Achieving sustainable regeneration and walkable communities through investigation of different urban configurations in Dubai, UAE

تحقيق الاستدامة في المناطق المعاد تخطيطيها وتشجيع المشاه فيها عن طريق دراسة التكوينات الحضرية المختلفة في

دبي, الإمارات العربية المتحدة

by

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A dissertation submitted in fulfilment

of the requirements for the degree of

SUSTAINBLE DESIGN OF THE BUILT ENVIROMENT

at

The British University in Dubai

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October 2017

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ABSTRACT

One of the major challenges facing urban planners in Dubai is the rapid growth of population. New developments were constructed within the last few years which caused the urban sprawl to reach the edge of the city. In this research, historical contend and sustainability factors were analysed to achieve sustainable regeneration within the Central Business District of Dubai along with enhancing walkability in the district through achieving thermal comfort within the urban form.

The thermal comfort was analyzed through the simulation of different configuration to analyze the main three parameters which includes air temperature, relative humidity and wind speed. ENVI-met modeling was used in this research to simulate the three urban configuration divided into three phases including the following: analysis of building form, analysis of building heights and the analysis of landscaping and vegetation on thermal comfort.

Throughout the research it was analyzed that creating wind channel form buildings has the best effect compared to the other proposed form. moreover, uniformed building heights shared similar results while the best height selected was the proposal of different heights in which air temperature was lower than other height configurations. Finally, the best configuration selected within the configuration of landscaping and vegetation was the optimization of grass, trees and water elements which had the lowers air temperature in comparison to the other configurations.

It was concluded through the research that there are potentials in enhancing walkability through sustainable regeneration in Dubai.

الملخص

من ابرز التحديات التي تواجه المخططون الحضريون في إمارة دبي هو النمو المتسارع لعدد السكان. في الأونة الاخيرة لوحض زيادة عدد المناطق التطويريه في المدينه مما ادى الزحف العمراني ليصل الى حدود الإماره. تمت دراسة المحتويات التاريخية للإماره وعناصر الإستدامة في هذا البحت لتحقيق الاستدامة في المناطق المعاد تخطيطيها وتشجيع المشاه فيها عنن طريق دراسة التكوينات الحضرية المختلفة في الاماره.

من خلال المحتوى البحثي، تم تحليل عدة عوامل تسعى في تحسين المناخ العام للمنطقة الحضرية من خلال استخدام برامج محاكاة للتصاميم التخطيطية المقترحه و قد تم تحليل تلك المخرجات بناء على العوامل الرئيسه وتشمل درجة حرارة الهواء، الرطوبة النسبية وسرعة الرياح على التصاميم المقترحة بحيث انه تم التركيز على عدة محاور وتشمل شكل المباني، ارتفاعات المباني والساحات العامة ضمن النسيج العمراني.

بناء على التحاليل البحثية تبين بأن المباني ذات الشكل الموازي للهواء هو الافضل مقارنة بالاشكال الاخرى المقترحة. وعلاوة على ذلك، تبين من خلال دراسة ارتفاعات المباني بان المباني ذات الارتفاعات المختلفة هي الافضل في درجة الحرارة بالمقارنة مع الارتفاعات المتساويه. كما انه قد تبين بان الغطاء النباتي يساهم في خفض درجات الحرارة في الساحات العامة و الممرات المفتوحة.

وقد تم الاستنتاج من خلال البحث و برنامج المحاكاه بأن هناك نتائج اجابية تساهم في تعزيز إمكانية المشي ضمن النسيج العمراني عن طريق اعادة تطوير المناطق الحضرية.

ACKNOWLEDGMENT

I would like to express my sincere gratitude to my supervisor Dr. Hanan Taleb who contributed to support me thought out the research from the research development up to the final stages of research. She contributed her knowledge to develop my understanding of sustainability in urban planning in which proudly it influenced my knowledge. As well as I would like to thank all my professors in the university who supported me to accomplish this work including Dr. Khaled Nasef from Dubai municipality.

Moreover, this thesis would have never been possible without the support of my mother and father as well as my friends who motivated me throughout the research process. And finally, I can thank Professor Abdulla Al Shamsi for his support from the first day of orientation in which I am really proud of the university outputs.

Table Of Contents

Table Of Figures

List Of Tables

1. **Introduction and Background**

1.0 Chapter overview

This chapter seeks to develop an overview of sustainability by building and developing a strong theoretical and practical foundation for the study. This chapter focuses on laying a theoretical background on sustainability, its relationship with achieving sustainable regeneration, the theory of sustainable regeneration and its limitations within the studied area.

1.1 Towards a sustainable regeneration

Since the beginning of the 21st century, governments worldwide placed strategic goals to achieve sustainability. In January 2016, there was an urgent call for global sustainability on January 2016, when the United Nations set forth 17 sustainable development goals for 2030. These goals are presented in Figure 1.1 and should be achieved worldwide in terms of fighting poverty and tackling environmental problems, such as climate change and the rising sea levels (United Nations, 2016).

Figure 1.1: Sustainable Development Goals (united Nations,2016)

Many cities have moved forward with the approach of sustainable development. Over the past 10 years, Melbourne has enhanced public transport and built urban areas with a zero carbon foot print in Moreland, Malborne. Other cities have pursued different approaches, for example, Malmo, Sweden, redeveloped sustainable districts, such as Malmo's western harbour, which was an old port that was demolished led to the construction of a new sustainable city.

According to Dubai municipality officials, 75% of Dubai's total area is developed while the other 25% is conserved, undeveloped and farm lands. Since most of the city is developed, there has been a recent need for sustainable regeneration, since the population growth rate is 1.4% annually. Thus, it is expected that Dubai's total population will reach three million by the end of 2020 (Dubai Muncipality, 2015). The need for sustainable regeneration is important to the city to stop the urban sprawl away from the city centre as well as to enhance the thermal comfort for the citizens and support walkability in the urban environment. There are several factors that could support Dubai's shift to sustainable regeneration, which includes the availability of strong infrastructure and increasing ease of connectivity between the city districts or urban nodes. The sustainable regeneration focuses on improving the community through integrating several approaches, such as addressing social equality and addressing economic and environmental problems of the city.

1.2 Sustainable initiatives

Like any other gulf country, construction is one of the largest industries in United Arab Emirates, which also generates most of the city's pollution. The gulf region with its growing population and increase in tourism increased the demand to have strong infrastructure via development in construction and building projects with different uses. In 2013, it was estimated that the total construction projects in GCC amount to $1.67 trillion, of which Saudi Arabia and United Arab Emirates share the biggest portion, with more than 68% of the total projects in GCC (Issa, 2015). Although governments use sustainability to enhance quality of life, the GCC countries still struggle with social, economic, political and technical difficulties. However, some programs have been implemented in response to worldwide sustainability movements. Within the GCC, one of the leading countries that established the sustainability assessment system is Qatar. Qatar established the Qatar Sustainability Assessment System (QSAS) to be the leaders in sustainable and good practices in the construction industry in Qatar. The code that was developed in Qatar is divided into eight categories, presented in Table 1.1. These categories include urban connectivity, site, energy, water, materials, outdoor environment, management & operations, and cultural and economic values. (GORD, 2017).

Table 1.1: Global Sustainability Assessment System overview, 2017, p.17

GSAS Criteria: Districts & Infrastructure

No	Category / Criteria
UC	**Urban Connectivity**
UC.1	Transportation Load
UC.2	Transportation Amenities
UC.3	Infrastructure Level of service
UC.4	Roads & Highways Network
UC.5	Intermodal Connectivity
UC.6	Utilities Provision
UC.7	Green Transportation
S	**Site**
S.1	Land Preservation
S.2	Water Body Preservation
S.3	Habitat Preservation
S.4	Vegetation (Greenscape/Greening)
S.5	Sea-Level Rise Risk
S.6	Walkability
S.7	Bikeability
S.8	Desertification
S.9	Rainwater Runoff
S.10	Parking Footprint
S.11	Amenities Provision
S.12	Public Space
S.13	Acoustic Conditions
S.14	GSAS Rated Typologies

No	Category / Criteria
E	**Energy**
E.2	Energy Delivery Performance
E.3	Primary Energy Sources
E.4	CO_2 Emissions & Offset
E.5	NOx, SOx, & Particulate Matter
W	**Water**
W.1	Water Consumption and Reuse
M	**Materials**
M.1	Regional Materials
M.2	Recycled Materials
M.3	Materials Reuse
M.4	Life Cycle Assessment (LCA)
M.5	Cut & Fill Optimisation
OE	**Outdoor Environment**
OE.1	Heat Island Effect
OE.2	Wind Comfort
OE.3	Air Flow
OE.4	Noise Pollution
OE.5	Toxic & Hazardous Substances
OE.6	Ambient Air Quality

No	Category / Criteria
CE	**Cultural & Economic Value**
CE.1	Heritage & Cultural Identity
CE.2	Support of National Economy
CE.3	Stakeholder Engagement
CE.4	Public Realm
MO	**Management & Operations**
MO.1	GSAS Construction Management Plan
MO.2	Wastewater Management Plan
MO.3	Organic & Solid Waste Management Plans
MO.4	Water Systems Management Plan
MO.5	Energy Systems Management Plan
MO.6	Refrigerants Management Plan
MO.7	Intelligent Transport systems Plan
MO.8	Information Systems Management Plan
MO.9	Landscape Maintenance Plan
MO.10	Infrastructure Maintenance Plan
MO.11	Community and Road Safety Plans
MO.12	Sustainability Awareness Plan

Another initiative was established by the Abu Dhabi Urban Planning Council in the UAE, named Estedama. The Estedama rating system focused on seven pillars, which include: liveable communities, precious water, resourceful energy, stewarding materials, innovation practices. Each pillar includes a sub-accreditation point, in which the liveable communities can earn the maximum credit points (35), which is in line with the government's overall vision (ADUPC, 2010). Table 1.2 presents the liveable community rating system.

