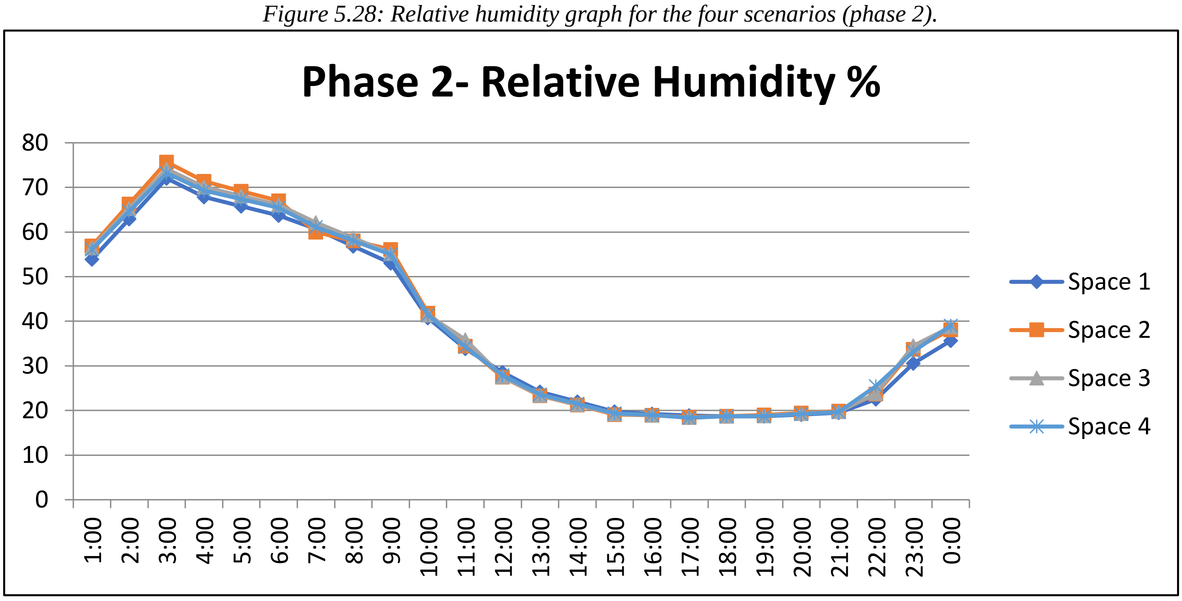
At phase two the simulation results are listed below for each variable starting by relative humidity where space one records the lowest average and highest average in wind speed. But space four presents lowest average in air temperature as well as better PMV value among all other spaces. The difference between space one and four in air temperature 0.04 C$^{\circ}$ which can be neglected considering the difference in wind speed between space one and four that reach up to 1.16m/s which is considered high difference when comes to small urban spaces between residential blocks. On the other hand, the difference in PMV between space one and four is 0.2, that is also considered minor as it can be adjusted by clothes or referred to age and activity at this space, therefore, it was concluded that space one has better thermal behaviour results than other three spaces as shown below table 5.11.

Table 5.11: Phase, two scenarios variables, average summery showing best scenario.

Phase 2 Average	Space 1 	Space 2 	Space 3 	Space 4 
R.H	**38.69156**	**39.90188**	**39.82625**	**39.56208**
Wind Speed	**2.94**	**2.760833**	**2.695417**	**1.788333**
Air Temp	**41.58208**	**41.99629**	**42.04165**	**41.54807**
PMV	**5.016667**	**4.840333**	**5.127292**	**4.815729**

The graph of the relative humidity presented figure 5.28 for the four scenarios shows a consistency of behaviour of all spaces over the day as results are recorded over 24 hours on 23 of June were the highest percentage is recorded at 03:00 am keep in mind space is not used at this time of the day due to users behaviour and space characteristic.

Figure 5.28: Relative humidity graph for the four scenarios (phase 2).



Second evaluation variable is the wind speed measured by a meter per second where space one also presents the highest average against all other spaces maintaining a consistency of behavior as shown in the graph below. The four scenarios in term of wind speed show also a consistency of behaviour as noticed over the day yet space 4 records the lowest result over the day as discussed earlier table 5.11 and shown below figure 5.29, while space one shows a jump start early in the day from 03:00 am to 08:00, were reading becomes average with other spaces.

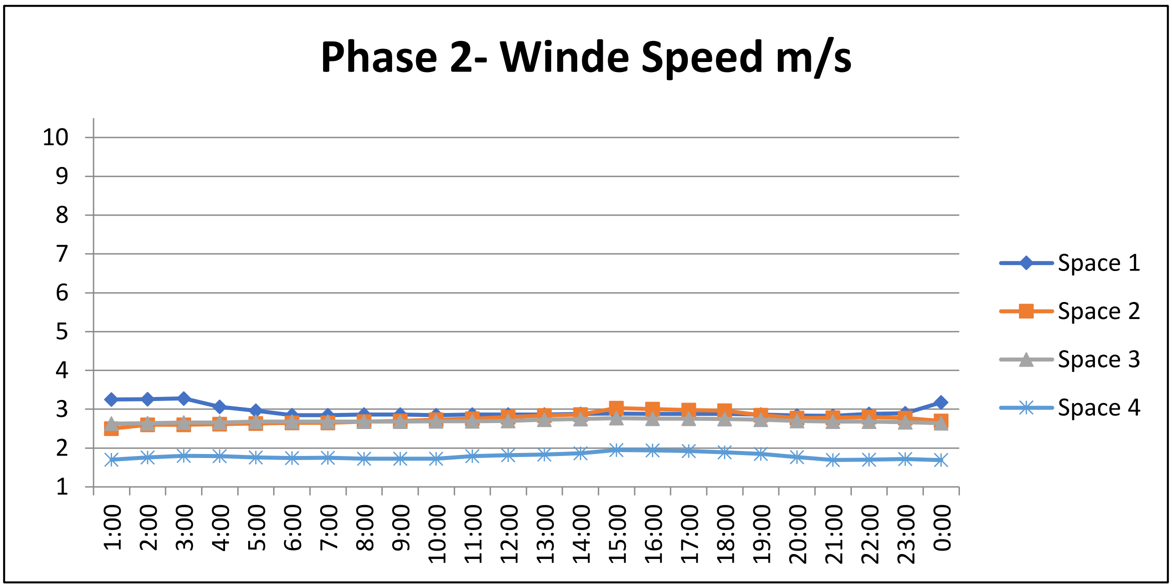


Figure 5.29: Wind speed graph for the four scenarios (phase 2).

Third evaluation variable is the air temperature measured in celsius where all four spaces are showing almost the same result in average over the day. Space four shows the lowest average with 0.04C° less than space three. The graph of the air temperature presented below Figure 5:30, for the four scenarios, shows a consistency and similarity of the results of all four spaces.

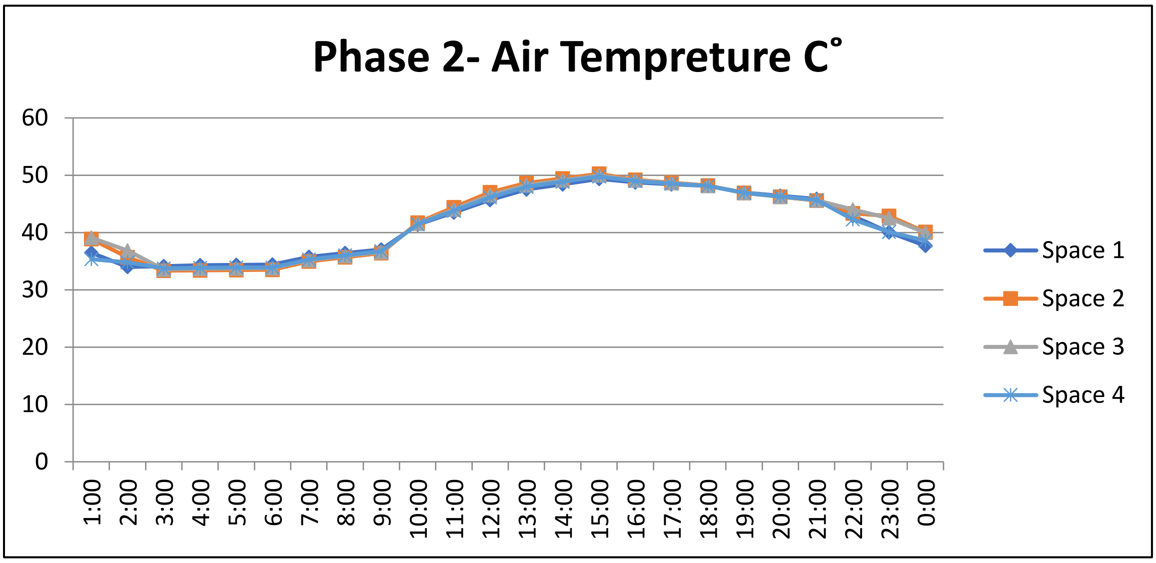


Figure 5.30: Air temperature graph for the four scenarios (phase 2).

Finally, the PMV value was also examined for all four spaces and space four records the lowest value that is close to the comfort area where the values should land between -1 and +1 considering zero is the optimal comfort zone, as per ASHRAE standard 55/2010.

The PMV graph below also shows a consistency of behaviour in term of results among all four spaces, were 15:00 recorded the highest value into consistency with the air temperature highest value recorded at the same hour that proves the link between PMV value from one side and air temperature, clothing factor, air velocity and metabolic rate on the other side as Fagner's equation stated in addition to other factors that are out of this research scope of work like vapour pressure of air, convective heat transfer figure 5.31.

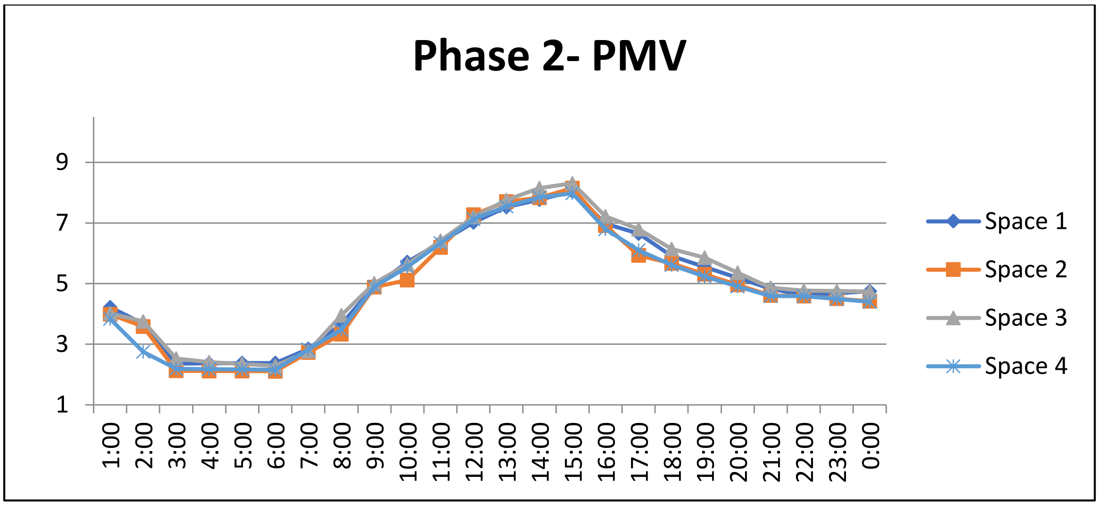


Figure 5.31: PMV graph for the four scenarios (phase 2).

As concluded from table 5.11 earlier and confirmed through graphs, Space one is the optimal case among all four spaces. Space one has a lowest R.H percentage yet it is above 30% that is considered dry and recorded as mean a minimum of June in Dubai by the Ministry of Presidential Affairs with remarkable highest wind speed and relatively low air temperature in comparison to other three spaces, as well as a close PMV value to the other spaces.

Space one has an equal access path in term of dimension, and all access is aligned keeping north-west direction clear as preferable wind direction in the UAE. While having the opposite access slightly smaller in dimension to block the high wind speed at the space around the architectural elements, this will decrease humidity for better thermal comfort results as Ragheb et al, (2016) concluded that utilizing the parameters of microclimate can potentially reduce the overall temperature by 3 degrees for outdoor thermal enhancement as per the findings of the Albanian open space research and as Taleghani, Kleerekoper, Tenpierik and Dobbelsteen (2013) who concluded that wind speed and radiant temperature are linked and affected by urban forms and different geometry.

5.4 Phase Three Introduction

This phase evaluates the impact of court-yard design over the outdoor thermal comfort parameters discussed early and used in previous phases see figure 5.32. Since Ahmed, Abu Hijleh (2016) concluded that building forms and courtyard proportion are the main influencers over outdoor thermal comfort levels. This research redesigned the optimal case of phase two that was space one into four different designs were four different court-yard designs were added to the software model and examined each one at a time for its impact on the thermal comfort evaluating variables used earlier that is similar to the parameters which (Zhao et al. 2016) counted on when studying the impact of five different scenarios of court-yard design using relative humidity, mean radiant temperature, ambient temperature and wind speed as evaluating parameters but at this research the temperature was calculated as Air Temperature and PMV value were added to relative Humidity and Wind speed forming the evaluation variables list.

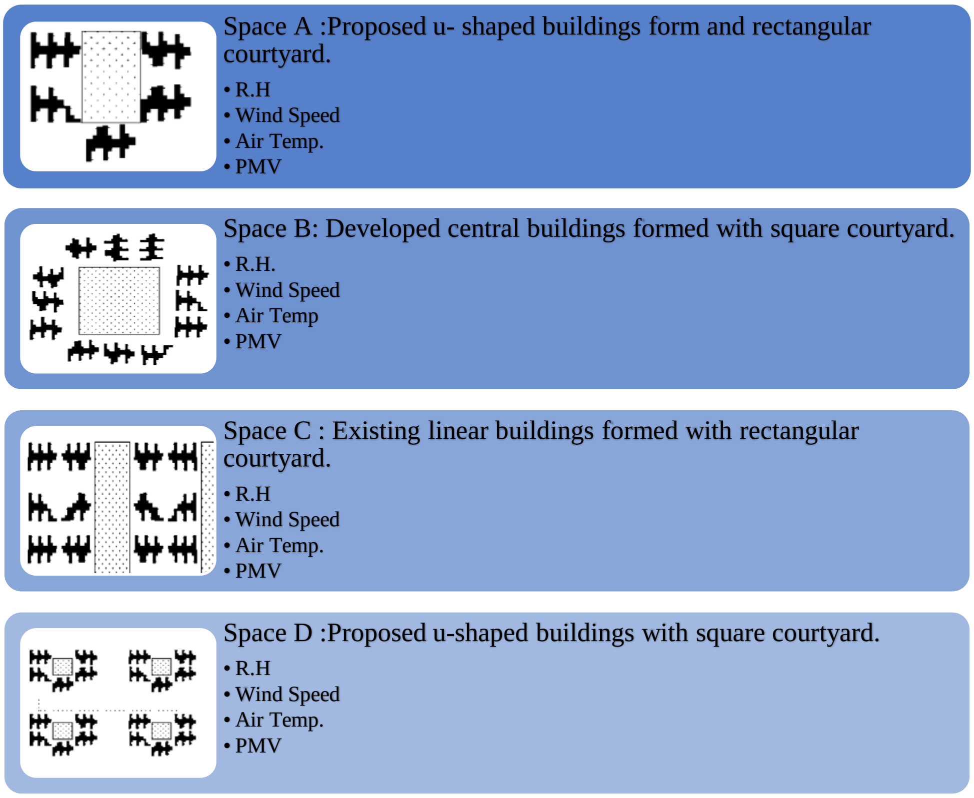


Figure 5.32: Phase 3 investigated scenarios variables.

5.4.1 Urban Courtyard Simulation of Space A

First suggested courtyard design is the U-Shape court with rectangular layout figure 5.33 that is open toward the wind from north-west direction as shown below at the master layout after repeating the same design over the full site keeping a total number of residential units the same as current existing design figure 5.34.

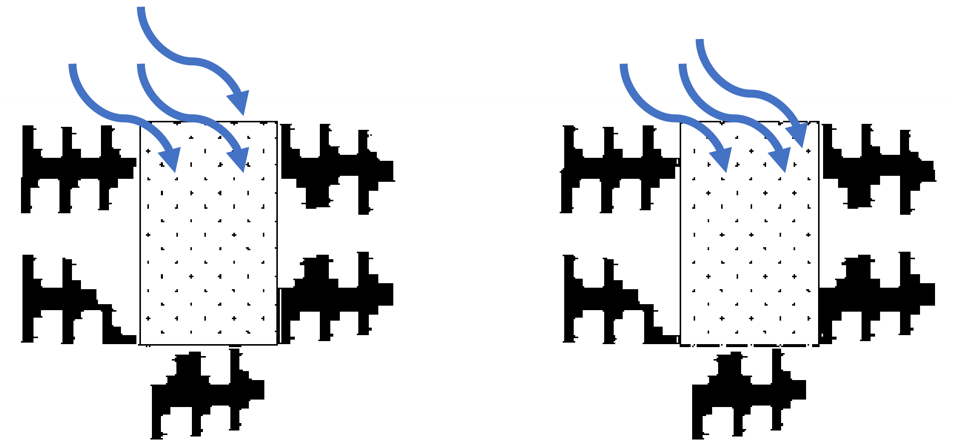


Figure 5.33: Phase 3- space A U-Shape building with rectangular courtyard layout.

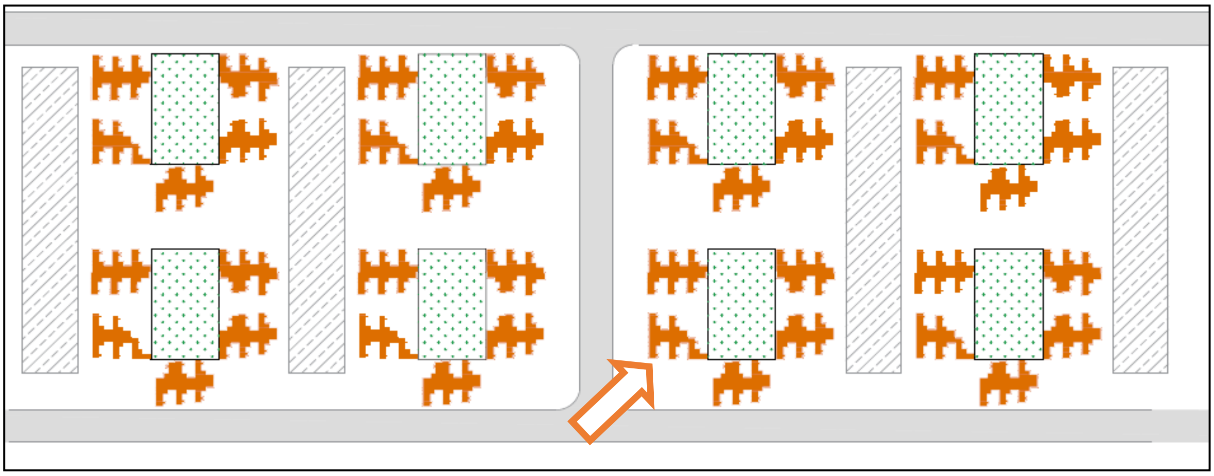


Figure 5.34: Phase 3- space A proposed design for the units' arrangement.

The simulation for this design shows that relative humidity reaches its peak at 03:00 am as it goes above 79.10 % while drops to 18.59% at 16:00 pm setting an average of 46.06 % over the day as presented below table 5.12. As for the wind speed, it records the highest value at 15.00pm as 2.59m/s, while the lowest value was 2.34 m/s recorded at 03:00 and 02:00 am figure 5.35, with an average of 2.45 m/s over the day.

Table 5.12: Summary of numerical data extracted in Phase 3- (space A) on June 23, 2017 for 24 hours.

Design 1	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	60.61	2.34375	37.555	4.03
2:00	69.86	2.34 ↓	35.8375	3.115
3:00	79.11 ↑	2.34 ↓	34.12	2.2
4:00	75.8	2.39	33.265	2.17
5:00	74.145	2.415	32.8375	2.155
6:00	72.49	2.44	32.41 ↓	2.14 ↓
7:00	68.97	2.46	34.09	2.74
8:00	67.1	2.47	35.3	3.8
9:00	65.45	2.48	35.77	4.86
10:00	54.045	2.49	36.66	5.675
11:00	49.9	2.495	40.21	6.13
12:00	42.64	2.5	43.76	6.49
13:00	36.5	2.545	48.13	6.69
14:00	27.58	2.58	49.99	7.625
15:00	18.66	2.59 ↑	52.5 ↑	8.56 ↑
16:00	18.59 ↓	2.58	50.12	7.33
17:00	18.795	2.56	49.92	6.715
18:00	19	2.54	49.73	6.1
19:00	21.125	2.47	47.245	5.81
20:00	22.1875	2.44	46.0025	5.205
21:00	23.25	2.4	44.76	4.6
22:00	28.52	2.37	44	4.55
23:00	34.48	2.355	42.5	4.37
00:00	56.795	2.3475	40.99	4.5
Average	**46.06677**	**2.455885**	**41.571**	**4.8983**

On the other hand, air temperature hits peak point at 15:00 pm where it was 52.5 C° awhile it reaches the lowest point at 06.00am recording 32.41C° setting an average of 41.57C° over the days shown in table 5.12. The PMV values also were tested over the day and noted that the highest value was recorded at 15:00 pm where it hits (8.56) while its lowest values were recorded at 06.00am as it drops to (2.14) with an average of (4.89) figure 5.35.

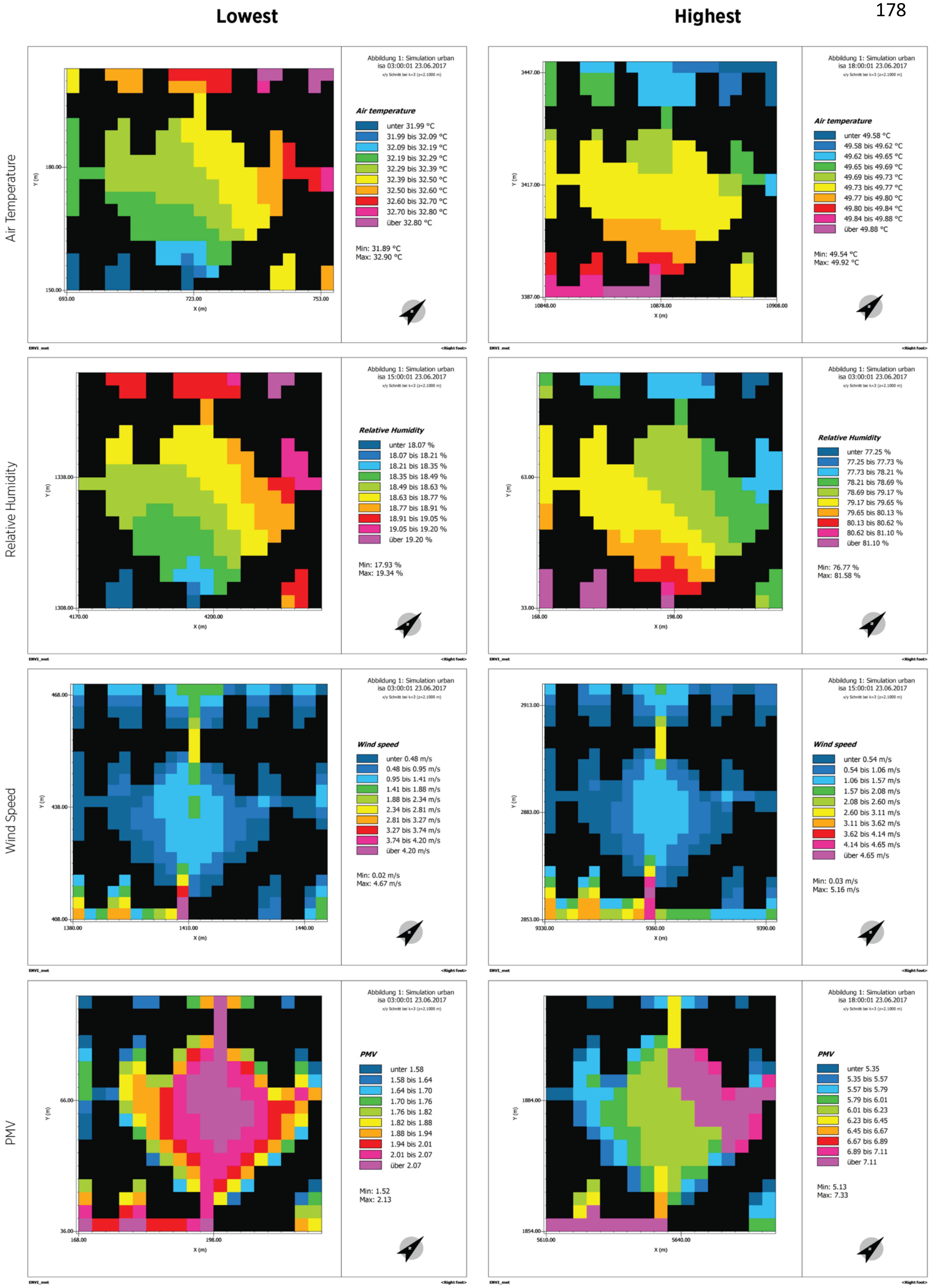


Figure 5.35: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space A (For the all 24 hours' maps refer to Appendix 3)

5.4.2 Urban Courtyard Simulation of Space B

The second design for the court-yard is suggesting a closed central urban space as shown below figure 5.36, since it is one of Zhao et. al. (2016) examined designs for court-yard layout. Yet a total number of residential blocks shell remain the same to compromise with the commercial value of the project figure 5.37.

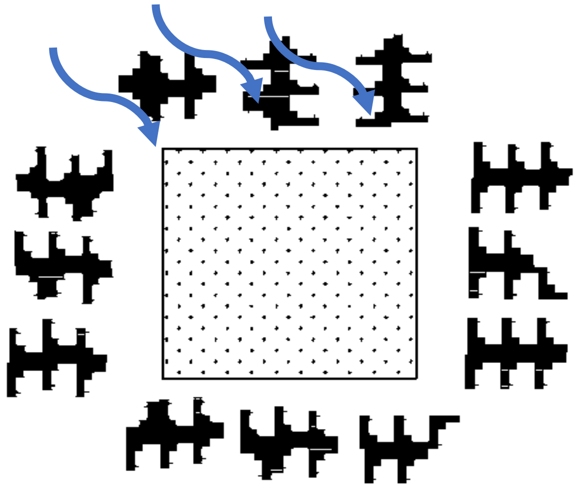


Figure 5.36:Phase 3- space B central building with square courtyard layout.

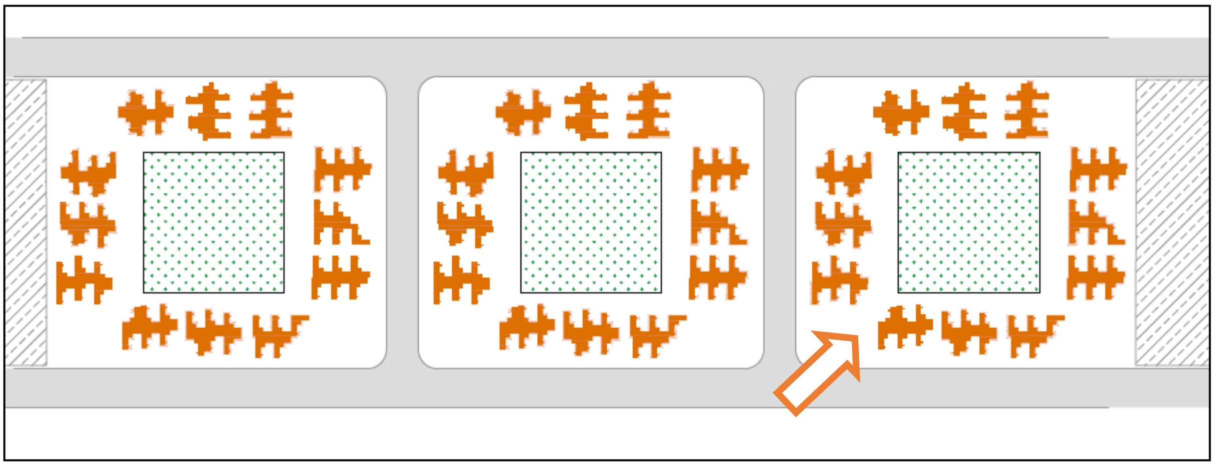


Figure 5.37:Phase 3- space B proposed design for the units' arrangement.

The model simulation of this design shows that relative humidity reaches its peak at 03:00 am as it goes above 76.50 % while drops to 19.11% at 18:00 pm as presented below table 5.13 setting an average of 44.61 % over the day that is less than space A presented previously.

Table 5.13: Summary of numerical data extracted in Phase 3- (space B) on June 23, 2017 for 24 hours.