Table 1.2: 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

Dubai established its own green building regulations in 2011, which were mandatory for governmental buildings and eventually became mandatory for all private developments in 2014. The green building rating system was officially established in 2016, when *Al Safaat* was established, using different rating systems including platinum, silver and gold certification. According to the executive council of Dubai, a plan was put in place with the collaboration of several governmental entities to achieve the vision of the Dubai 2021 plan.

The plan, presented in Figure 1.2, included the development of six aspects of sustainable growth: the people, the society, the experience, the place, the economy and the government.

Figure 1.2: 2021 Dubai plan objectives (The Executive Council, 2014)

For place, the objective is to create a smart and sustainable city with a safe and resilient built environment, that is sustainable within its resources, integrated and connected, and has a healthy and clean environment (The Executive Council, 2014).

Unfortunately, the municipality of Dubai did not settle on a definition of a green community or sustainable city, but several developers followed their own interpretations to achieve sustainable cities, such as the Dubai Sustainable City and Desert Rose. According to Dubai municipality officials, the urban planning department is under the process of setting regulations for sustainable communities, along with the municipality pioneer project, the Desert Rose, which would be considered the largest sustainable community in the world with several uses, including commercial, residential and mix-use areas, while also producing most of the energy consumed in the community as well as to supply energy to other communities (GulfNews, 2016).

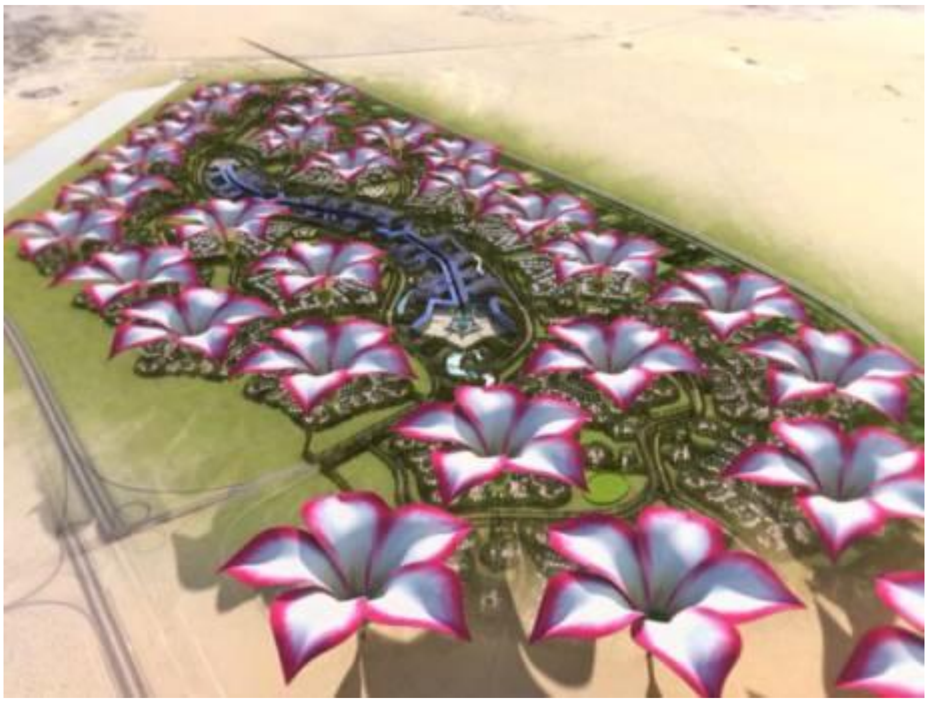


Figure 1.3: The Desert Rose (Gulf News, 2016)

In addition to the Desert Rose, there are several studies presented by the urban planning team that consider other sustainable achievements, such as transit-oriented development across several districts in the city.

1.3 The research importance

The increase of energy consumption along with the increasing population leads to the increase of carbon dioxide emissions, which eventually causes a city to be environmentally unfriendly. Statistically, Dubai has experienced both social and economic growth trends. The Oxford Business Group report (2016) noted that Dubai not only plays host to numerous residents and activities, but also has a critical conduit role for the transfer and transportation of cargo into the GCC and MENA region. This is mainly because many flights have connection terminals in Dubai, due to the high traffic demand from and into the city. Geographically, the city is located in the southeast region of the Arabian Gulf. Regarding size, the city has a total geographical space of 3,978 km2. With an overall population of over 2.5 million people, the approximate population density in the urban area of Dubai is 642.17 people per square kilometer (Oxford Business Group, 2016).

1.3.1 Social perspective

Socially, the city is home to a wide variety of ethnic groups, whose populations have also been on the rise over the years. Overall, the main ethnic groups in the city include Emiratis, as well as many Asians, such as Indians, Pakistanis and Filipinos, among others (Maps of World, 2016). Overall, the city's population growth rate has been rising for the last three decades. For instance, statistics indicate that between the years 1968 and 1975, the city population growth rate was above 300%. This positive trend has continued to date, although at lower rates. For example, in the period of 2013-2015, the population growth rate was 1.4%. This positive growth rate in the city implies that a greater number of residents will continue to settle in Dubai. An additional reason for the high population base in Dubai is tourism. Over the years, as illustrated by the Dubai Department of Tourism and Commerce Marketing (DTCM, 2016), the city has marketed itself, rightfully placing itself among the most preferred tourist destinations globally. To this effect, every year, the city receives a vast number of tourists. For instance, in 2014, the city attracted a total of 13.2 million tourists, which was an 8.2% rise from 2013 (DTCM, 2014).

From the social analysis above, it is apparent that the overall population base in the city will increase into the future, either through increasing permanent residents or acquiring a high number of tourists. For instance, in 2020, the city is expected to host a large contingent of global investors and tourists for the 2020 global expo, an event expected to last for six months (EXPO 2020 DUBAI, 2016). Therefore, this study is developed based on the expected growth of the city. It is also developed with the aim of evaluating the agility of the city infrastructure, such as its current expansion potential limits, current and projected infrastructural investment, as well as the available resources and their optimum utilization levels. As such, the obtained findings were analysed to evaluate if the city is sustainable in the long-term, which is determined by the city's ability to effectively adopt this rising population base and resource demands into the foreseeable future. The key elements in this evaluation include land use, resources, sustainability and walkability.

1.3.2 Economic perspective

The second tribute of this study's analysis is in regard to economic activities. The relevance of the city to the entire UAE economy is detailed by the UAE government's Vision 2021. The vision that has different pillars that recognize the need for the economy to diversify its earnings and revenues from the overreliance on the oil industry to other sectors. One of the approaches recommended for this diversification is through developing Dubai as a financial and economic hub, not only for the region, but also globally. This achievement is demonstrated through statistics offered by the Dubai Statistics Centre (DSC), an agency of the Dubai government. The centre reported as of November 2016 that the city had contributed to 4.1% of the UAE's GDP earnings. Additionally, a negative inflation rate of -0.13% and an overall trade amounting to 0.6 trillion AED were established (DSC, 2016). This is an increase from the 2015 trade amount, which was 0.57 trillion AED. This implies that the economy's trade earnings are on the rise and are forecasted to increase as the city emerges as a global economic hub.

The economic performance rates imply that the economy will contribute to utilizing the existing resources, such as human workforce, infrastructure and aids to trade. Infrastructure, as Brebbia, Gospodini and Tiezzi (2008) argued, is evaluated based on the ability to expand the existing infrastructure, such as office apartments and streets' ability to hold a high number of trade participants. Additionally, this would imply that the demand for these resources would surge into the future. Thus, for the strategic planning of the city, it is critical to evaluate the existing resources, including naturals factors such as space and lands, as well as human-made factors, such as infrastructure, are sustainable and able to support this vision for the long-term. This was the second of the three reasons that informed the study about evaluating the sustainability level of Dubai. Also, the evaluation focused on the environmental implications of the expected changes and if the forecasted changes impact on the environmental sustainability of the city.

1.4 Statement of the problems and research focus

After a thoughtful review of the literature available in the field regarding urban configurations and the heat island effect and their effect on thermal comfort and urban form, some limitations may be identified. Some of these limitations include the lack of a holistic view of the urban configuration on a city scale, as well a lack of connectivity between the urban elements of open spaces, building form, height, orientation and other influences, enhancing the thermal comfort, in which each element was studied separately without showing a direct relationship or influence of each aspect on another. Many of these investigations solve each issue separately without connecting all the aspects together to enhance the microclimate.

The literature review shows that many researchers focused on addressing the impact of soft escape on outdoor thermal conditions. Other studies explore the impact of a cluster of buildings and roads on the overall community. In these studies, the researchers consider one point of a street as representative of the behaviour of the space as whole. However, there was little available literature about urban design as a whole, yet each cluster or block interacts with the next, creating an enlarged area connected together. Many researchers endeavoured to link mitigation strategies of UHI to the urban design, where it has been recognized as an important factor that defines the measurement of outdoor thermal comfort. The researchers focused on air temperature, wind speed and relative humidity to determine urban comfort. Many papers address the hot arid climate; however, there is a lack of investigation and data focusing on the gulf region, which imposed additional challenge in data collection for similar literature to compare. Moreover, there is no paper addressing the regeneration of the central business district in

Dubai. This research focuses on connecting the gap in micro-climatic research in relation to the urban design and analyses on how different urban configurations may influence the wind variations, air temperature and relative humidity.

1.5 Aims and objectives

The research aim is to enhance walkability in the central business district of Dubai though the sustainable regeneration. The research question aims to answer whether different configurations within the Central Business District (CBD) behave differently in terms of wind variations and temperature through the hottest times of the year. In the UAE, CBD in Dubai was selected as the study location due to its strategic tourism and retail position. Three main urban configurations are investigated, which include the existing form of the CBD. The other form includes the Dubai municipality optimization. As well other three configurations including several building forms, building heights and landscaping. This study examines the historical context, the present situation and the expected growth of the selected urban area, to specify the urban form to best suit the climatic condition that would reduce the problem of heat island effect.

The aim of this research is achieved through the following set of objectives:

1. To review the historical and present context of the CBD urban area to understand environmental problems and challenges.
2. To identify the most important variables affecting the outdoor thermal comfort in a hot climate.
3. To propose different configurations and simulate them through a computer software to analyze the improvement of temperature and wind variations.