Design 1	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	61.11	2.155	37.01	4.255
2:00	68.9	2.15	34.955	3.2325
3:00	76.69 ↑	2.16	32.9 ↓	2.21
4:00	73.21	2.15	32.965	2.18
5:00	71.47	2.145	32.998	2.165
6:00	69.73	2.14	33.03	2.15 ↓
7:00	66.01	2.13	34.53	2.86
8:00	64.89	2.125	35.58	3.815
9:00	62.29	2.12	36.03	4.77
10:00	51.06	2.12	38.79	5.62
11:00	45.45	2.12	41.34	5.98
12:00	39.83	2.12	43.89	6.47
13:00	34.1	2.155	47.585	7.1
14:00	26.915	2.16	49.21	7.92
15:00	19.73	2.19	51.28 ↑	8.74 ↑
16:00	19.35	2.2	51	7.675
17:00	19.23	2.205	50.21	7.1425
18:00	19.11 ↓	2.21 ↑	49.42	6.61
19:00	20.841	2.185	47.28	6.16
20:00	21.707	2.18	46.21	5.56
21:00	22.572	2.16	45.14	4.96
22:00	24.99	2.16	43.3	4.88
23:00	35.5	2.16	43	4.88
00:00	56.095	2.16	41.12	4.8
Average	**44.616**	**2.1567**	**41.616**	**5.089**

As for the wind speed records the highest value at 18.00pm that is 2.21m/s figure 5.38, while the lowest value was 2.12 m/s figure 5.38, recorded from 09:00 to 13:00 as shown in table 5.13 with an average of 2.15 m/s over the day that is also less than space A. On the other hand, Air temperature hits peak point at 15:00 pm where it was 51.28 C° while it reaches the lowest point at 03.00am recording 32.9 C° as shown in table 5.13. setting an average of 41.61C° over the day that is 0.1 C° more than space A. The PMV values also were tested over the day as shown below and noted that the highest value was recorded at 15:00 pm where it hits (8.74) while the lowest values were recorded at 06.00am as it drops to (2.15) with an average of (5.08) over the day as presented at table 5.13.

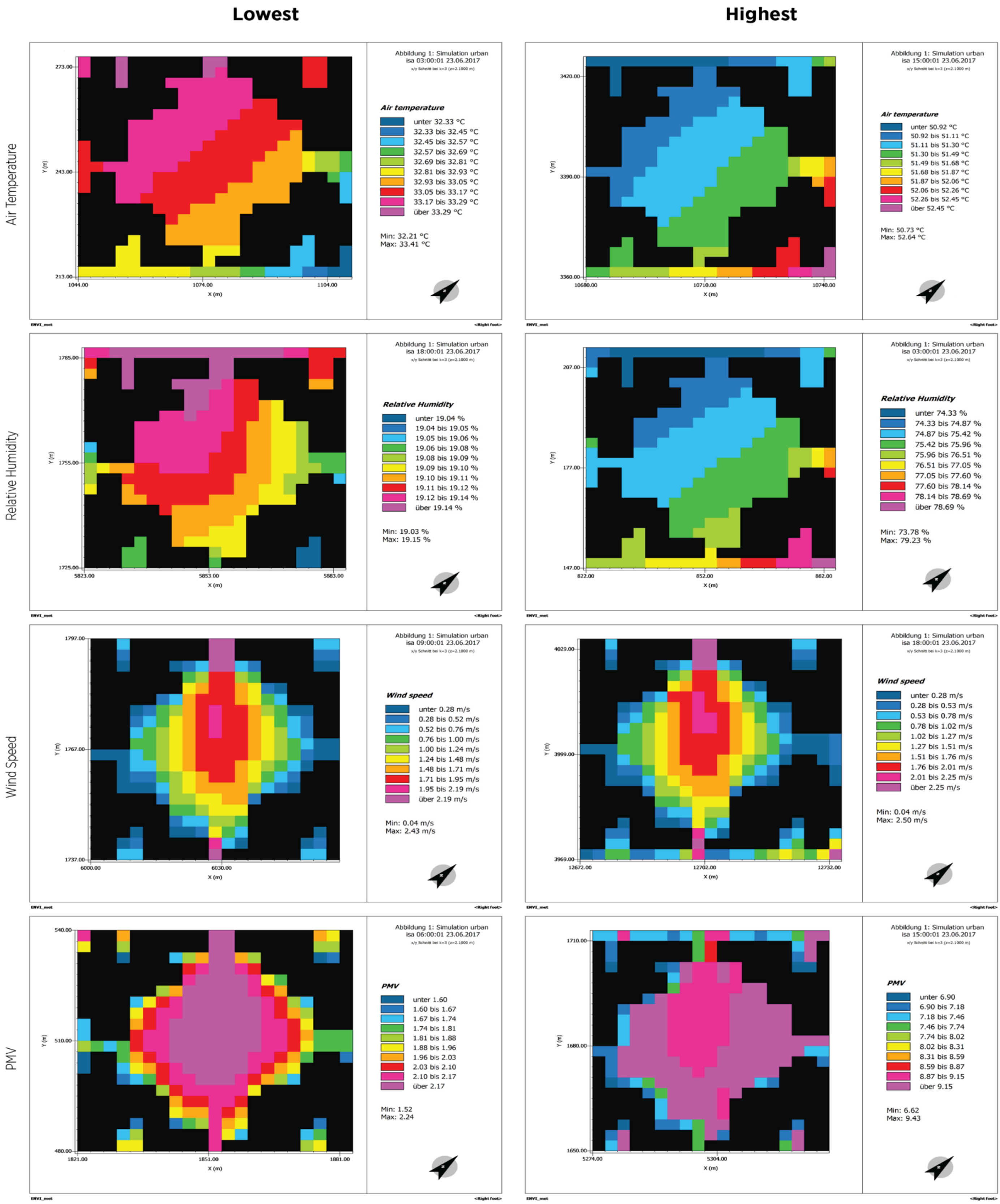


Figure 5.38: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space B (For the all 24 hours' maps refer to Appendix 3)

5.4.3 Urban Courtyard Simulation of Space C

The third court-yard design is suggesting a linear open space between the residential units as shown below figure 5.39. Space is wide open from North-west direction that is the privilege wind direction see figure 5.40, all the way down to South-east while a smaller access is located on the sides due to the setback required by the building code discussed earlier in section 4.5 urban texture variables chapter four. This design reduces the privacy of the space and provides better connectivity options to other adjacent court-yards.

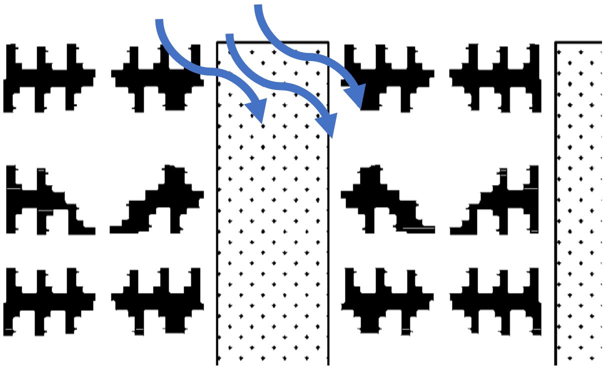


Figure 5.39: Existing linear buildings formed with rectangular courtyard.

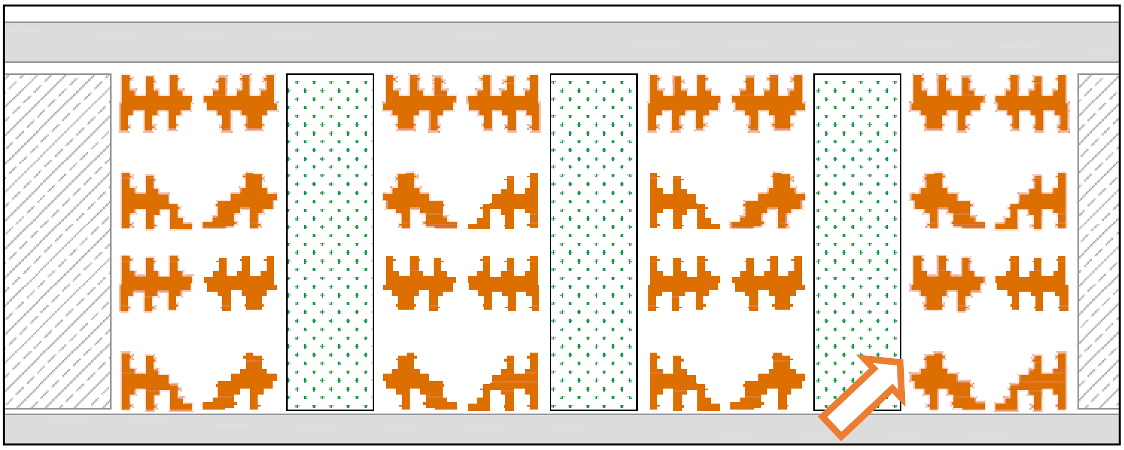


Figure 5.40: Phase 3- space C proposed design for the units' arrangement.

The model simulation of this design shows that relative humidity reaches its peak at 03:00 am as it goes above 76.60 % while drops to 19.11% at 18:00 pm as presented in table 5.14 setting an average of 44.59 % over the day that is almost equal to Space B and less than space A.

Table 5.14: Summary of numerical data extracted in Phase 3- (space C) on June 23, 2017 for 24 hours.

Design 1	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	62.46	1.2338	36.365	4.31
2:00	68.99	1.235	34.588	3.2
3:00	75.52 ↑	1.24	32.81 ↓	2.09
4:00	72.145	1.235	32.84	2.065
5:00	70.458	1.2325	32.855	2.0525
6:00	68.77	1.23	32.87	2.04 ↓
7:00	65.29	1.23	34.43	2.36
8:00	63.33	1.23	35.41	3.605
9:00	61.81	1.23	35.99	4.85
10:00	51.265	1.23	39.96	5.67
11:00	46.81	1.235	41.8	5.99
12:00	40.72	1.24	43.64	6.49
13:00	33.33	1.265	47.66	6.49
14:00	26.52	1.27	48.83	7.65
15:00	19.71	1.29 ↑	51.68 ↑	8.81 ↑
16:00	19.52	1.27	50.12	7.6
17:00	19.315	1.27	49.79	6.995
18:00	19.11 ↓	1.27	49.46	6.39
19:00	20.825	1.225	47.27	5.98
20:00	21.683	1.19	46.175	5.295
21:00	22.54	1.18 ↓	45.08	4.61
22:00	27.85	1.21	44.84	4.555
23:00	36.42	1.225	42.65	4.52
00:00	55.97	1.2325	39.92	4.5
Average	**44.598**	**1.2374**	**41.543**	**4.9216**

As for the wind speed it records the highest value at 15.00pm as 1.29 m/s while the lowest value was 1.18 m/s recorded at 21:00 pm as shown in table 5.14 and followed by figure 5.41 with an average of 1.23 m/s over the day setting the lowest record so far , but it was noticed that there is no big variation over the day as the differences are not really noticeable.

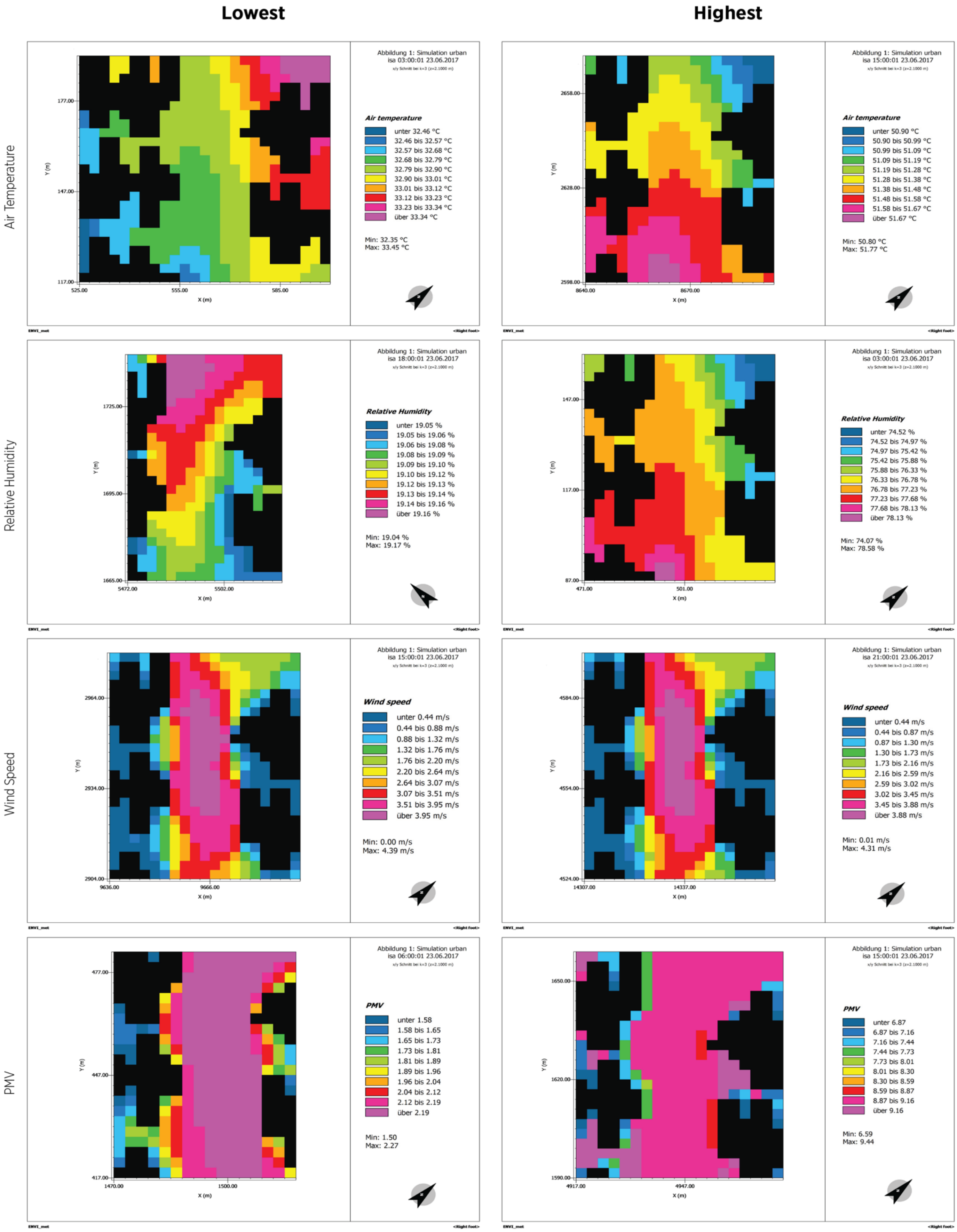


Figure 5.41:ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space C (For the all 24 hours' maps refer to Appendix 3)

On the other hand, Air temperature records the highest value recorded at 15:00 pm that was 51.68 C° while it reaches lowest point at 03.00am recording 32.81C° as shown in table 5.14. setting an average of 41.54C°, over the day with no big difference between both spaces presented earlier. The PMV values also were tested over the day were the highest value was recorded at 15:00 pm similar to air temperature and wind speed peak points as PMV value hits (8.81) refer to figure 5.41, while the lowest values were recorded at 06.00 am as it drops to (2.04) with an average of (4.92) see table 5.14.

5.4.4 Urban court-yard simulation of Space D

The fourth court-yard design is similar to design one as it is a U-Shape yard but with a square instead of the rectangular layout. Space is wide open from North-west direction to the privilege wind access as shown in figure 5.42.

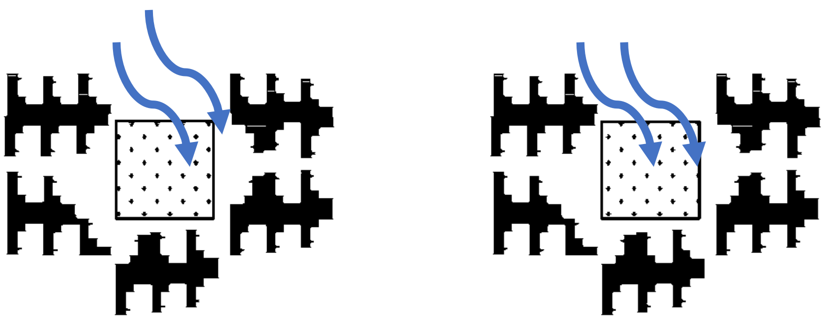


Figure 5.42: Proposed u-shaped buildings with square courtyard.

The model simulation shows that relative humidity reaches its peak at 03:00 am as it goes above 83.30 % and that is the highest percentage so far at this simulation while it drops to 17.22% at 15:00 pm as presented in table 5.15 setting an average of 48.03% over the day and that is the highest among all four spaces at this simulation phase. As for the wind speed, it records the highest value at 15.00pm as 2.98 m/s while the lowest value was 2.58 m/s recorded at 21:00 pm as shown at table 5.15 with an average of 2.70 m/s over the day and that is the highest average among all other designs as well.

On the other hand, Air temperature hits the highest value at 15:00 pm where it was 54.4C° while it reaches lowest point at 06.00am recording 31.2C° as shown in table 5.15 and figure 5.43.

Table 5.15: Summary of numerical data extracted in Phase 3- (space D) on June 23, 2017 for 24 hours.

Design 1	R.H %	Wind Speed m/s	Air Temp. C°	PMV
1:00	67.49	2.6544	35.12	4.22
2:00	75.4	2.65	33.23	3.08
3:00	83.31 ↑	2.67	31.34	1.94
4:00	80.4	2.64	31.28	1.915
5:00	78.945	2.625	31.25	1.903
6:00	77.49	2.61	31.22 ↓	1.89 ↓
7:00	74.32	2.6	33.15	2.22
8:00	73	2.595	34.66	3.535
9:00	71.15	2.59	35.07	4.85
10:00	57.95	2.6	40.1	5.715
11:00	51.11	2.62	42.29	6.19
12:00	44.75	2.64	44.47	6.58
13:00	30.15	2.81	49.46	6.89
14:00	23.685	2.86	52.12	8.075
15:00	17.22 ↓	2.98 ↑	54.44 ↑	9.26 ↑
16:00	18	2.95	49.98	8.015
17:00	18.44	2.945	50.03	7.393
18:00	18.88	2.94	50.08	6.77
19:00	21.6	2.76	47.09	6.14
20:00	22.96	2.76	45.59	5.45
21:00	24.32	2.58 ↓	44.09	4.76
22:00	30.63	2.625	42.85	4.68
23:00	37.77	2.6475	40.85	4.68
00:00	60.54	2.6588	38.89	4.6
Average	**48.013**	**2.7088**	**41.03**	**5.073**

Setting an average of 41.03C° over the day falling at the same point similar to all other designs presented earlier with 0.35 C° less than design three that makes it the lowest degree among all. The PMV values also were tested over the day as the highest value was recorded at 15:00 pm as (9.26) while the lowest values were recorded at 06.00am as it drops to (1.89) with an average of (4.80). This simulation shows an alignment were maximum wind speed, Air temperature and PMV value are meeting minimum R.H percentage all at 15:00 of the day. see figure 5.43.

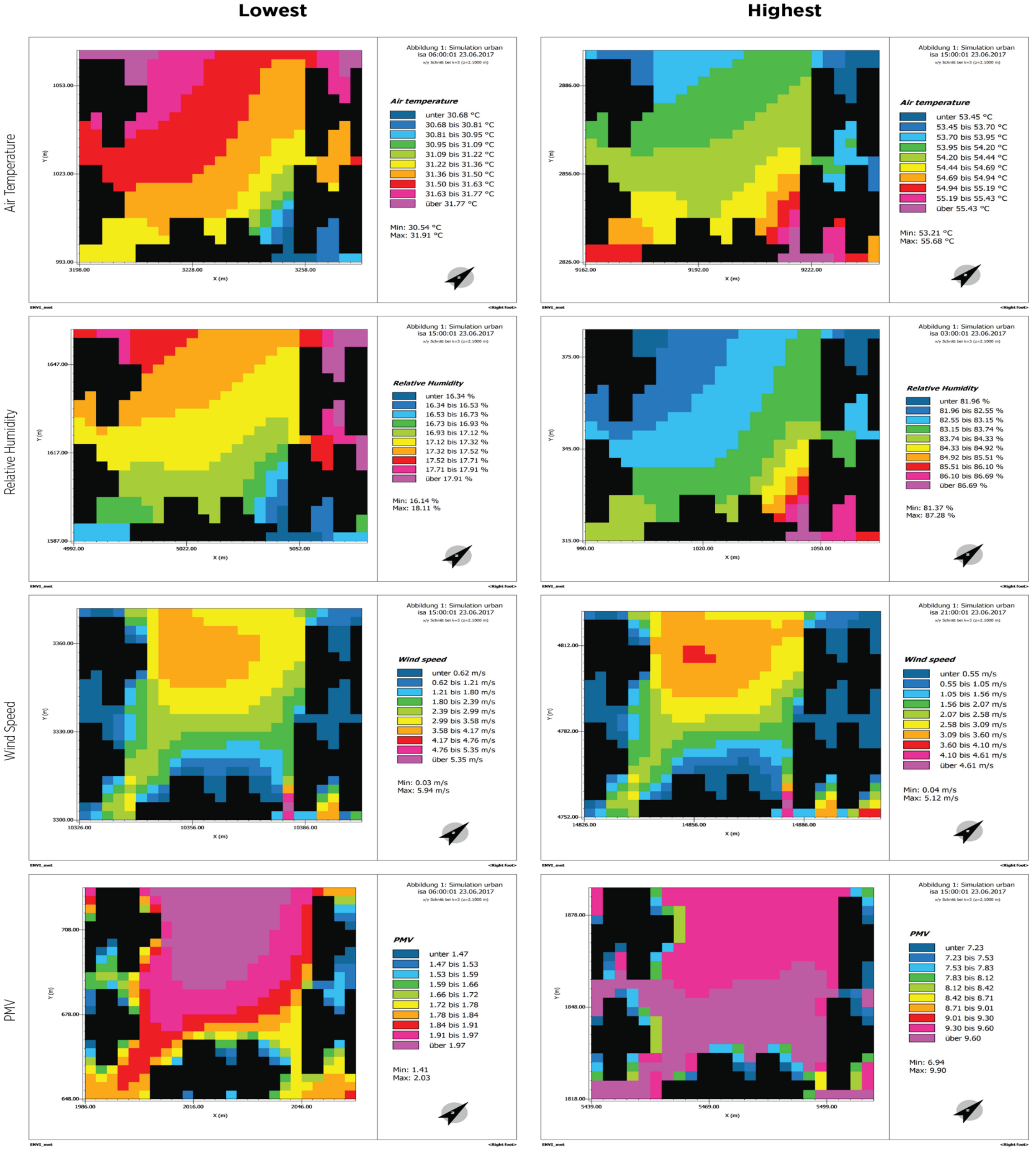


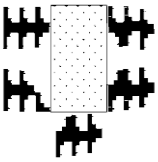
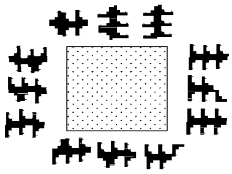
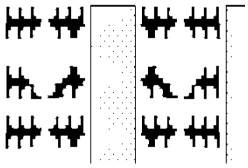
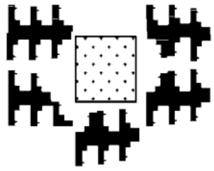
Figure 5.43: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV – Space D (For the all 24 hours' maps refer to Appendix 3).

5.4.5 Phase Three Summary and Discussion

The impact of court-yard design over the thermal comfort is a topic that was studied and discussed by many researchers, Svediv, (2015) for example list number of advantages accurse when adding court-yard to the project such as enhancing privacy, allowing better ventilation , reducing air temperature and providing flexible urban movement between different zones starting by public zone to semi-public, ending up with semi-private and private zone. Svediv, (2015) indicates that court-yards impacts social and environmental sustainability factors of the projects and since our research targets the environmental aspects of the selected case study project, it was essential to suggest redesigning for the optimal building configuration to test the courtyard enhancement possibilities on it by testing the evaluating variables used earlier to judge the building configuration in order to track the improvement.

The results of phase three as listed in table 5.16, shows that design one records the lowest relative humidity average among all as well as the lowest PMV value which is closer to the range of comfort that falls between (-1) and (+1). On the other hand, design four records the lowest Air Temperature yet the difference is only 0.35 C˚ and in term of wind speed design four sets higher value with a difference of 0.25 m/s yet the humidity has increased 2.25% in Space D compared to Space A recording highest value among all but still the PMV of Space D is falling at the same range with design two and three, yet design one keeps the lowest record with difference of 0.19 from design 2 that keeps the highest record of PMV.

Table 5.16: Phase three scenarios variables average summery showing best scenario.

Phase 3 Average	Space A 	Space B 	Space C 	Space D 
R.H	**46.06677**	**44.616**	**44.598**	**48.013**
Wind Speed	**2.455885**	**2.1567**	**1.2374**	**2.7088**
Air Temp	**41.571**	**41.616**	**41.543**	**41.03**
PMV	**4.8983**	**5.089**	**4.9216**	**5.073**

According to the results presented table 5.17, Space D was selected as the optimal case at this phase. Hence the aim of this research is to enhance thermal comfort variables in urban spaces the U-Shape square court-yard found to be the best improvement for the previous selected optimal building configuration as presented in table 5.17 were R.H has increased from 38.69% to 48.3% yet it is still under the mean average R.H recorded by Ministry of Presidential Affairs. while air temperature less by 0.39 C° and wind speed is less by 0.24m/s. Yet it is the closest to the minimum wind speed recorded this month. while PMV value remains the same in both cases.

Table 5.17: Comparison between the optimal case in phase 2 and the optimal case in phase 3.

Phase 3 Average	SPACE 1 (Phase Two)	Space D (Phase Three)	Ministry of Presidential Affairs / National center of metrology records
R.H %	38.69156	48.013	Mean = 55
Wind Speed m/s	2.94	2.7088	Minimum = 3.9
Air Temp C˚	41.58208	41.03	Mean Max= 47.9 / Mean = 33.1
PMV	5.016667	5.073	————

5.5 Phase four Introduction

In addition to the impact of urban configuration over microclimate basic parameters, Monteiro (2010) studied building surface materials and found that the use of warm ground cover, as well as building facade materials will impact the microclimate condition and affect the users at the urban space. The warm ground cover materials Monteiro (2010) was talking about indicated the hard landscaping materials like asphalt and interlock that can be replaced with sand and natural stone where it is appropriate. On the other hand, open urban spaces can make use of the green cover to improve the thermal condition of the space which will help on bigger scale to mitigate Urban Heat Islands as Sadeghne had. (2013), linked both factors to each other as users are subject to both factors continuously. In order to look for options Kenawy, Afifi, and Mahmoud (2013) were evaluating the impact of replacing the buildings and ground cover with natural vegetation and green coverage, This results in a reduction in temperature within the urban communities. This in fact supports (Yilmaz, Irmak, & Matzarakis, 2013), were it was concluded that plantation has an impact on urban community climate that significantly results as an impact on the urban heating levels which will impact users at a microclimate level.The case study of this research is a residential cluster that has zero percent of green cover between the residential unites therefore at phase four this studyintroduce three different percentages of green coverage designs starting by 15% to 30% to 45 % and compare the result to the main base case that is concluded from phase three earlier as it is the optimal court-yard design that has zero percent of green cover.

5.5.1 Greenery Coverage Simulation of Option 1 (Zero Percent)

The first case suggest following the current status at the site were urban spaces between the residential blocks does not include any greenery coverage, but only pavement material for sidewalks while the plantation is limited to the private courtyard of each villa in compliance. With Dubai Green Building Regulations that it is compulsory having one palm tree at least in each private villa at any project in Dubai, see figure 4.16 chapter four, section 4.5 presented earlier. Since the base case for this phase is considered the selected optimal case of the previous phase that was space D see figure 5.44, therefore, the outcome results are not going to be tested again since no change accrued to the model or input variables see figure 5.45.

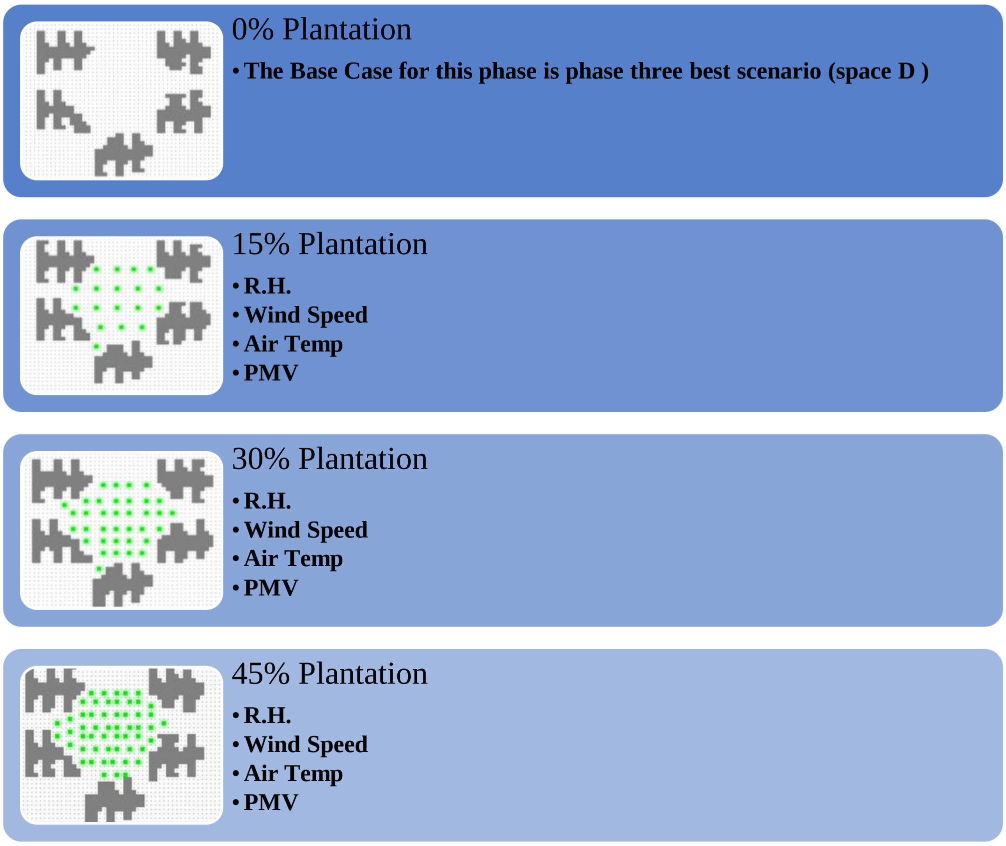


Figure 5.44: Phase 4 investigated scenarios variables.