4. To simulate and compare results through visual and numerical values and define the most favorable form, orientation and building height against several important parameters including wind speed, air temperature and thermal comfort behavior.
5. To draw future recommendations based on the best urban performance configuration of the three studied alternatives in terms of thermal behavior.

1.6 Research outline

The research paper presents a study of three urban configurations compromising of physical characteristics of building forums and spacing to compromise the best enablement of pedestrian movement. The paper is divided into six chapters. The first chapter is an introduction and overview of sustainable urban development and defines the guidelines for achieving sustainability in the urban context.

Chapter two is a comprehensive literature review discussing several factors impacting sustainability, including historical context, impact of sustainable regeneration, and factors that help decrease the heat island effect. The studies have been reviewed based on the applied methodology to determine the best investigation tool for thermal comfort.

Chapter three is the methodology section, which includes a literature review of papers with related topics, but different methodologies to compare their relative advantages and limitations. This chapter contains the description and justification of the selected methodology and the research parameters for this dissertation.

Chapter four discusses the research parameters that are proposed, as well as the base case that is considered, in addition to other proposed configurations, which are used to identify the best configuration in terms of thermal behaviour.

Chapter five informs the results, findings and discussion. The simulation results are sent in comparison to identify positive and negative aspects in each design. The optimal design among the configurations is addressed.

Chapter six recommends a design and conclusion based on the findings. Factors that affected the findings are highlighted and recommendations for further studies and future research are suggested.

2. Literature Review

2.0 Chapter overview

In this chapter, a descriptive literature review seeks to achieve a better understanding of sustainability and its effectiveness in the urban environment. Several studies present influencing factors of sustainability, namely the social, economic and environmental aspects of urban planning. Moreover, a better understanding of sustainable regeneration is reviewed with topics related to the main aim of the research, enhancing the thermal climate and walkability within the urban area of Dubai. Several urban planning models are analysed, such as the form of cities and examples of different forms worldwide and in Dubai to develop a better understanding of street layouts and building forms. Further, measures and influences are discussed within the literature review to provide greater context to the studied area, the central business district of Dubai, also known as “old Dubai”. Finally, analysis is conducted on the enhancement of thermal comfort, which leads to a walkable environment. Several approaches and parameters are defined based on sustainable components to enhance walkability in the area. Additional factors to consider are urban layout, orientation and landscape. The literature review examines detailed information and several mitigations proposed as best practices globally that address a similar thermal climate to achieve a successful result that could be implemented. In the final part of the chapter, the site boundary is represented along with the site analysis and the microclimate data is summarized.

2.1 Introduction to sustainability

Humanity has strived since the mid-twentieth century to address similar concerns to today, such as peace, freedom, development and environment. The bottom line for these issues for humanity at the global level is the word sustainability. Newman and Kenworthy (1999) described sustainability as the retention of existing conditions in the long-run. Therefore, sustainability is the ability of a situation to remain positive in its current form into the foreseeable future. Overall, the tenets of sustainability are threefold: social, economic and environmental sustainability elements. The economic sustainability variable ensures a steady economic growth and provision of opportunities to all in the market. This sustainability focus on economic development would provide the basic way of living for two-thirds of the world and a higher standard of living for the wealthy third of the world. The second element is the creation and attainment of environmental sustainability (Thiele, 2013). However, it was not until the last four decades that environment became the focus of international and national governments. The other concerns under economic and social needs is the attainment of sustainable development. In 1982, the United Nations took the initiative in focusing on the environment and development. In 1992, the United Nations held a conference in Rio de Janeiro about the environment and development, which was named “The Earth Summit”. The forum discussed agendas on environmental sustainability. Ten years after the Earth Summit, the World Summit on Sustainable Development was considered the main step for sustainable development, in which goals and strategies were placed, leading to the rapid spread of the concept of sustainable cities with the central mission according to United Nations (Vollaard, 2014).

Sustainability is the concern of our modern world and it is defined as the ability to ensure the needs of the present generation without affecting the needs of the future generation (Goldie, 2005). Although the brief definition does not mention the environment or development, it is a generalized definition. There are two types of sustainability: strong sustainability and weak sustainability. Strong sustainability is the replacing of one need or resource by the same resource. For example, several cities have faced urban sprawl, in which the city spreads towards the forest, leading to deforestation. However, forests are replanted in other areas to secure the resource. On the other hand, weak sustainability is to replace one resource with another. An example of weak sustainability is the replacement of oil and gas as a source of income by another industry like tourism to enhance the economy (Thiele, 2013). To illustrate a better understanding of the difference between strong and weak sustainability, Figure 2.1 shows how both situations are equally sustainable, if the weak sustainability allows for substitution of resource, as long as the total capital stays constant and does not decrease.

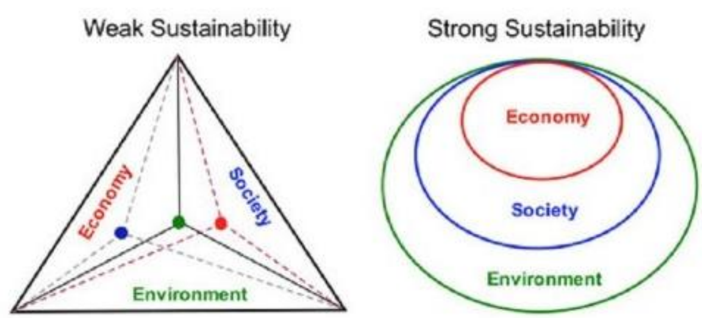


Figure 2.1: Strong and weak sustainability (Laitinen, 2016)

As mentioned, the sustainable development concerns focus on three pillars: economic, environmental and social development. These three pillars are connected and each one may affect the other positively or negatively. For example, the economy may affect the environment negatively due to the pollution produced by the economy. On the contrary, economy may affect environment positively through enhancing the social life of the society through the creation of job opportunities (Goldie, 2005). The social aspect affects the economy in a positive way, in that it supplies the economy with the workforce and technology, whereas the environment is affected negatively by human beings as a source of pollution. The environment aspect does affect the society positively by securing both health and recreation, and affects the economy in a positive way by supplying resources, such as energy and lands. There should be equality among the pillars, considering the pros and cons of each pillar to ensure a sustainable development growth (Goldie, 2005).

2.2 Sustainable city

During the beginning of the 21st century, governments started moving towards the establishment of sustainable cities and districts. The key factors to measure the accomplishment a sustainable city consider the three factors of sustainability including society, economy and environment. Regarding environmental influences, Campbell (1996) described environmental sustainability as the process through which a city allows for environmental conservation and preservation. As such, an environmentally sustainable city is one that can manage and control its environmental impact to the extent that the naturally available resources and conditions are retained for the foreseeable future. Unless this is achieved, such a city is perceived as environmentally sustainable (Ng, 2010). To this end, Campbell (1996) noted that one of the issues in creating an environmentally sustainable city is pollution control, which includes air, water and noise pollution, among others.

A theoretical description of an environmentally sustainable city can be derived from a linear city planning approach. Lee, Han, Leem and Yigitcanlar (2008) credited this as one of the most effective approaches to reducing air and noise pollution. The residential buildings and apartments were located near the river sources, which implied that the clean wind blowing over such a river allowed the residential area to access clean and unpolluted air. Similarly, the location of heavy industries at the furthest end ensured that the emitted unclean or polluted gasses were blown away from the cities by the blowing winds (Freestone, 2010). Likewise, the location at the furthest end ensured that the noise from the industries would not cause noise pollution and ensure that any waste products were not deposited back into the river sources.

A second factor influencing cities' sustainability is social sustainability. This form of sustainability is well demonstrated by Campbell's (1996) arguments. The literature review explains that a sustainable city is one that ensures that the society's needs are met and is dynamic enough for the changing social conditions and needs. One aspect of social dynamics is population. As such, cities, as evidenced by history, are established with a small population base. However, as infrastructure grows and expands, there is increased growth in the population base. This is statistically illustrated through projections in the Chinese market. It is projected that by 2050, a total proportion of 2.5 billion people will be added to the current proportion of city dwellers. This is the same trend globally where greater numbers of people are migrating to urban settings. This means that such urban settings will be faced with the rising pressures to provide social amenities and resources for the ever-rising populations. To this end, Ng (2010) noted that a socially sustainable city is one that can absorb these pressures. For instance, a city is sustainable if it has the scope and ability to expand over the future to accommodate the rising population. Additionally, it is sustainable if its infrastructure is capable of expanding based on the rising population.

The third element of a sustainable city is its economic layout and conditions. Economic sustainability is the ability by a city to provide enough income, production and consumer opportunities to allow for a closed economy. A sustainable city is one that can operate under the traditional household economy model. The model, as Erceg, Guerrieri and Gust (2005) illustrated, is based on the ability to balance between household incomes, consumption and the producer's revenues and expenses, as well as the produced quantities. To this effect, a household closed economy model asserts that it is only when the variables between the producers and the household are balanced that the economy is perceived as sustainable (Erceg, Guerrieri & Gust, 2005).

This is applied theoretically in the case of an economically sustainable city, but with modifications. In this case, a sustainable city is one that offers enough opportunities for the producers. Although the resources and inputs for production could be outsourced, such a city should have the capacity to provide enough infrastructure and aid to trade for an effective production process. Additionally, the existing consumer base and earning levels should be sufficient to meet the minimum required demand for products to sustain the market producers. Finally, to guarantee economic sustainability into the future, the city should have enough resources and potential for production and the anticipated rising consumption.

Based on the analysis of the sustainable factors of cities, Table 2.1 summarizes the aspects that should be considered when planning and what should be achieved through the three main influential factors.

Table 2.1: Sustainable Planning Consideration (Author)

Sustainability factors	**Desired outcome**	**Considerations when planning**
Environmental	Ensure environment and natural resources for conservation and sustainability	• Consider the available resources and their renewability or depletion potential • Seek alternative resource for use in the event that the optimum level of a resource is reached
Social	Ensure the city is agile enough to accommodate an ever-rising population	• Evaluate the geographical structure and topography either allowing or limiting physical expansion • Consider alternative layout structures and layouts to allow for expansion in future • Develop a social amenities infrastructure, not for the current population, but for long-term use even when city population rises
Economic	Ensure there are enough production, income, and consumption opportunities in the city	• Ensure the city has enough diversification to allow for a complete economy with both producers and consumers.

2.3 Sustainable Regeneration

As previously mentioned, there is an urgent call for sustainability throughout the world. Sustainable development is the main challenge governments urge to achieve in new urban areas. In this research, the sustainable development studied is the city of Dubai. Dubai's urban area is 75%, while the other 25% is reserved as conservation and farm lands. The only solution for Dubai's further development is to consider sustainable regeneration. Sustainable regeneration is the process of upgrading an existing place rather than planning new urban areas. The main aim is to promote land values, improve environmental quality and solve urban problems to meet socioeconomic objectives. Urban redevelopment is defined as the process of enhancing the urban space physically through the consideration of resolving urban spacing to improve physical, social, economic and ecological aspects of urban areas through various actions, including rehabilitation, redevelopment and heritage preservation (URBACT, 2015). When considering sustainable urban regeneration, the three main aspects are social, economic and environmental. In the process of achieving social sustainability in a regenerated area, there are 10 social sustainability dimensions to be considered, including education, employment, health, environmental health, sense of culture, social participation and cohesion, quality of life, demographic change, social mixing, and wellbeing (The Scottush Government, 2011). Other aspects that should be achieved are the enhancement of the urban land, legislations to include more open spaces for social interaction, and betterment of walkability and accessibility from different land uses to the open spaces. The aim of regeneration is to improve the image of the regenerated area to attract new inward investments and offer variety of housing units across socioeconomic classes in the same community. Few studies focused on social and economic aspects of regeneration. However, which Baing and Wong (2010) examined the impact of reuse of Brownfield development on the economy. The British government placed strategic objectives for urban regeneration policies that aimed to reduce urban sprawl and thus, promote a more compact urban form. Due to governmental objectives, the government noticed a population growth, which lead to the increase of housing prices in the Brownfield between 2001 and 2007. The healthy regeneration or what is sometimes known as "city recycling" has many economic benefits for the community. There are also some important considerations that should be highlighted, such as infrastructure capability to support the regeneration of the community. Based on the economic derivation index between 2001 and 2005, as shown in Figure 2.2, the transit Brownfield areas positioned the employment rate better than other areas in Britain.

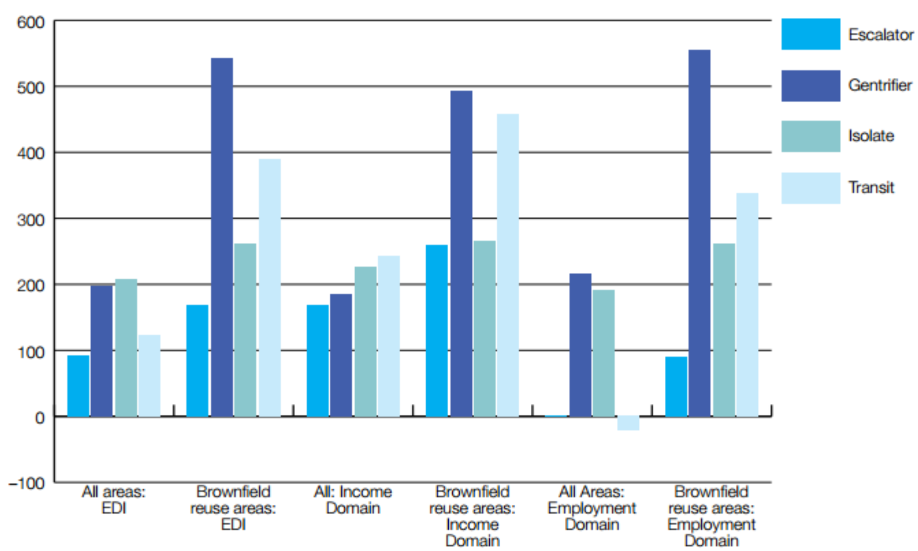


Figure 2.2: Mean rank change of the Economic Deprivation Index (Baing & Wong,2010)

However, it has been noted that several Brownfield areas were over occupied due to the high density of population which tends to increase the density in the area, which leads to a deficiency of the available infrastructure, increasing the flood risk. The government solved the issue by changing the use of undeveloped plots to be open parks and children's playgrounds as a temporary solution until the infrastructure was enhanced. Meanwhile the open parks enhanced the social sustainability of the area due to the availability of multiple open spaces in the community (Baing & Wong, 2010).

A small number of papers addressed the environmental impact of urban regeneration. Collier (2011) discussed the effectiveness of sustainable regeneration and its long-term consequences and concluded that regeneration would stop urban sprawl, while increasing land value (Collier, 2011). Another study by Kim and Jung (2011) addressed Korea's green growth policy and manifested an urban regeneration project by utilizing assessment tools to support their findings. The results showed that the urban micro climate, such as wind and temperature, was enhanced according to various planning factors and measures that lead to the increase of the wind speed 0.2 m/s in daily average. Recently, Dubai had a district that was regenerated by the developer Meraas, in which part of Al Wasl district was converted from a residential area with building heights of G+1 to a mix-use area with commercial, leisure and residential areas with building heights of G+4. According to Essa Nasser, Project Manager for Meraas Developments, the new development, called The City Walk, created a new move in Dubai's market by offering new job opportunities and enhancing liveability of the districts surrounded by The City Walk. The City Walk's main aim was to enhance the walkability in the city centre. This was achieved through maintaining the thermal comfort by accounting for water elements, shading systems and passive cooling. Figure 2.3 shows the difference of Al Wasl before and after the regeneration.

Figure 2.1: on the left 2010 on the right 2016 (google earth)

Sustainable regeneration affects districts and cities positively if the community needs are understood by urban planners. The literature review concluded that sustainable regeneration enhances the society, economy and environment by tackling the issues in smart ways, such as achieving the thermal comfort in micro climates, which eventually leads to walkable communities. Several urban parameters enhancing walkability will be reviewed within this chapter.

2.4 Urban planning forms

There are several urban planning forms created based on the historical context, urban layout and the natural settlement. There are three types of urban forms: grid form, liner form and centralized form; each has its own pros and cons as well as its own advantages and potential. The following section presents the urban forms with detailed description.

2.4.1 Grid form

This urban planning approach includes the use of rectangular streets to navigate across an urban setting and city. In this context, the planning process includes the division of land into respective blocks that at most are rectangular, but in very few instances can also be square in structure (Ballon, 2012). As such, the streets in this urban planning process are structured in right angles. This implies that such streets run from east to west and from north to south. The use of the grid in the urban planning approach is one of the oldest forms of urban planning. Reviews and arguments, such as those developed by Zhu, Li and Fang (2005), and Marcuse (1987) confirm this assertion. For instance, this was the urban planning approach applied in the urbanization process in Rome and New York City's formative years. It was equally applied and expanded in the urbanization process in other European urban centres, as well as China, among many other global examples. Specifically, the ancient towns in the Koreas, such as Gyeongju, the capital of Unified Silla, and Sanggyeong, the capital of Balhae were developed through the Chinese grid planning system (Cheng & Masser, 2003). This was an idea borrowed from traditional Chinese towns such as Wuhan and Kaogongji. Traditional documents on the Kaogongji city planning reveal that the city was developed through a square block system. As such, it would have three main gates on each side of the city perimeter, which led to nine main streets that criss-crossed the city from north to south and from east to west respectively (Ballon, 2012). A more recent demonstration of the use of this urban planning approach is in the Milton Keynes city in the UK, which began construction in late 1967. The city is comprised of 10 east-west or horizontal roads, and 11 north-south, also referred to as vertical roads (Walker, 1982). Figure 2.4 presents the grid form in Dubai and Milton Keynes city in the UK.

Figure 2.4: grid form (left) Al Satwa, Dubai (right) Milton Keynes, UK (google earth)

A critical analysis of the application and use of this urban planning approach offers both pros and cons. For instance, as Marcuse (1987) noted, the use of this planning approach ensures ease of navigation. In this regard, road and highway users can easily navigate through a city even if they are new in the area. Marcuse (1987) also argued that the need for a tour guide through a grid-planned urban setting is lower than that through towns planned with different approaches. Additionally, Simmonds and Hack (2000) stated that land adjudication through this approach was easy, especially at later stages, where land is demarcated into smaller units in the long-term. Nevertheless, Yokohari, Takeuchi, Watanabe and Yokota (2000) noted that the use of the grid system was a major challenge for effective land use. In addition, the concept of the right of way, which influences the breadth of roads, especially at intersections, was the greatest challenge. Yokohari et al. note that much land in this design was allocated for the streets, thus leading to an ineffective approach to land management (Yokohari, Takeuchi, Watanabe & Yokota, 2000). This is especially so in current land management systems where land in cities is a scarce resource that should be effectively managed and used optimally.

2.4.2 Liner form

This is a form of the city setting where the required composites of a city were organized and structured to run parallel to each other. In this regard, a linear city is one whose segments and components are structured into different bands that are parallel to each other (Freestone & Amati, 2014). Unlike the grid urban planning format, the linear planning from expansion approach was different. The grid format allowed for the expansion of a city, regarding its length and width. However, this is not the case for linearly planned cities. On their part, linear cities were traditionally developed along rivers to allow for power generation and fresh air to the cities, as well as the supply of water, which is a key resource (Bosselmann, 2008). If the city were to expand, the liner form allows for the addition of components at the edges of each of the bands. Thus, in the long-term, the city expands in length and along the river line but does not change or expand in depth. This city planning process includes formations such as the residential band, which is usually closest to the river, while the industrial band is usually at the furthest end of the river. In between these bands are agricultural zones, buffer zones with major highways, and production zones, among others, based on the region in which the city is located (Bosselmann, 2008). A traditional example of a city developed through this approach include Madrid, Spain, which was traditionally designed and conceptualized by Arturo Soria through the liner planning approach (Freestone & Amati, 2014). Figure 2.5 presents a liner planning approach in Dubai and Madrid.