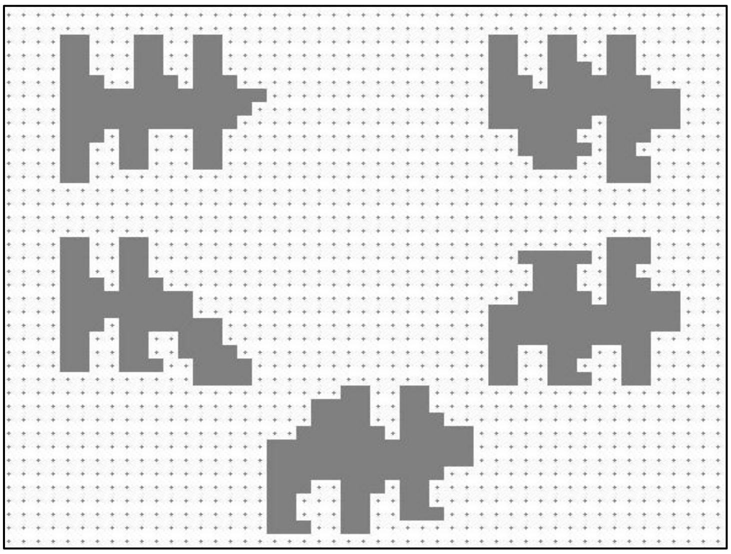


Figure 5.45: Space D optimal case of the phase 3(ENVI-met, 2017).

5.5.2 Greenery Coverage Simulation of Design 1 (Fifteen Percent)

Design one suggest having 15% of greenery coverage using local species that can adapt with local climate as shown figure 5.46. The design proposes (local palm trees surrounded with 1m height flower boxes containing 60cm height shrubs).

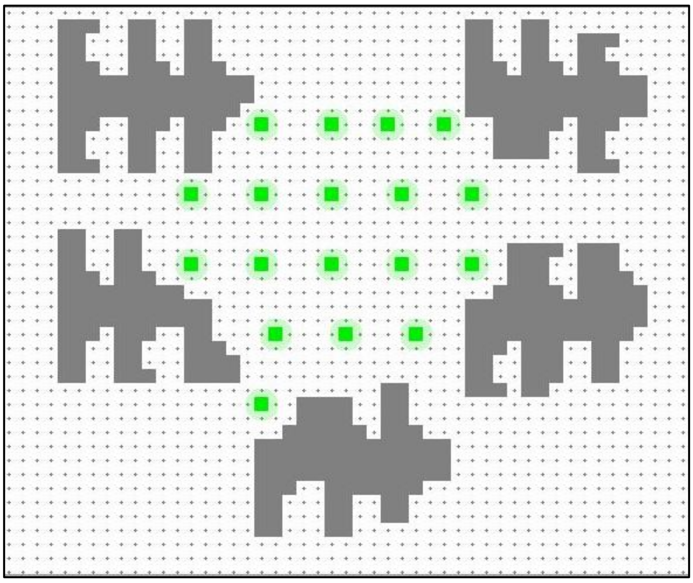


Figure 5.46: Phase 4- 15 % greenery coverage scenario arrangement (ENVI-met, 2017).

The model simulation records relative humidity at its highest on 03:00 am where it was 89.14% and at its lowest on 15:00 pm were it was 19.5% ending up with an average of 52.45% over the day see table 5.18. As for wind speed the highest value were 2.62m/s at 18:00 & 19:00pm while the lowest value was 2.2m/s at 12:00pm with an average of 2.38m/s. On the other hand, air temperature sets its peak point at 15:00, where it records 55.12C° figure 5.47, and its lowest points at 06:00 am where it records 30.03C° with an average of 41.01C° over the day. while PMV value has its highest record at 15:00 pm that was (9.95) figure 5.47, and lowest value at 06:00 as it records (1.58) with an average of (5.06) over the day like the previous result that has zero percent of green coverage which sets the optimal case of phase three.

Table 5.18: Summary of numerical data extracted in Phase 4- (15 %) on June 23, 2017 for 24 hours.

Green Cover 15%	R.H %	Wind Speed m/s	Air Temp. C°	PMV
1:00	61.925	2.33	38.89	4.025
2:00	76.32	2.48	34.52	3
3:00	89.14 ↑	2.53	30.04	1.62
4:00	86.94	2.44	30.035	1.6
5:00	85.84	2.395	30.033	1.59
6:00	84.74	2.35	30.03 ↓	1.58 ↓
7:00	80.8	2.3	31.855	2.97
8:00	79.945	2.27	32.01	3.63
9:00	79.09	2.24	33.68	4.29
10:00	69.525	2.22	38.8	5.11
11:00	64.743	2.21	40.88	5.94
12:00	59.96	2.2 ↓	43.92	6.77
13:00	39.77	2.375	48.02	7.51
14:00	24.44	2.4625	51.57	8.73
15:00	19.58 ↓	2.55	55.12 ↑	9.95 ↑
16:00	20.22	2.58	52.88	8.62
17:00	21.575	2.6	51.15	8.23
18:00	22.93	2.62 ↑	49.42	7.29
19:00	26.66	2.62 ↑	46.78	6.055
20:00	29.65	2.445	45.32	5
21:00	32.64	2.27	44.14	4.82
22:00	33.675	2.27	42.74	4.535
23:00	33.98	2.27	42.26	4.44
00:00	34.71	2.27	41.78	4.25
Average	**52.45**	**2.3874**	**40.017**	**5.036**

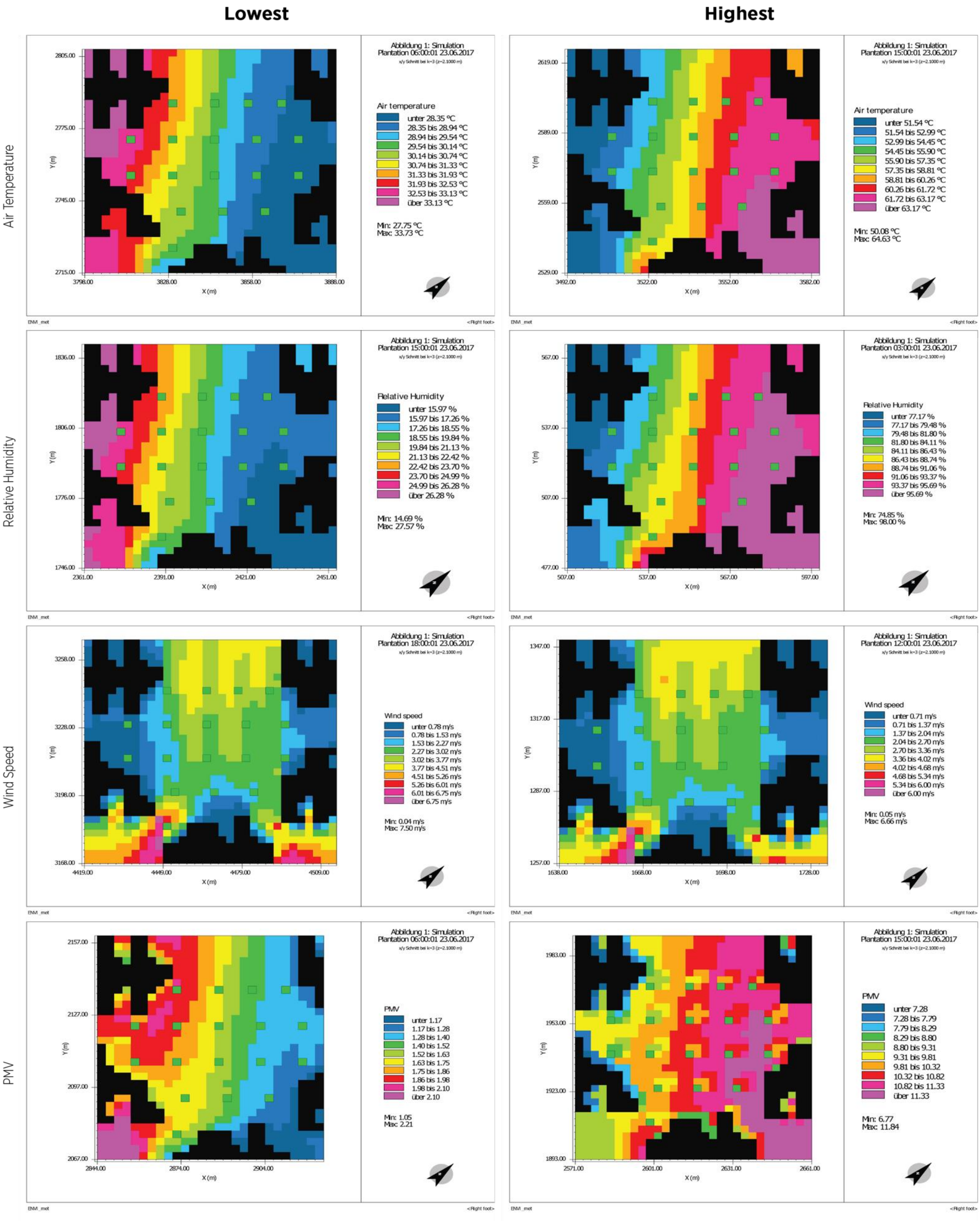


Figure 5.47: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV –15% greenery cover (For the all 24 hours' maps refer to Appendix 4).

The simulation of this design indicates a reduction in wind speed in its average as well as its highest and lowest points، as seen in table 5.18 this leads to an increase in R.H from 48.31% to 52.45 % and this impacts the air temperature as no variation is noted at its average result, yet the peak point at 15:00 is higher than the previous case by 0.68C˚ note that at the same time R.H is recording the lowest percentage over the day, while the wind speed is 0.07m/s away from the highest record of the day. It is believed that R.H and wind speed helped to stabilize the air temperature that results in keeping PMV within the same range as the previous simulation.

5.5.3 Greenery Coverage Simulation of Design 2 (Thirty Percent)

Design two increases the percentage up to 30% of ground cover that will be applied by adding an additional number of previous palm trees surrounded by the same flower box with the same type of shrubs in order to eliminate the positivity of plant type impact over the result see figure 5.48.

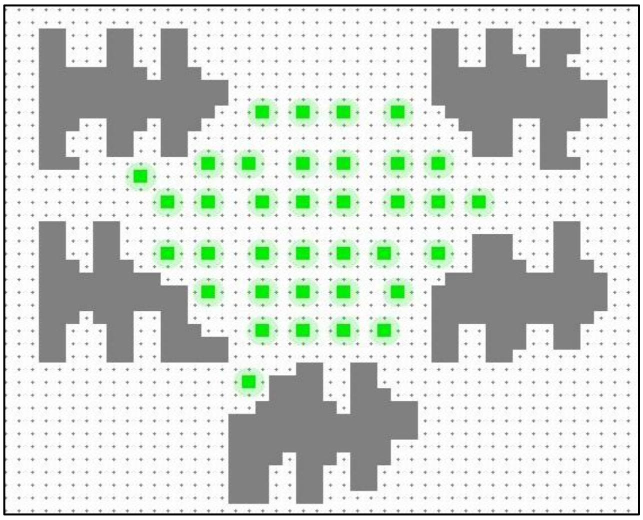


Figure 5.48:Phase 4- 30 % greenery coverage scenario arrangement (ENVI-met, 2017).

The model simulation records relative humidity at its highest on 03:00 am where it was 88.48% and at its lowest on 18:00 pm, were it was 24.26% with an average of 59.19% refer to table 5.19, while the wind speed sets its highest records at 18:00 pm as it was 2.29m/s, see figure

5.49, while it records the lowest value at 12:00 pm and 21:00 pm as it was 2.14m/s setting an average of 2.19m/s. On the other hand, air temperature sets its peak point at 15:00 where it records 54.63C° and its lowest points at 03:00 am where it records 28.49C°with an average of 40.52 C°. As for PMV the highest value was at 15:00 pm were it records (9.77) while its lowest values were on 03:00 up to 06:00 am were it records (1.31) figure 5.49, with an average of (5.22) over the day that is (0.05) more than Design one and (0.19) more than base case for this phase, see table 5.19.

Table 5.19: Summary of numerical data extracted in Phase 4- (30 %) on June 23, 2017 for 24 hours.

Green Cover 30%	**R.H %**	**Wind Speed m/s**	**Air Temp. C°**	**PMV**
1:00	67.75	2.16	38.11	3.9
2:00	80.21	2.2	34.21	2.57
3:00	88.48	2.23	28.49	1.31
4:00	86.23	2.205	28.555	1.31
5:00	85.11	2.1925	28.588	1.31
6:00	83.98	2.18	28.62	1.31
7:00	83.1	2.18	30.795	2.54
8:00	81.43	2.17	30.92	3.24
9:00	79.75	2.16	32.97	3.94
10:00	77.12	2.15	39.45	5.04
11:00	75.81	2.14	42.68	6.325
12:00	74.49	2.14	45.93	7.61
13:00	55.6	2.19	48.11	8.41
14:00	47.87	2.215	51.37	9.09
15:00	36.7	2.24	54.63	9.77
16:00	30.31	2.24	50.5	8.785
17:00	27.29	2.265	49.98	8.5
18:00	24.26	2.29	49.46	7.8
19:00	31.31	2.25	46.52	6.33
20:00	36.07	2.195	45.5	5.87
21:00	40.82	2.14	43.58	4.86
22:00	43.92	2.15	42.2	4.485
23:00	35.87	2.15	41.21	4.28
00:00	47.01	2.16	40.22	4.11
Average	**59.19**	**2.1914**	**40.525**	**5.112**

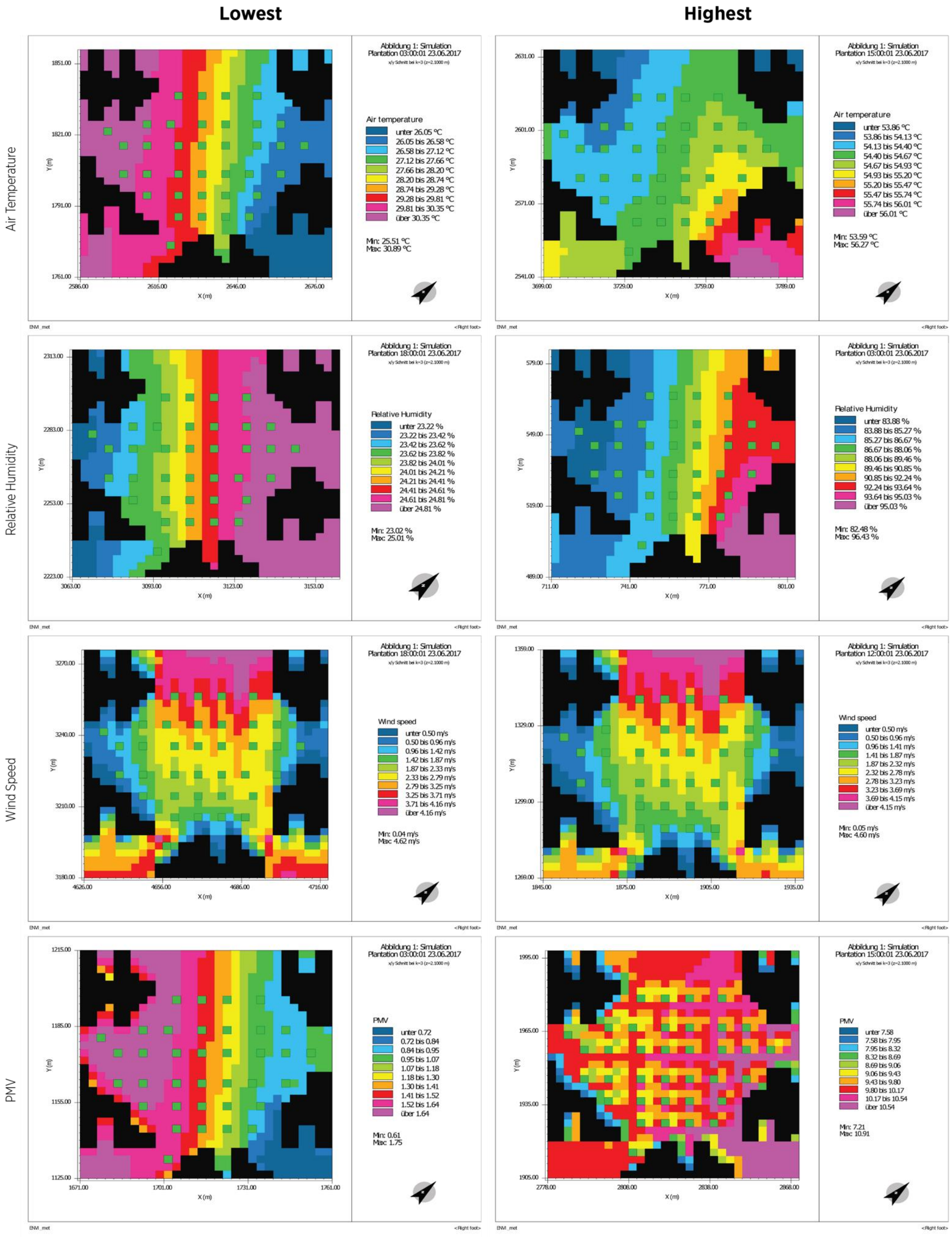


Figure 5.49: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV –30% greenery cover (For the all 24 hours' maps refer to Appendix 4).

The simulation of this design shows a further reduction in wind speed in when compared to the previous case. This leads to an increase in R.H from 52.45 % to 59.19% in addition to decrease in air temperature going from 41.07C˚ to 40.52 C˚, however, the peak point remains at the same hour, with attention to the R.H. at the same time of the day as it is higher than the previous case as it goes from 19.58 to 36.7 at this time of the day.

5.5.4 Greenery Coverage Simulation of Design 3 (Forty-five Percent)

The last design increases the percentage to reach up to 45% see number of previous palm trees surrounded by the same flower box with the same type of shrubs, in order to eliminate the positivity of plant type impact over the result see figure 5.50.

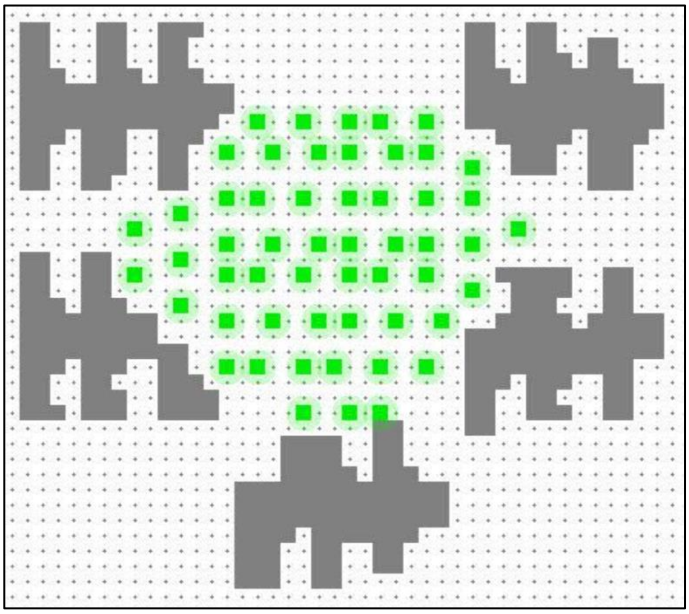


Figure 5.50: Phase 4- 45 % greenery coverage scenario arrangement (ENVI-met, 2017).

The simulation results presented in table 5.20 indicates that relative humidity sets its highest value at 03:00 am where it was 95.17% that is the highest value in this research and at its lowest at 18:00 pm were it records 24.54% setting an average of 67.98% over the day. Simultaneously the wind speed sets its highest records at 18:00 pm as it was 1.95m/s figure 5.51. while its lowest record was at 01:00 am as 1.6m/s were the averages of the day is 1.72 m/s that is the lowest among all designs. On the other hand, air temperature sets its peak point at 15:00 where it records 56.65C° and its lowest points at 06:00 am like the previous option where it records 26.29C°with an average of 55.49 C°.

Table 5.20: Summary of numerical data extracted in Phase 4- (45 %) on June 23, 2017 for 24 hours.

Green Cover 30%	R.H %	Wind Speed m/s	Air Temp. C°	PMV
1:00	77.81	1.6	35.55	3.11
2:00	83.54	1.74	31.99	1.98
3:00	95.17	1.87	26.33	0.88
4:00	93.97	1.84	26.31	0.88
5:00	93.37	1.825	26.3	0.88
6:00	92.77	1.81	26.29	0.88
7:00	91.21	1.77	28.98	1.98
8:00	90.56	1.725	30.88	2.83
9:00	89.9	1.68	31.67	3.68
10:00	87.53	1.665	40.25	4.98
11:00	86.34	1.66	45.56	6.76
12:00	85.15	1.65	48.83	8.54
13:00	64.94	1.765	52.32	9.8
14:00	57.1	1.8225	54.485	10.09
15:00	44.72	1.88	56.65	10.38
16:00	38.51	1.9	54.48	9.355
17:00	31.53	1.925	52.28	8.42
18:00	24.54	1.95	50.08	8.33
19:00	36.55	1.75	46.22	6.5
20:00	43.31	1.72	43.33	5.77
21:00	50.07	1.69	42.36	4.67
22:00	55.26	1.635	403.33	4.245
23:00	57.14	1.6	39.12	4.14
00:00	60.45	1.58	38.34	3.82
Average	**67.98**	**1.7522**	**55.497**	**5.121**

while the PMV highest value was recorded at 15:00 pm see figure 5.15 and table 5.20, as it reaches (10.38) while its lowest values were at 03:00 am and 06:00 am were it records (0.88) that is the lowest value of this research setting an average of 5.12 over the day, see table 5.20.

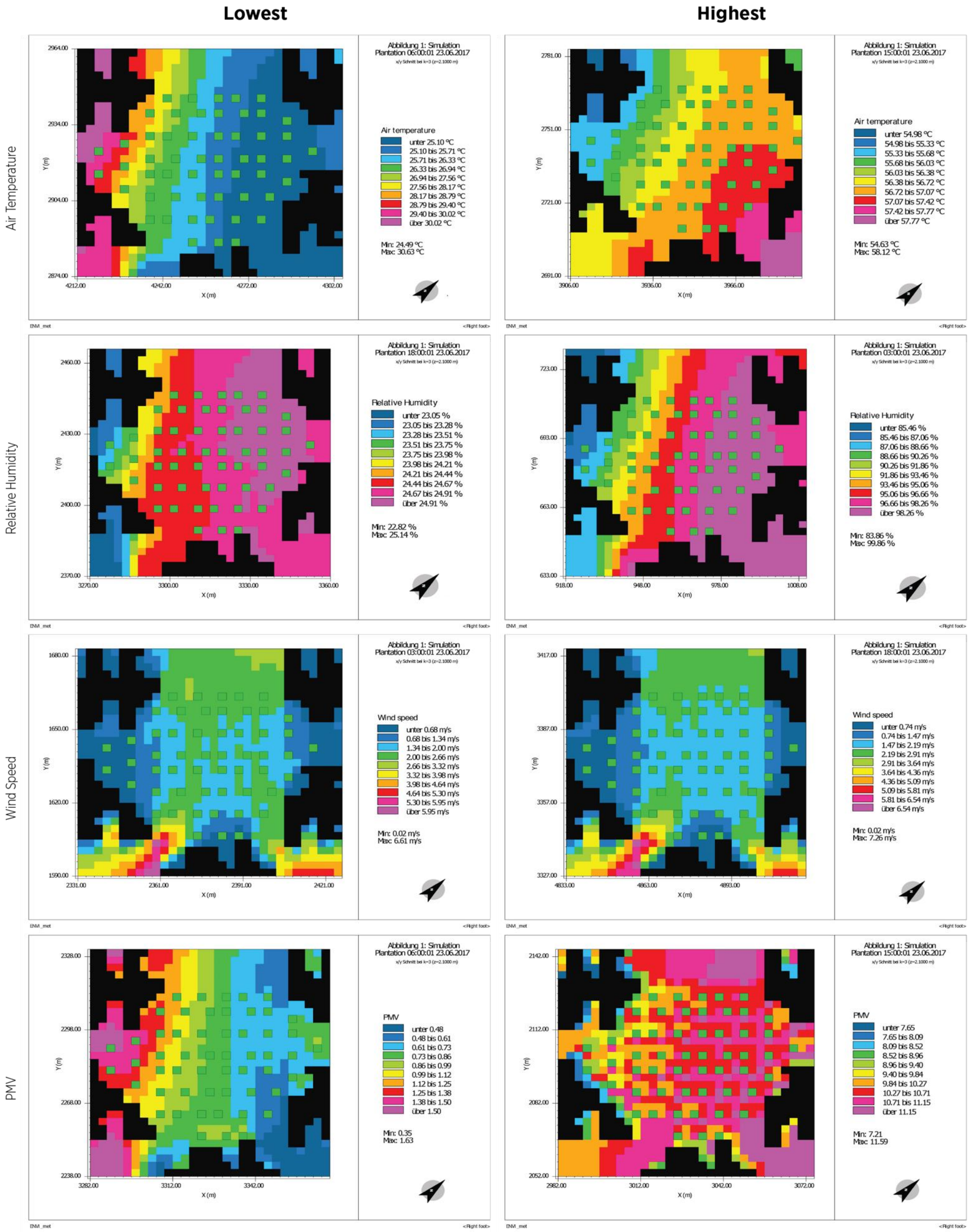


Figure 5.51: ENVI-met maps showing the highest and lowest readings for air temperature, RH, wind speed, and PMV –30% greenery cover (For the all 24 hours' maps refer to Appendix 4).

Even though PMV sets a very close value to the optimal comfort value as per ASHRAE Standard 55/2010 where it hits lowest values close to zero from 03:00 to 06:00 keep in mind that the urban space is not used now of the day due to its characteristic and addressed function as well as users culture, therefore, the impact of this optimal case will not impact users directly. Note that maximum air temperature was recorded simultaneously with maximum PMV value were both recodes wets the highest records overall simulation at this research. on the other hand, the lowest R.H percentage was recorded at simultaneously with the highest wind speed record, even though this speed is much lower than previous simulations in this phase.

5.5.5 Phase Four Summary and Discussion

As Trihamdani, Lee, Kubota, & Phuong, (2015) were studying mitigating UHI by different green space configuration it was concluded that using mixed forest and green cover in a green network that is designed equally will result in a noticed reduction of heat spots over the day. also, Setaih, Hamza, & Townshend, (2013) highlighted that planting local green vegetation and trees is a common strategy used in hot aired areas. This research also investigated the impact of green plantation added to the optimal case of phase three presented earlier. Using the same evaluation variables used by Setaih, Hamza, & Townshend, (2013) and Thani, Mohamad, &Jamaludin, (2013) used that are listed table 5.21 were it was noticed that the base case that has zero percent of green cover recorded the lowest R.H percentage and highest Wind speed against the case was green cover sets 45% of court-yard space were R.H recorded the highest percentage and wind speed were at its lowest level.

Table 5.21: Phase four scenarios variables average summery showing best scenario.

Phase 4 Average	Base case 0%	Design 1 15%	Design 2 30%	Design 3 45%
R.H	**48.013**	**52.45**	**59.19**	**67.98**
Wind Speed	**2.7088**	**2.3874**	**2.1914**	**1.7522**
Air Temp	**41.03**	**40.017**	**40.525**	**55.497**
PMV	**5.073**	**5.036**	**5.112**	**5.121**

This remark meets Setaih, Hamza, & Townshend, (2013) were it was noted that trees may stand as windbreakers when it is needed at hot areas, yet this drawback feature can be subsidized by the evaporate cooling feature that comes with the increase of vegetation and distribution of plants which adds to the increase in R.H percentage in addition to low wind speed which results in design 3 was the Relative humidity recorded a big difference compared to design 2.