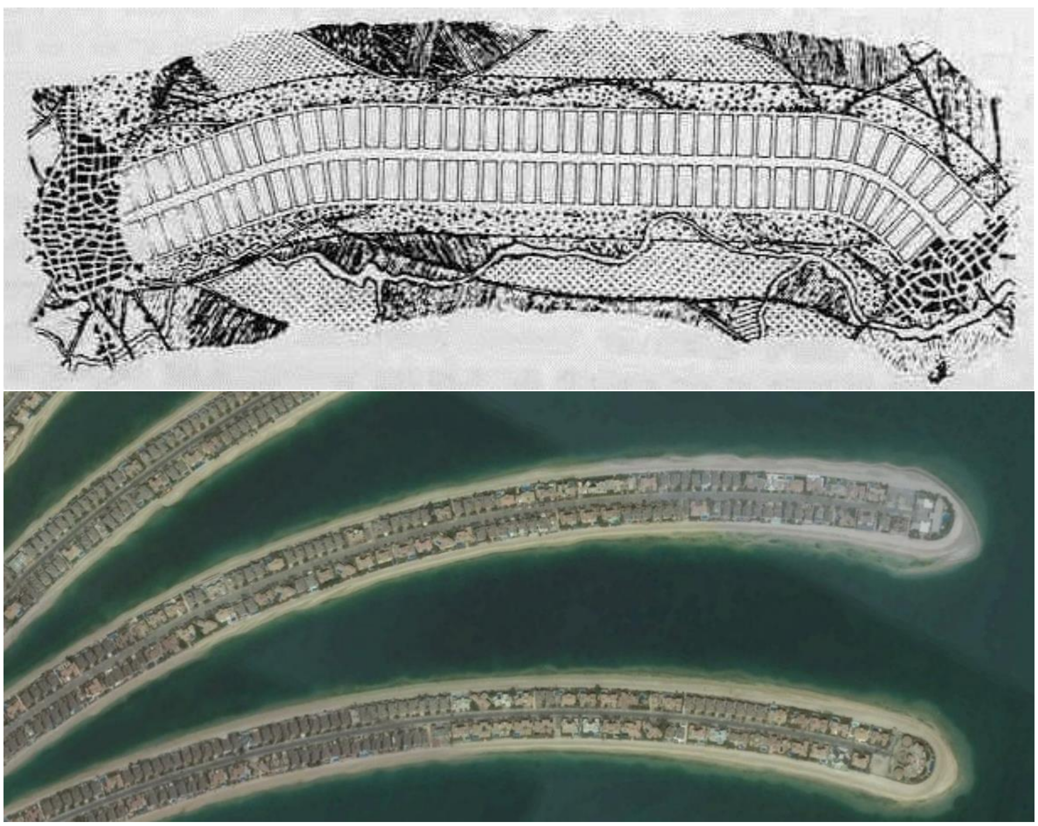


Figure 2.5: liner form (bottom) palm Jumeirah, Dubai (above) Madrid Spain (google earth)

The adoption and use of the linear urban plan has equally, similar to all other forms described, has its share of strengths and weakness, as well as shortcomings. Bosselmann (2008) argued that a linear city planning approach ensures that there is the classification and demarcation of each of the city components. This is a critical component in the wake of increased pollution challenges in a majority of cities globally. In this regard, Lu and Wen (2006) noted that the use of a linear city makes it easier to control and manage each band pollution aspect by limiting the unwanted interaction between bands in a city. However, as Freestone & Amati (2014) illustrated, a major challenge with this city planning approach is the limitation to expanding in width. Hence, if the longitudinal expansion limits are attained, it is hard to diversify the cities on a latitudinal direction. Consequently, although there would be opportunities and space for expansion, such city structures are very rigid and cannot be adjusted. This contrasts the grid and the centralized city forms.

2.4.3 Centralized form

This is the third form of urban planning. In this form, the approach is different from others in that the planning process starts from the centre outwards. On the contrary, the forms mentioned above, namely the grid and the liner forms, include earmarking the perimeter and developing the city within the confines of the perimeter and scope determined. However, as Newman and Thornley (1996) illustrated, the centralized form of urban planning includes planning a city from a centralized core point. Therefore, this form of the city provides the key facilities and amenities that are core to the growth of a city. These include infrastructure and trade, and existence support services, offered at the centre, commonly referred to as the headquarters in the current city layouts. As such, once these facilities and layout are provided, the cities grow in waves or rings over a longer period. One example of this urban planning approach is Moscow.

As Golubchikov (2004) stated, Moscow was developed from the centre, taking into account the availability of space for expansion and availability of core services. The city thus developed in rings from its traditional form to its current modern layout. To this effect, Newman and Thornley (1996) argued that one of the strengths of using this planning form is the ability and flexibility to expand. Therefore, it is possible to structure and provide new rings of expansion through different infrastructure and layouts, based on the ring needs and geographical conditions of the area. This is unlike the grid approach where the expansion and streets have to be at right angles, implying challenges if the geography makes it a challenge for vehicles and people to use such streets. However, Golubchikov (2004) argued that the use of this urban planning approach limits the ability to create uniform structures and layout in a city setting. Consequently, this increases navigation confusion and often leads to poor planning due to the lack of a long-term city expansion strategy. Figure 2.6 presents a central planning approach with an example from Moscow and Dubai.

Figure 2.6: centralized form (left) Jumeirah Village, Dubai (right) Moscow (Google earth)

2.4.4 Central Business District

Although the above reviews focus on the entire city layout, there are different segments in a city. The two main segments are the city periphery, which includes the residential and outer sections. The central business district (CBD), which is the inner layer of a city (Queensland, 2013), is the busiest and most productive section of a city. More often than not, the CBD is centralized, and often at the heart of many cities. Under the centralized planning form discussed above, the concept of CBD becomes clearer. The planning approach only focuses on developing an effective and fully functioning CBD. Thus, Fielder and Feeney (1972), through a classical review, argued that once a CBD is effective and efficient, the outer city layers and rings are easily formed, as they conglomerate to gain from the CBD outcomes and product outputs. Theoretically, a CBD has some underlying characteristics. One of the core characteristics of a CBD is the intersection of transportation means and types. For the most part, CBDs are accessed through metro and road. As such, all outer roads and metro systems should have a connection to the CBD (Queensland, 2013). Figure 2.7 presents the CBD of Dubai with the road and metro connections across the district.

Figure 2.7: Dubai CBD (Amakin, 2016)

In this context, the existence of this interconnection between the CBD and outer city rings is to ensure that all have access to it. Hence, the CBD is the centralized business location, housing main trade and government services. Therefore, a key effectiveness feature for any CBD is to ensure that there are as many intersections, rails, and roads accessing it. This ensures the elimination of possible congestions and access delays. It is estimated that in America, the economy lost a total of $124 billion in 2013 due to traffic congestion in cities, a high proportion of which are in efforts to access either into or out of the CBD in the respective cities. Therefore, an effective CBD is one that has enough transportation infrastructures to allow movement into and out the vicinity. Figure 2.8 presents a CBD street density comparison from different cities.

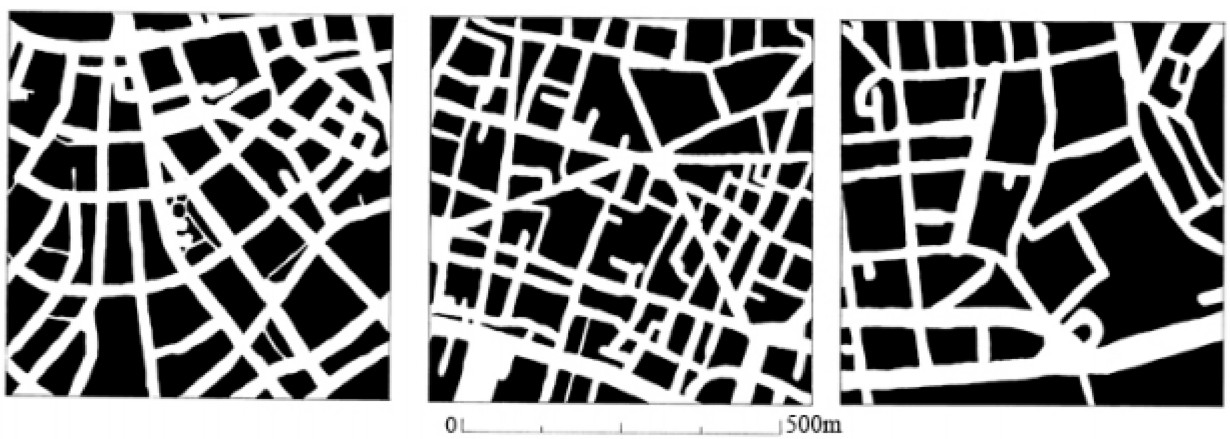


Figure 2.8: CBD street density comparison L to R: Boston, London and Singapore (Chin, 2008).

A second transport-based characteristic of an effective CBD is the ease of movement in and around the CBD itself. In this regard, the CBD incorporates the movement of many people moving to and through the area (Hutton, 2004). Therefore, there is the need to ensure that there are designated and easy to access pathways and walkways in such an area. Moreover, alternative methods of transportation should be considered via dedicating driving and cycling lanes, in addition to walkways in any CBD.

Through the provision of these infrastructural supports, a CBD can allow the free and easy flow of movement by all means of transport. This is a major attraction for investors. This study investigates how the Dubai CBD applies and plans for these variables (Queensland, 2013). As such, the existing transport infrastructure, including the access routes, walkways, driving lanes, and cycling lanes were evaluated with the anticipated population rise for people accessing CBD in the future. In particular, the review evaluated the current and potential expansion capacity of these infrastructural support services into the future. As such, this would demonstrate if the city is currently sustainable or not, and if any current sustainability will be sustained in the long-term.

An additional characteristic feature of a CBD is the presence of trade. These areas include supply chain support systems and financial support systems among others (Queensland, 2013). As discussed recently, an economically sustainable city is one whose systems ensure a balanced economy and are flexible enough to the changing market needs. For instance, the sustainability limit of a city in finances is evaluated based on the extent to which it attracts and has the potential to attract new financial industry investors. Additionally, this is evaluated based on the level and extent to which the city has the capability to absorb obtained earnings and revenues. If it lacks the relevant absorption capacity, then the city economy is not sustainable in the long-term, as it would lead to inflation (Fielder and Feeney, 1972). This is because such an economy would have a high flow of money and low production capacity in the market. Therefore, in the evaluation of a sustainable CBD, the focus would be to evaluate both the capabilities of the CBD economy to earn revenues, as well as produce products in the market. This was the basis on which the Dubai CBD was evaluated and investigated. As such, the study evaluation sought to establish the current economic sustainability of the Dubai city CBD. Moreover, it evaluated the long-term city CBD sustainability. This occurred with the economic plans for the city, such as Vision 2021, among others. The economic growth strategy for the city was evaluated against the growing economy's needs to establish any potential changes to ensure that the city CBD remains sustainable through all aspects. The CBD in Dubai is considered the hub of trade through history and shaped Dubai's social and economic aspects. Further historical background and sustainable influences is presented in the following section.

2.5 History of Dubai

Dubai was converted within the last decades from desert to an oasis of concrete and glass. The drastic transformation started with Dubai's modern history since its founding in 1833, when the Al-Maktoum family declared their leadership of Dubai with Shaikh Maktoum. Figure 2.9 presents Dubai as a first settlement. Dubai was considered a potential oasis for merchants due to the natural settlement of the creek, as well as its suitable location for the re-exporting market, such as with wood and textiles from India to Al Basra and other neighbouring coastal cities.

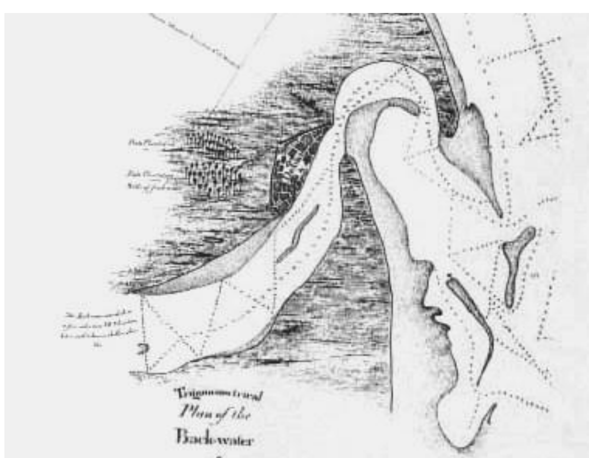


Figure 2.9: Dubai sketch map 1822 (Dubai Muncipality, 2013)

During the 1840's the trade industry grew steadily with a total number of 40 shops focusing mainly on pearling, retail and food trading (Ramos, 2009). There was a great initiative by the ruler of Dubai to attract merchants and guarantee their migration from surrounding countries in which in 1901, when he made a trip to Lingaa to attract businessmen. He also offered them benefits if they were to move to Dubai. From the early 1900s to 1929, Dubai trading was generally dependent on pearling, which lead to placing Dubai on the world map as a healthy business opportunity for profitable pearling trade. The pearl trading did modernize the socioeconomic growth in Dubai due to the imposed taxes on the pearling fleets until the early 1930s. Dubai faced its first economic crises due to two factors: the invention of the Japanese pearl and the global economic depression. Many merchants where affected financially and most went bankrupt. Others traded illegally to secure their money (Ortega, 2009). In 1938, the Dubai reform movement happened and the merchants moved to obtain governmental support to boost the economy. By 1939, Shaikh Saeed established the merchants *majlis*, which was considered a municipal council with more than 15 merchant members and Sheikhs, who would track the city's financial state. The merchants had direct influence into the city's social, economic and political development from the mid-20th century to today. Their influences shaped the city based on the market needs as well as the direct connectivity and agreements between the Sheikhs and the city residents.

2.5.1 Shaping the urban form

The Dubai government faced a great depression during the invention of the Japanese pearl, which encouraged it to garner support from the merchant's free trade, due to the location of Dubai as a central hub between the east and the west. Fortunately, oil was discovered in Dubai in 1966, which led the British government to support the economy and caused economic growth (Ramos, 2009).

During the pearl boom in 1930s, Dubai was still a town that accommodated 10,000 people, 70% of whom were involved in the pearling industry. Dubai's urban form was divided into three settlements, separated by the creek. The hub of business was located in Al Rass area in Deira, in which there were 1,600 dwellings and 350 shops located at the entrance of the city through the creek. On the opposite side, Al Shandagha was settled by the Sheikhs on the entrance of the creek. The location of the Al Shandagha settlement was chosen wisely due to the control of trading fleets in an out of the city. This allowed for the management of the imposed taxes on these fleets, where the money received is completely controlled by the Al Maktoum family. The third settlement was Bur Dubai, which was considered the residential settlement for Dubai merchants. The creek served as a central urban element that supports the transportation route between the three settlements. Each settlement has different uses based on its location (Al-Sayegh, 1998).

In 1958, Shaikh Rashid oversaw the affairs of Dubai in the name of his father Shaikh Saeed. He focused mainly on supporting the city infrastructure, as well as the establishment of the municipal council for decision-making and infrastructure follow up at the municipal level.

2.5.2 Dubai urban infrastructure

In 1955, Shaikh Rashid, the Vice President of Dubai at the time, decided to improve the available infrastructure around the creek. He also considered a study that proposed the building of a new harbour at the edge of the creek to increase the capacity of storage as well as to enhance the import and re-export market with the support of British banks. Along with the start of the dredging of the creek, Dubai issued its first master plan to cope with the boom in the market and its infrastructure, which was planned by John Harris in 1960 (shown in Figure 2.10).

Figure 2.10: John Harris first Dubai Master Plan 1960 (Dubai Municipality, 2013)

Harris's plan outlined the city transport system and studied the foreseeable natural growth of the city. He also established the land use plan that was presented in the master plan, showing the industrial, commercial and residential areas in the city. Additionally, he presented studies for expected growth and land uses that are subject to change. In 1957, the Dubai municipality was officially established as a governmental entity that placed regulations on buildings, roads and urban planning of Dubai. It also followed up with the land law that was established after Harris's first master plan (Dubai Muncipality, 2016). One of the first projects delivered by the Dubai municipality was the discovery of fresh water near the Al Awir area, which became the main source of fresh drinking water. The water connected from Al Awir to Dubai to serve the citizens. Another major project that went through the Dubai municipality was Al Maktoum bridge, which connected Deira to Bur Dubai and created an alternative passage for vehicles alongside the available creek water passage.

The oil extraction industry caused a significant boom in Dubai. Shaikh Rashid led the development of Dubai from a small town to a metropolis during this time. Figure 2.11 shows Dubai in 1950. In the 1960s, Dubai decreased its dependency on British funding through the establishment of the national bank of Dubai. During the 1960s, Dubai started to focus on the hotel sector by establishing a number of hotels to serve the oil exploration employees, along with the international businessmen and expatriate traders.

Figure 2.11: Bur Dubai overseeing the creek and Al Rass 1950 (Dubai Municipality, 2013)

The massive growth in the creek and harbour lead to the reformation of the deep-water port, the new Port Rashid, which was completed in 1967 and doubled in size by the end of 1970s. In 1988, the United Nations signed an agreement with Dubai municipality to issue a report on the development of Dubai and specifically the central business district. The report presented several sustainable factors to enhance Dubai's growth.

2.5.3 Sustainable initiatives

Dubai has made a series of strategic decisions that have led to its success. Public opinion was the main approach in decision making, guided by the *majlis* establishment. The society had a major influence on shaping the city based on its needs. For example, Bur Dubai was a semi-enclosed residential area surrounded by walls to secure the residential settlement and ensure privacy from the market and trading settlements. Other sustainable factors achieved in the twentieth century were the enhanced economical sustainability through attracting foreigners to invest in Dubai infrastructure, and greater job opportunities for new investors, resulting in the creation of a healthy economic environment during the Sheikh Rashid era (Ramos, 2009). The investment in the infrastructure created a solid ground for investors and banks to enhance their economic sustainability along with the support of oil production and exports. The government followed a strategic plan to boost economic growth by presenting the Dubai Development Plan 1988. The plan's main aim was to shape Dubai's urban growth and specifically the CBD area, which includes the three settlements together. The plan also established regulations and limited the boundaries of the CBD development. The CBD district consists of Al Rass, which was the first business and trading hub in the city from the 19th century, alongside Al Daghayah, Al Naif, Regga West, Al Khaleej, Al Nakheel, and

Deira Sea Corniche on the Deira side. On the Bur Dubai side, Al Shandagha was demarcated as a residential settlement for Al Maktoum family and other settlements in Bur Dubai adjacent to Al Shandagha were Al Diwan and Mussala Dubai. The plan was created to limit the development in the district as well as to secure its sustainable growth. The plan in Figure 2.12 presents the CBD boundaries and the settlements.

Figure 2.12: Central Business District Boundaries (Dubai Muncipality, 1988)

During the early twentieth century, most of the residents of Al Rass area were locals. During the 1970s, due to the massive development of the economy in the settlement, most of the local residents shifted away from the Al Rass settlements to the surrounding area, which encouraged expats and foreign traders to settle in Al Rass. Based on the statistics in 1985, 60% of the total residents of CBD settled on the Deira side, while the other 40% settled in the Bur Dubai side with a total of 73,720 residents, with a density of 339 people per hectare. Further, 76.5% of the total number of population work and live on the Deira side, which is a factor for the CBD, since it is alive during the day and night and provides all services (Dubai Muncipality, 1988). In 1985, 40% of job opportunities were available in Al Rass, due to the economic growth. Local citizens played an essential part in the growth, as 90% of locals worked in the four core businesses in Al Rass: trade, transportation, money exchange and services. The other 10% of the locals were farmers and fishermen. According to the development plan, it was mentioned that potential opportunities were offered for investors to support the hotel industry in CBD. The total number of tourists that visited Dubai in 1985 was 450,000. So, several plots were designated to support the vision of touristic growth and creation of touristic attractions (Callen, et al., 2014).