On the other hand, Bruse, & Skinner, (1999) stated that a reduction in temperature is noticed after introducing green plantation side by side with a reduction in wind speed just this meets the results of design 1 were 15% of the courtyard was covered with green boxes that contain palm tree surrounded with local shrubs, each box is 3x3m and shrubs are 60cm height above ground. This clearly sets a reduction of almost 1C˚ air temperature between 0% green coverage that sets the base case and 15% of green coverage were the R.H also was raised as indicated by previous studies because of an evaporative cooling feature that is introduced by the addition of trees. Despite the increase in R.H percentage, it remains below the average percentage recorded by the Ministry of Presidential Affairs / National Center of metrology which records the mean relative humidity in June to be 55%, and as far is 52% is within the comfortable range since the lowest recorded average over the year in Dubai is 53% in August were air temperature records 41.4C˚, as per the Ministry of Presidential Affairs / National

Center of Metrology which records. Like (Yilmaz, Irmak, & Matzarakis, 2013), conclusion and Kenawy, Afifi, and Mahmoud (2013) it is found that adding 15% of green cover to the urban courtyard mitigate the thermal comfort level of space by reducing air temperature that will impact PMV, while it reduces the wind speed, therefore, increasing the greenery percentage is not recommended. Given these points design (1) was selected as the best case of this phase were 15% of the court-yard is converted to green boxes as presented table 5.22.

Table 5.22: Phase four scenarios variables average summery showing best scenario.

Phase 4 Average	Base case 0%	Design 1 15%	Design 2 30%	Design 3 45%
R.H	**48.013**	**52.45**	**59.19**	**67.98**
Wind Speed	**2.7088**	**2.3874**	**2.1914**	**1.7522**
Air Temp	**41.03**	**40.017**	**40.525**	**55.497**
PMV	**5.073**	**5.036**	**5.112**	**5.121**

5.6 Phase five Introduction

This phase aims to evaluate the impact of the outdoor thermal enhancements results after applying different passive design strategies on the existing base case design starting with phase one were optimal orientation was examined. Moving to phase two that investigate four different urban configurations to select the most efficient one based on the result of the evaluation variables selected earlier in chapter four, then going to phase three were four different courtyard designs were added to the optimal case selected from phase two as per previous research papers that recommends adding courtyard design for the hot arid weather as it enhance and improve the thermal comfort level at the project. Finally, phase four examined the best percentage of green cover introduced to the optimal courtyard design from phase three. These strategies impact the thermal characteristics of the urban space around the building as presented in table 5.23.

Table 5.23: Comparison between the optimal case in phase 1 and the optimal case in phase 4.

Evaluation Variables	Phase one (Base case)	Phase 4 (Optimal case)	Difference
R.H %	56.27	52.45	Reduction of 3.82
Wind Speed m/s	2.955	2.3874	Reduction of 0.56m/s
Air Temp C°	41.02	40.017	Reduction of 1C°
PMV	5.1018	5.026	Reduction of 0.08

Therefore, this tested the impact of the reduction presented earlier in table 5.23 of the evaluation variable over the indoor Energy consumption on 23 June the same day were all simulation analysis were carried on eliminating the changes in time and date that might impact the final results.

As per (Zhao et al. 2016), the relationship between the PMV value, wind speed and air temperature is representing in the psychometric chart shown in figure 5.51, which indicate that the enhancement strategies which applied previously in the four phases were moving towards the comfort zone area in the psychometric chart in terms of PMV, air temperature and wind speed.

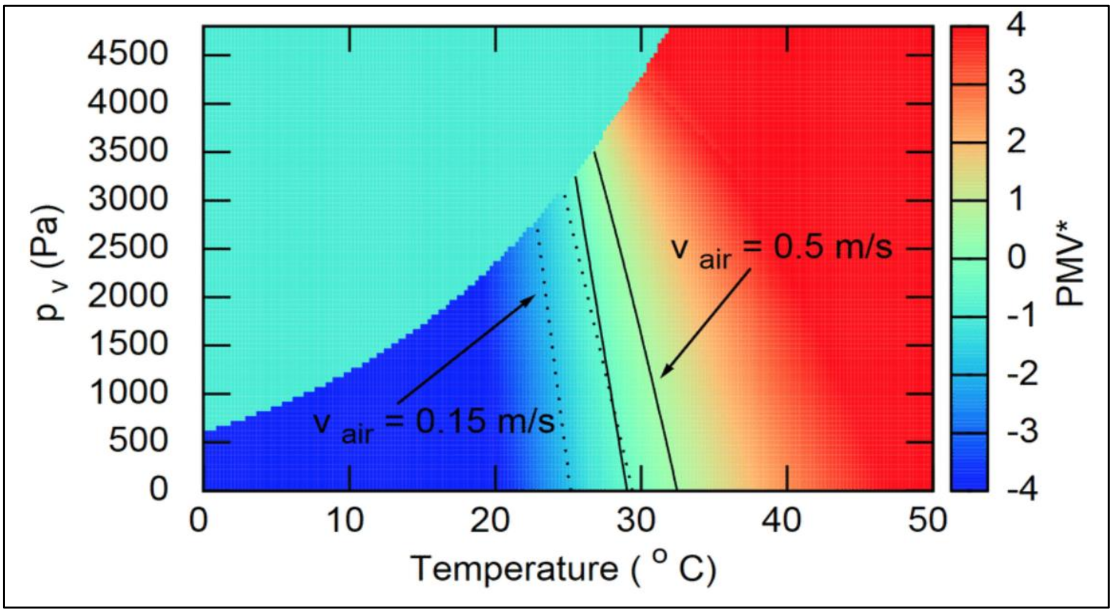


Figure 5.51: PMV - Comfort zone position for =0.15 m/s (dotted line) and = 0.5 m/s (solid line), (Adapted from Zhao et,2016).*

5.6.1 Indoor Energy Consumption Analysis- Base Case

The base case virtual model was built using DesignBuilder as discussed earlier in chapter 4 section 4.6.11, and explained in chapter two. In alliance with De la Torre, & Yousif (2014) and Feng, Ming, Ruey (2015) who used DesignBuilder to simulate the indoor thermal comfort and energy consumption as well as Nga, E. Y. Y. (2017), were the same software was used to calculate the energy consumption under extreme summer condition at Hong Kong in one of the typical public housing designs.

The model was built using Abu Dhabi weather file since it is the only file registered in the programme related to U.A.E see table 5.24, yet the input data can be adjusted and modifiers as explained earlier chapter four therefore, the collected data of air temperature, relative humidity, and wind speed as well as all other weather information related to Dubai were inserted and modified to ensure accuracy as the model is subject to Dubai climate properties.

Table 5.24: DesignBuilder data input sheet (DesignBuilder, 2017)

	Value
Program Version and Build	Energy Plus, Version 8.5.0-c87e61b44b, YMD=2017.10.11 05:38
Run Period	BASE CASE (23-06:24-06)
Weather File	ABU DHABI - ARE IWEC Data WMO#=412170
Latitude [deg]	24.43
Longitude [deg]	54.65
Elevation [m]	27.00
Time Zone	+4.00
Hours Simulated [hrs]	48.00

It is important to notice that the project is using the geographical location of Abu Dhabi since the only recorded city in U.A.E at its database is the capital city of United Arab

Emirate and this data is not changeable unlike the weather details, therefore, both final report indicates the geographical data as shown in table 5.24 above.

The base case energy graph results from the simulation on 23 June is presented in figure 5.52, it indicates the energy consumption of three different cooling temperature set point starting from 23C˚ that is the blow colour line at the top and at 25C˚, that is the second line with red colour and finally at 27C˚ cooling set point which is the lower green line. While the vertical axis Shows the energy load in kW/h where the minimum is 1900 kW/h while the horizontal axis shows the percentage of the wall to the window that is starting by 20%.

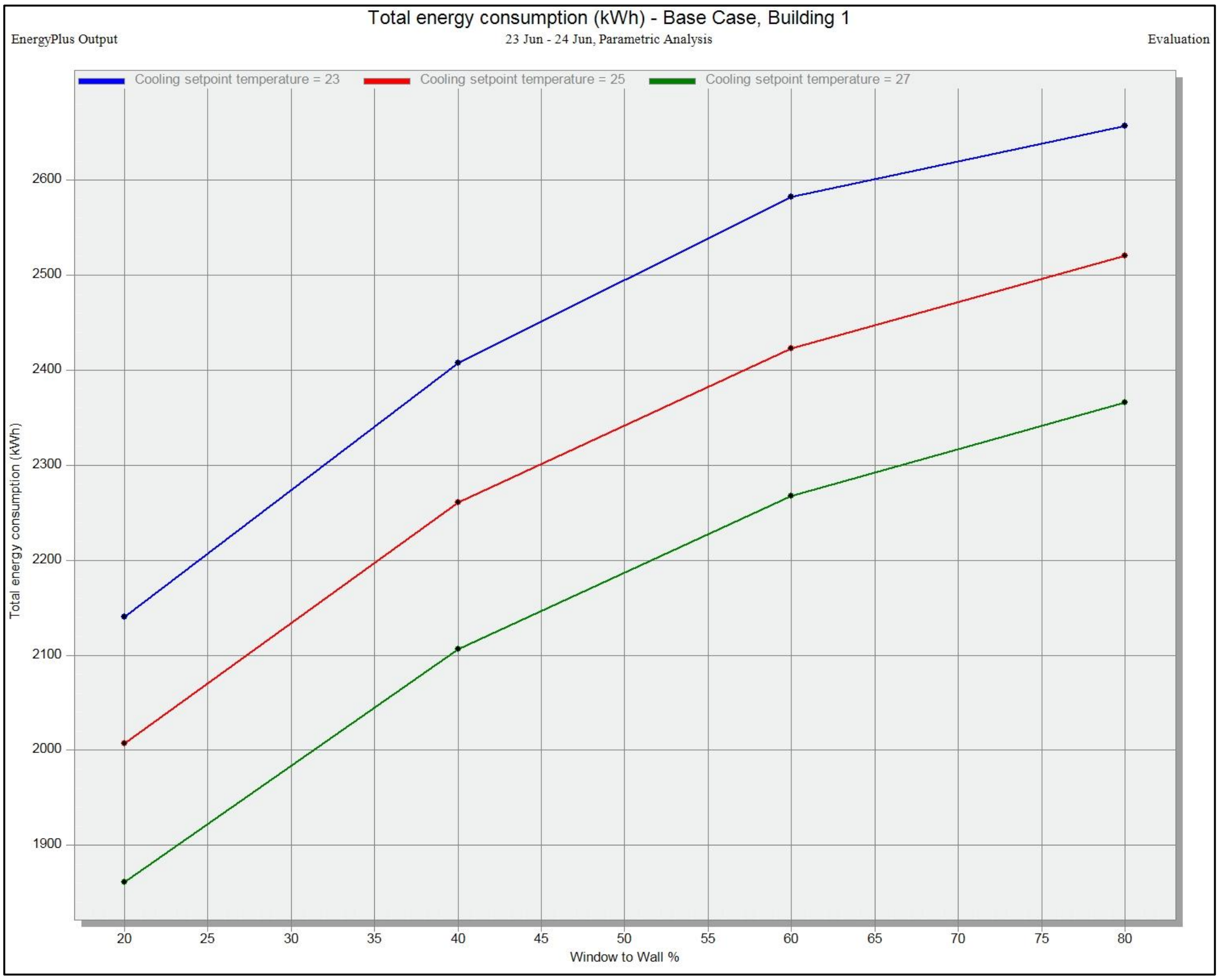


Figure 5.52: Base case energy graph results from the simulation on 23 June (DesignBuilder, 2017)

The model is built with respect to the existing design in term of floor area and height as well as windows orientation and approximate sizes figure 5.53, since the Auto Cad software copy for the individual units are not published for public therefore the window sizes are set according to site visit and 3D renders images created by project developer and published on the internet.

Figure 5.53:DesignBuilder model for the residential units with respect to the real villa (DesignBuilder, 2017).

As per the construction details listed in table 5.25, the window-wall percentage in the current design is 24% at its maximum limit, therefore, the 20% is considered on the output graph shown figure 5.52. The table also indicates the window open area at each side of the building.

Table 5.25:DesignBuilder model construction details (DesignBuilder, 2017)

	Total	**North (315 to 45 deg)**	**East (45 to 135 deg)**	**South (135 to 225 deg)**	**West (225 to 315 deg)**
Gross Wall Area [m2]	**1632.43**	**530.60**	**286.33**	**529.20**	**286.30**
Above Ground Wall Area [m2]	**1632.43**	**530.60**	**286.33**	**529.20**	**286.30**
Window Opening Area [m2]	**380.04**	**127.35**	**64.81**	**123.00**	**64.88**
Gross Window-Wall Ratio [%]	**23.28**	**24.00**	**22.64**	**23.24**	**22.66**
Above Ground Window-Wall Ratio [%]	**23.28**	**24.00**	**22.64**	**23.24**	**22.66**

The simulation analysis shows that to meet the cooling set point at 27C° then the energy needed on 23 June is below 1900 kW/h which indicates the total energy consumption.

But as per Dubai Municipality green code known as Al-Safa'at it is essential that interior dry bulb temperature does not exceed 25.5C˚, while the minimum limit is 22.5C, therefore the cooling setpoint considered for this evaluation is 25C˚ That is the second line represented in red colour this indicates that total energy consumption is around 2000 KW/h on 23 June see figure 5.54, while having 12 condition zones with total area of 1366.92 m² that is setting a volume of 4715.88 m³ air-conditioned space.

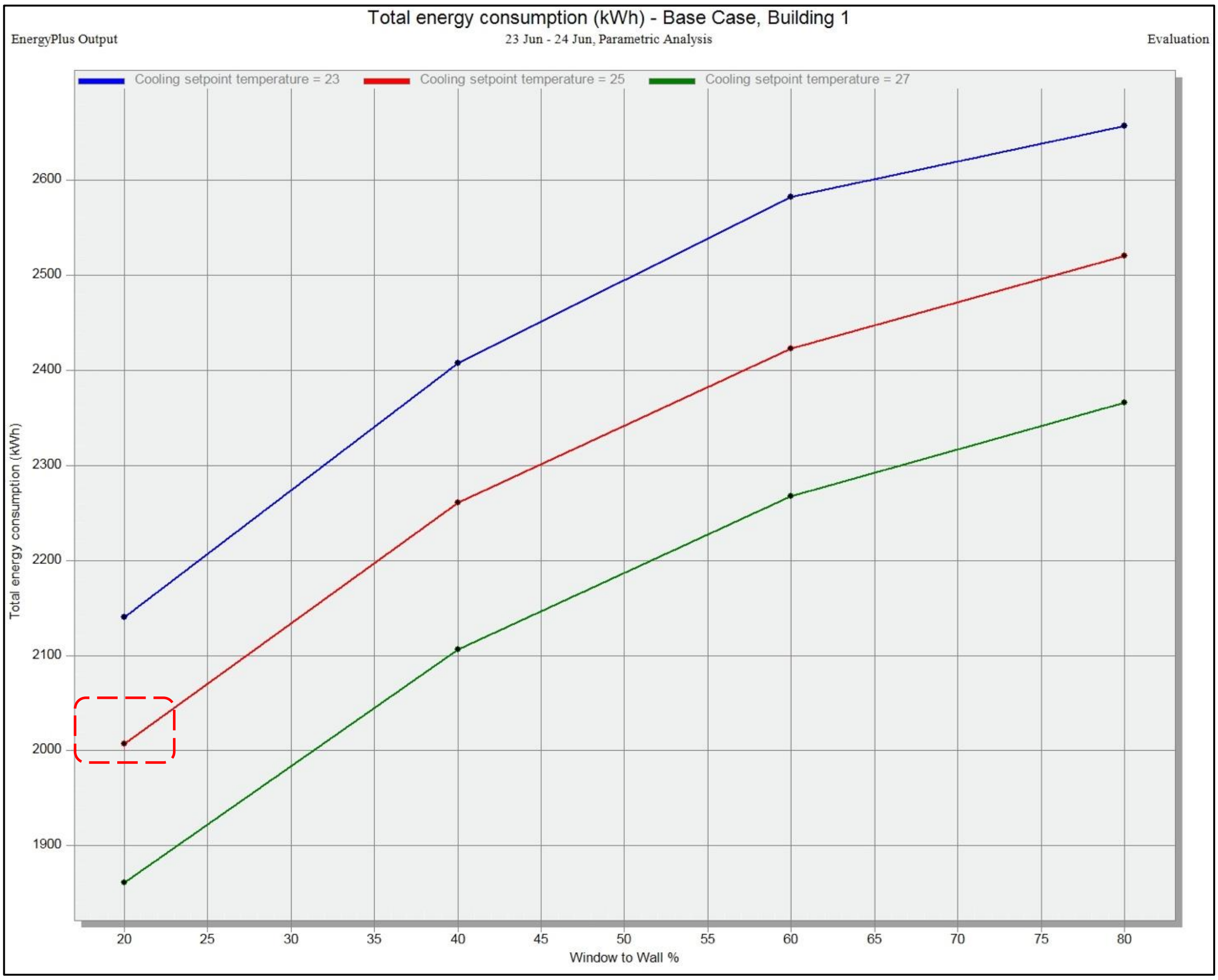


Figure 5.54: Base case energy consumption graph results from the simulation on 23 June (DesignBuilder, 2017)

5.6.2 Indoor Energy Consumption Analysis- Optimal Revised Case

To analyze the impact of outdoor thermal modification over the indoor energy consumption the same virtual model used for the base case was re-examined but after changing the weather data input to meet the result of the optimal case presented earlier in this chapter see table 5.24. Using the same file helps to eliminate the impact of any change related to the construction properties or any other fixed parameters as the same data is saved without any change or modification.

The geographical information of the location remains the same since the same file is used as the analysis runs in Abu Dhabi and the name of the weather file recorded in the software database is Abu-Dhabi, yet the weather data information can be changed manually and that was done to feed the model with the final results of air temperature, wind speed, and relative humidity as per the optimal case of phase four as shown earlier table 5.24, as this is essential in evaluating the response of energy consumption to the decrease in the evaluation variable.

The simulation analysis shows that in order to meet the cooling set point at 25C˚ as per the upper limit set by Dubai Municipality green code known as Al-Safa'at, the total energy consumption is recorded 1800 kW/h on 23 June see figure 5.55, while having the same number of condition zones that is 12 condition zones with the same total area of 1366.92 m^2 that is setting a volume of 4715.88 m^3 air-conditioned space. This indicates a decrease in total energy consumption as it goes from 2000 to 1800 kW/h

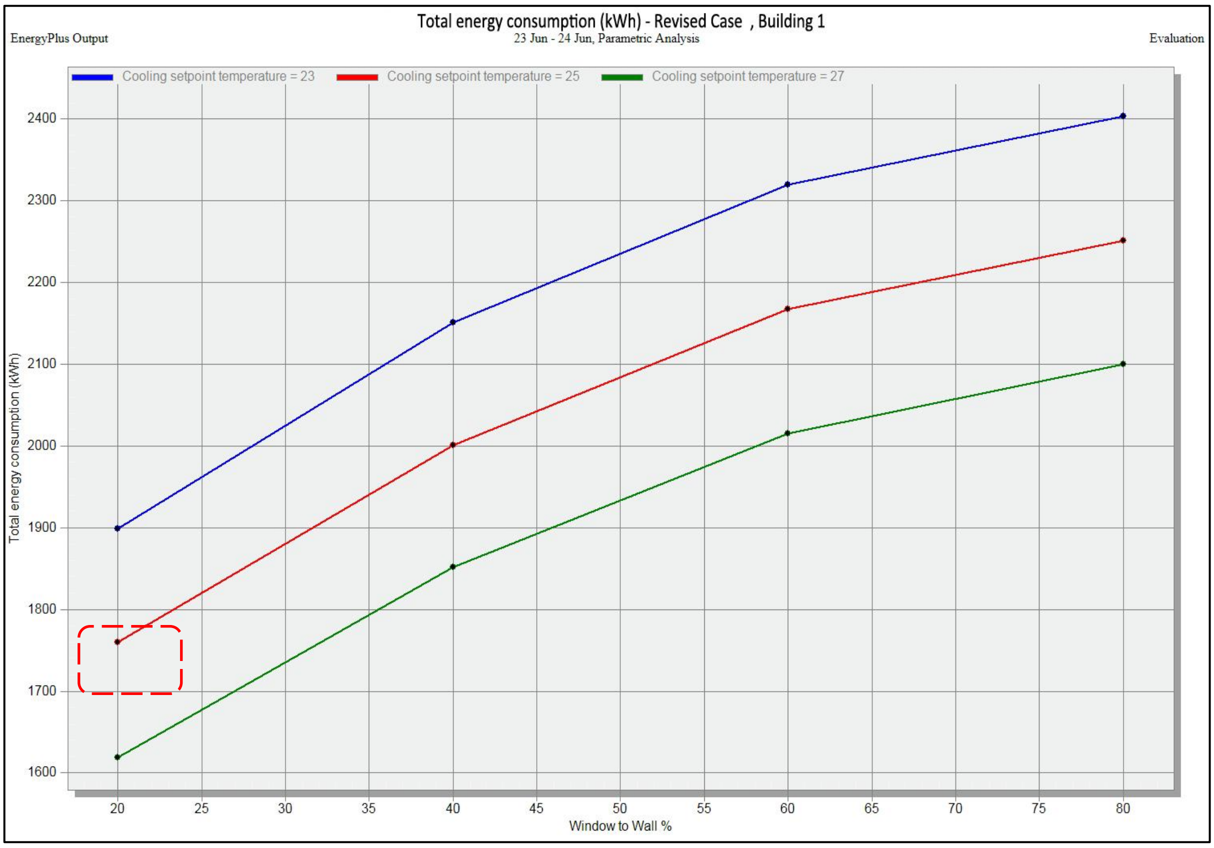


Figure 5.55: Revised case energy consumption graph results from the simulation on 23 June (DesignBuilder, 2017).

This result meets Feng, Ming, Ruey, (2015) results where it was found that there is 10% increase in energy consumption between residential dwellings located at the hottest urban sites and the research baseline site which highlights the impact of urban microclimate over indoor energy consumption, also Abdallah (2015) concludes that a building with well studied climatic responsible design helps in mitigating the indoor thermal comfort which results in energy consumption saving in the long term.

6 Conclusion

Climate change and global warming increase the environmental challenges urban designers and architects are facing when designing outdoor urban pathways and public areas, and indoor architectural spaces. Future urban development must consider the environmental aspects of each site and the climatic characteristics of each region to mitigate their impact and comply with the requirements of both environmental and social sustainability, which will conserve natural resources and create a better world and economy for future generations.

To investigate strategies that enhance outdoor thermal comfort and indoor energy consumption requires exploring different options and designs. These should be tested using simulation software and virtual models reflecting real-life parameters and construction methods, as this will save time and allow scholars to explore innovative concepts without facing limitations in resources such as money and materials. Furthermore, to maintain a scientific approach, it is important to review existing research on this topic to deepen one's knowledge on the subject.

Dubai Sustainable City (DSC) was used as a case study project because it adheres to Dubai's green building code and is based on fundamental urban sustainable development, according to the developer. Because it is the first development of its kind in the region, it demonstrates practical strategies that were carefully designed after extensive research. Although this makes improving outdoor thermal comfort parameters and indoor energy consumption more challenging, it allows one to begin from the point where others ended.

The software simulation analysis method was used to conduct the research, which involved using Envi-Met4 to build a virtual model to analyse four strategies identified in previous research, namely building orientation, building configuration, courtyard design, and vegetation. These factors were found to have a profound effect on outdoor thermal comfort by affecting basic weather parameters such as air temperature, wind speed, relative humidity and

PMV value. These parameters were used to comprehensively evaluate each strategy using a four-phase approach.

In phase one, the optimal orientation for the master plan layout was investigated by setting three orientations in addition to the existing base case. Basic weather parameters, or evaluation variables, namely relative humidity, wind speed, air temperature, and PMV value, were used for the investigation, as these variables determine thermal comfort levels in outdoor spaces. To select the optimal case, the simulation ran for 24 hours on 23 June to represent summer in Dubai, the most challenging conditions in urban outdoor spaces. All data for each hour were extracted and listed in a table for comparison and to identify the most comfortable thermal results and thus the preferred layout.

It was found that the existing layout orientation, or the base design, was the best, as it is positioned at 45˚ to the prevailing wind direction. It is important to allow the prevailing north-westerly wind to penetrate the site when designing the pathways, as this creates wind tunnels that enhance air flow when passing from cluster to cluster. It has also been noted that higher wind velocity is linked to higher air temperature. Because this is a hot arid region that needs a moderate percentage of relative humidity to drive the temperature down, high-velocity hot air does not improve thermal levels in outdoor spaces. It was further found that relative humidity is highest early in the morning when air temperature and PMV value are lowest, while humidity is lowest when air temperature is highest. These findings support the results of previous studies that identified a connection between relative humidity and air temperature.

In phase two, the best building configuration types of the four types in the existing layout were studied, as this layout was identified as the most suitable in phase one. The results indicated that keeping the prevailing wind direction clear and trapping wind between architecture units for longer helps to reduce relative humidity where needed without affecting temperature, because the small urban spaces between architecture units are not as humid as large open spaces and pathways. As the architectural features of the project and the facade details fell outside the research scope, and because these features are not subject to change because they adhere to Dubai building code regulations, the proposed configuration did not include any modifications to buildings heights, placement or forms. In addition, the existing configuration was selected to allow repetition throughout the study and to determine a single thermal comfort level throughout the selected cluster.

These findings address the first research question, as Space One represents the most favourable building form, where wind flow is encouraged by keeping the prevailing direction clear from constructed barriers and providing a small opening at the opposite end that stops air flow and holds it inside the space longer. This was found to be related to the most significant microclimatic factor in the United Arab Emirates, namely air temperature, which affects relative humidity but does not significantly respond to changes in relative humidity caused by wind speed.

Previous researchers noted that, in addition to building configuration, different courtyard ratios and layouts between buildings affect thermal conditions in outdoor spaces and indoor thermal comfort. Therefore, the influence of four courtyard designs, added to the optimal building form previously identified, were investigated in phase three. Three of the four courtyard designs considered the prevailing north-westerly wind by keeping the north-westerly direction open to encourage air flow. In contrast, the fourth design featured a fully closed, square courtyard based on a design described in a study conducted by Tolba, (2015).

The total number of units did not change from the existing case, as a proposed strategy should not compromise the commercial value of the project. Thus, the unit density, floor area ratio and number of sellable units had to be maintained, and all proposed scenarios and designs preserved the commercial characteristics of the development.

By analysing the four courtyard designs using the same evaluation variables used over all phases, it was found that a square courtyard open to prevailing wind yields the best thermal behaviour, with the lowest air temperature despite having the highest relative humidity. Wind speed was also the highest—in fact, it was 0.25 m/s faster than the second highest speed recorded. It was concluded that courtyard ratio affects wind circulation, and that the square shape is better that the rectangular one. It allows equal distribution of air and better penetration, because it allows maximum air flow at the entry point and deepest penetration due to the lack of constructed barriers.

Phase four addressed the regional climactic requirements. This area is known as a hot arid region, especially during summer. Humidity drops to a maximum of 53% during August, according to the National Centre of Meteorology, and previous studies concluded that vegetation is vital for enhancing thermal comfort level in hot arid zones. Consequently, phase four incorporated green coverage as a 3 x 3 m spot containing one indigenous palm tree surrounded by 60 cm of shrubs distributed over the site in configurations of 15% greenery, 30% greenery or 45% greenery.

After testing these options for thermal behaviour using the evaluation variables used throughout the study, it was found that 15% green coverage yielded the best results, with a moderate increase in relative humidity related to the evaporative cooling effect, while keeping the air temperature low. In the 45% greenery configuration, air temperature was almost 15 ˚C higher due to the reduction in wind speed, as many barriers were added because trees are vertical obstacles that reduce air flow in the space.

All the above strategies were found to influence outdoor thermal comfort by affecting air temperature, relative humidity, wind speed and PMV value. Furthermore, in previous studies, it has been concluded that the surrounding outdoor environment affects indoor spaces. Hence, in phase five, Design Builder was used to examine total energy consumption, similar to previous studies on the same topic. Using the results derived in phases one to four that led to improvements in the outdoor environment, the analysis showed that the total energy load needed to mitigate the indoor environment was reduced and that the total energy consumption was 200 kW/h lower than in the base case.

Throughout the research phases, it was revealed that the United Arab Emirates is setting higher standards regarding regulations and building codes related to sustainability. This will enhance and support any further development related to the basic parameters and benchmarks referred to in this paper and other previous studies. Additionally, this encourages urban designers and architects to push the limits when it comes to improvements and to exploring innovative ideas for environmental sustainability that will be recommended and updated in later versions of building codes and green standards.

6.1 Recommendations for future study

The outcomes of this research set a strong foundation for further research that could enhance and add to the value of these research results. Future studies should focus on

1. Exploring the optimal orientation for master plan development regarding its urban design pattern, as the grid system design might require a different orientation than other designs. Moreover, the differences between residential areas and commercial areas or other industrial areas should be considered, as each space has distinct characteristics in terms of building heights and outdoor usage.
2. Studying the impact of the revised setback required by the Dubai Municipality and its influence on microclimatic variables to identify potential improvements or enhancements that will meet the target of reducing indoor energy consumption and improving indoor thermal comfort.
3. Encouraging the proposal of different ideas and designs for shading elements over pedestrian pathways in residential clusters that comply with Dubai municipal regulations

in terms of height and aesthetic quality. This will encourage walkability and affect the microclimates around residential units.

4. Comparing different vegetation options for the same percentage of green coverage in one space, which will provide basic information for architects and urban designers on the effects of different plant species on the surrounding environment. This could enrich the range of trees and shrubs suited to the weather and climate for landscape designers and architects to choose from when designing outdoor spaces.

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الحمد لله الذي تتم بنعمته الصالحات ....

Appendix 1

Appendix 2

Appendix 3