The 1988 plan specified each neighbourhood by specific land use, in which Al Daghayah, Al Naif and Al Nakheel are considered hubs of commercial and residential settlements. Commercial lands were placed on the main roads, while residential plots were in the middle of the settlement. Regga West was considered a hub of financial and governmental services. Al Khaleej consists of a residential area with building heights of G+2. Deira Sea Corniche was considered the main leisure attraction, which included the tallest hotel in Dubai, the Hayat Regency. The plan in Figure 2.13 presents the activities within CBD in 1985. The yellow colour represents residential and commercial plots, while the orange colour represents the markets and Souqs. The dotted line represents the pedestrian paths.

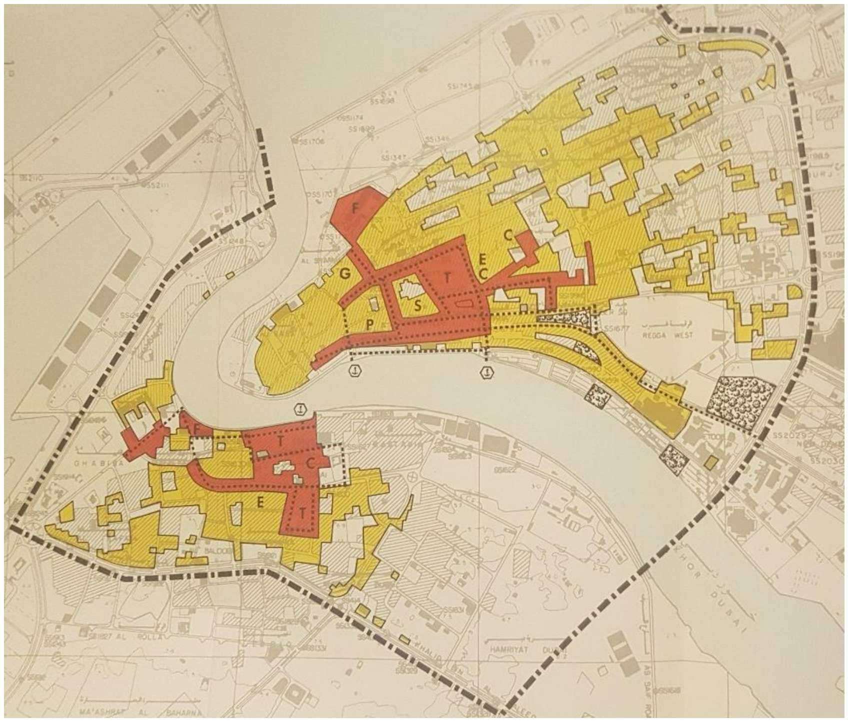


Figure 2.13: Land Activity Pattern within CBD (Dubai Municipality, 1988)

According to the CBD land activity pattern plan, several studies were conducted to analyse the pedestrian movement within the CBD and the study concluded that there are potentials in enhancing the pedestrian walkways within the Al Rass development to reduce the vehicle traffic and increase pedestrian safety, which led the study to recommended further studies on enhancing walkability within the city centre.

2.6 Walkability & thermal comfort

Achieving walkability became one of the most important concerns for urban planners in the last decade, due to the direct effect on public health, environmental, social and economic objectives. The Dubai sustainable initiative section had a call for further studies on the matter of walkability within Dubai's urban districts. To have a successful walkable community, three dimensions must be considered: traversability, compactness and a physically enticing environment. The traversable community is the community that promotes physical movement from one place to another without obstacles. A compact environment could enhance walkability by providing shorter distances to and from a destination. A physically enticing environment is achieved through the availability of safe side walks with appropriate street furniture and street trees. If the three walkability dimensions are achieved, the urban development would result in a sociable and liveable space that would enhance the economy through the availability of shopping areas within the pedestrian access. Another benefit of walkability is that social equity is improved, as well as the preservation of environment. It progresses urban areas through the creation of a human-scaled, happier and healthier society (Forsyth, 2015).

Choi (2012) conducted an observation study to understand pedestrian behaviour in three different neighbourhoods in Stockholm and found that more than 80% of the walking trips are from residential buildings to public transport, while the other 20% fall in different categories, such as walking to a public service zones, walking for pleasure and walking for exercise. Figure 2.14 presents some walkways from the study (Choi, 2012).

Figure2.14: walkways in Stockholm (Choi, 2012)

A study presented by Reyer, Fina and Siedentop (2014) uses the walk score approach to measure walkability in Seattle, USA and Stuttgart, Germany. The walk score is also considered the walkability index, which is measured based on rating indexes derived from distance from and to commercial spaces and public facilities. Figure 2.15 presents the walkability index in Stuttgart. The researchers concluded that the highest scores achieved based on the availability of a safe walking environment eventually showed more walking minuets per week that directly affect public health and wellbeing (Reyer, et al., 2014).

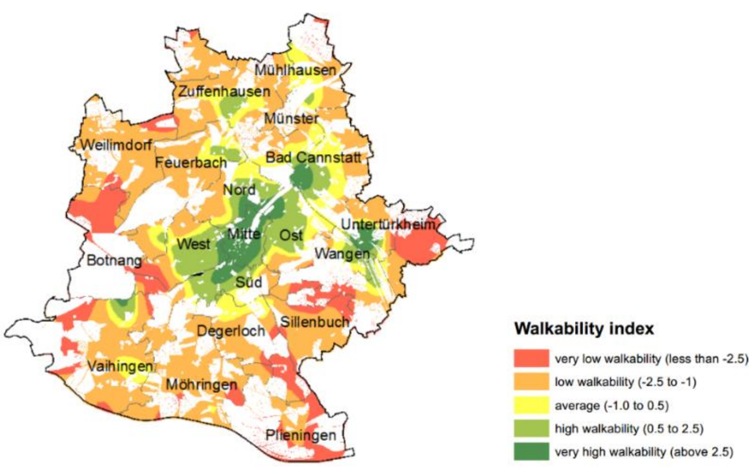


Figure 2.15: Walkability index (WAI) for the City of Stuttgart (Reyer, et al., 2014)

Another observational study carried out by Al Sabbagh, Yannas and Cadima (2016) examined pedestrian tolerance and thermal comfort in a hot, arid climate. The findings revealed that the tolerance walking time in open areas without shade ranged between eight minutes during the hot period of the year and ten minutes during the warm periods of the year. Some factors have shown that when a pedestrian shift from an indoor space to an outdoor space, the transition between the two spaces can worsen the comfort level and thermal sensation, so a smoother transition should be implemented through passive cooling or sufficient shading system. Another finding mentioned in the research suggested that the wind movement can extend the distance of pedestrian travel if oriented north-south. It was noted in the research that during the hot season in Dubai, the pedestrian’s movements do not exceed five minutes, which is equivalent to 400 meters. Thus, to improve thermal comfort, a longer exposure to shade and wind is required, as well as outdoor cooling to give enough time to regain thermal equilibrium naturally (AL SABBAGH, et al., 2016).

In terms of thermal comfort, there are four major parameters known as micro climate measures. These are air temperature, air velocity, humidity and radiant temperature. More green areas would decrease the heat stress by reducing the humidity, air temperature and radiant temperature. Dou (2014) investigated the air velocity in different urban settlements and concluded that the compact urban form has the best air velocity, which improves thermal comfort. In a compact city, the higher the wind speed is, the lower the temperature is. Dou finds that an increase of wind speed by 1 m/s would decrease the temperature by 0.139 degrees Celsius (Dou, 2014). To increase the thermal comfort, wind speed and wind orientation should be taken in consideration for open spaces in cities with hot climates. During hot summer days, shadows and well-ventilated pedestrian space should be prioritized by the urban planner to provide recreation and communication spaces near living areas (Barlag & Kuttler, 2015).

2.7 Urban parameters

The urban regeneration is shaped based on social, natural and built elements. However, the shape of the urban development is in response to the evolution of the local urban context, with respect to the economic needs. Through history, urban configuration is directly related to the natural evolution in which building forms, street geometry and open spaces are shaped more organically based on the natural context. Sustainable urban configuration aims to arrange building forms and type to increase the natural ventilation between the buildings and add landscaping within urban open spaces to cool down the effect of solar radiation and encourage walkability, similar to the implementation of old urban developments (Ahmed, 2016). The urban parameters considered in the research are urban form, building heights, landscaping and vegetation.

2.7.1 Urban form

In general, urban layout is affected by several factors, which includes densities, land uses and the social structure within the city. Meanwhile, the urban configuration can affect the microclimate within the urban form. The three main urban layout configurations are presented by Ritchie and Thomas (2009) to study the features of each configuration and analyse the pros and cons to conclude the best configuration. The researchers investigated the three different configurations, which include courtyard, slab, and tower block, all with the same gross floor area. It was determined that the slab form would be functional if oriented towards the wind direction, so that the wind would penetrate deep within the urban geometry while the researchers mentioned the slab form may cause a sense of boredom, which is imperative to the liveability of the community. The tower block form’s main weakness is that it blocks the sun light on adjacent buildings depending on the urban context. However, it would maximize the open space which would be served by landscaping and playgrounds. The courtyard form is recommended based on several factors. One factor, the enhancement of the community privacy, leads to more liveable space and is thought to be the optimal design in terms of thermal comfort due to the reduction of sun exposure, which leads to the reduction of heat gain. Moreover, the courtyard form allows for better ventilation and reduces the air temperature.

Another study by Thapar and Yannas (2008) studied the effect of the microclimate in different areas in Dubai, based on the urban configuration. Field measurements and Envi-met simulation program was taken inconsideration to assess the impact of the urban configuration and its effect on the air temperature. It was concluded that the courtyard form is the most sustainable, due to the availability of water elements, vegetation, ventilation and shading, which all influence the microclimate by lowering air temperatures. Figure 2.16 shows the Envi-met simulation of the three different configurations, including high-rise building, midrise buildings and the courtyard block.

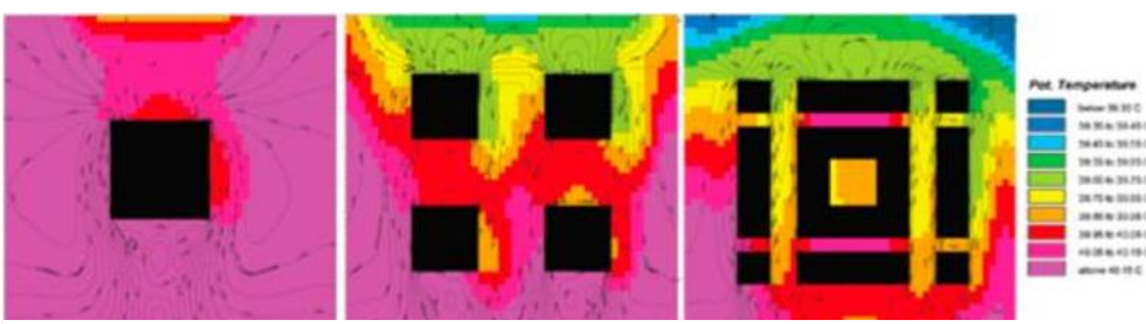


Figure 2.16: (left to right) ENVI-met simulation result for single high-rise building, four midrise buildings and courtyard block (Thapar and Yannas, 2008)

2.7.2 Building height

One of the most essential elements that shapes the urban layout of the city is the street. Streets cover almost a quarter of the urban form and street design and orientation plays a key role in creating thermal comfort. The urban streets vary in geometry, which is defined by the aspect ratio of the building height and the street width. The microclimate is affected by two factors: street width and street orientation. The street orientation can contribute to enhancing the air flow and solar radiation within the urban form (Shishegar, 2013).

The airflow pattern is affected directly based on the built environment and the approaching wind direction. It is essential to study the wind flow in a design built environment, especially street canyons, which formulate the urban flow pattern due to their positive effect on the thermal comfort, human health and air quality. According to OKE (1988), air movement over an urban area is divided into two layers, shown in Figure 2.17. The urban canopy layer is the layer around the building and the street level, while the boundary layer is above the buildings where heat transfer and pollution are the main factors influencing air temperature.

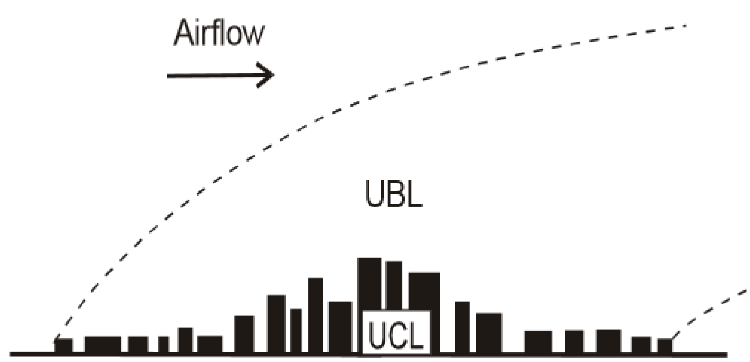


Figure 2.17: The Urban atmosphere and the two main layers (IAUC, 1995)

In the urban canopy layer, wind flow is usually slower due to the availability of barriers such as buildings and trees. As illustrated in Figure 2.18, the boundary layer provides airflow in the urban canopy, which is strongly affected by the street orientation and building ratio. The buildings with least height to width ratio are considered as isolated flow, as there are no direct interactions between leeward and windward flows. When increasing the height to width ratio, the street canyon gets isolated from the wind movement in the boundary layer (OKE, 1988).

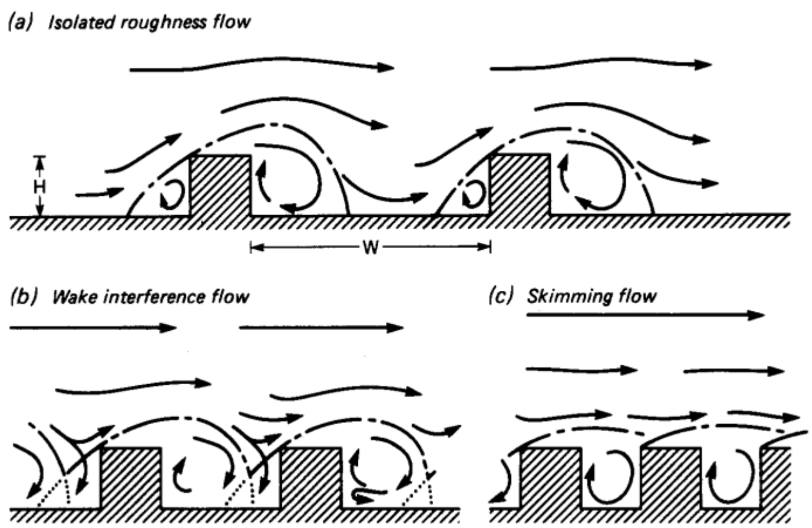


Figure 2.18: the wind flow in association with air flow over buildings with increasing H/W (OKE, 1988)

A case study was implemented in Dubai by Al-Sallal and Al-Rais (2012) and has proven that the narrower the street canyon is, the higher the wind speeds, which allows for better passive cooling that enhances the thermal comfort. Researchers concluded that the ideal ratio is in the range of 2 to 0.67. This is due to the availability of a light to gentle breeze (Al-Sallal & Al-Rais, 2012). Ali-toudert and Mayer (2010) investigated the street orientation and the aspect ratio in Ghardaia, Algeria to analyse the temperature difference through the usage of a simulation program, called Envi-met, which examined the aspect ratio and the road orientation. The study concluded that the lower the height to width ratio is, the higher the temperature is for all type of orientations. As shown in Figure 2.19, north-south streets as well as the east-west streets with a height-width value of 4 are considered the best cases. Additionally, north-south streets have several advantages that are thermally less stressful for people than the east-west orientation. For the east-west orientation, shading strategies that include trees and galleries is the only way to augment human thermal comfort (ALI-TOUDERT & MAYER, 2010).

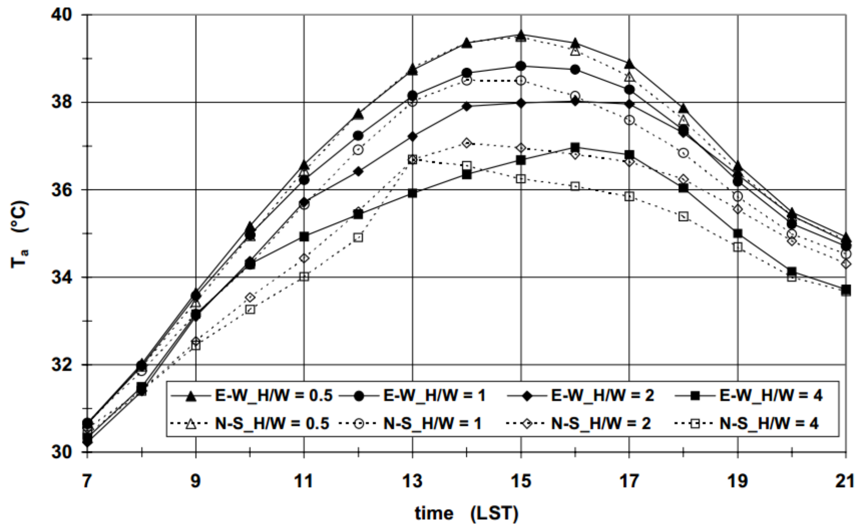


Figure 2.19: air temperature simulated variation within the urban canopy with H/W ratio from 0.5 to 4 and for N-S and E-W orientations in a typical summer day (ALI-TOUDERT & MAYER, 2010).

2.7.3 Landscaping and vegetation

Urban areas are usually warmer than surrounding areas with temperature differences that are greater in summer and at night by several degrees Celsius. This phenomenon is known as the heat island effect. The factors that affect the heat island effect are infrared emittance, surface properties and solar reflectance. Vegetation can play a significant role in decreasing the heat island effect through regulating the urban microclimate. This can influence operational energy demand through the cooling effect provided by shading. The main contributor of the heat island effect is the absorption of solar radiation by building roofs and walls in which heat is gained during the day and released during the night (Nuruzzaman, 2015).

Doherty, Nakanishi, Bai and Meyers (2009) developed several strategies to improve the climate within the urban form, which resulted in the creation of a habitat for wildlife and recreational places for people. The first strategy discussed is the placement of trees in front of buildings to block direct sunlight on building walls and windows that tend to decrease the need for air conditioning and make working and living environments comfortable. Another strategy is the planting of trees across the landscaping, which eventually reduces the albedo and modifies the energy balance of the city. Trees block carbon from the atmosphere, which reduces the atmospheric carbon dioxide. Trees also minimize urban smog by trapping the precursors to ozone production. The third strategy is allocating green roofs or rooftop gardens to improve the thermal efficiency and reduce energy consumption, as has been under trial in many cities in Europe. Roof gardens are estimated to save up to 14.5% of energy consumption, depending on the soil thickness and vegetation type. The fourth strategy is adding water bodies within the urban form, such as lakes and fountains, which eventually moderate the local climate, reduce air temperature and upgrades the habitat for birds and plants, which can also serve as recreational spaces for humans (Doherty, et al., 2009).

Rajabi and Abu-Hijleh (2014) investigated the effect of vegetation on the reduction of the heat island effect in Dubai and concluded that trees have the best contribution to reducing the surface temperature in urban areas. With trees, temperatures in urban areas decreased by 7 degrees Celsius during the hottest hours in summer and by 3 degrees Celsius during the hottest hours in winter. This signifies that greenery mitigates excessive heat in micro climatic conditions. Moreover, researchers studied green roofing in Dubai and concluded that adding a green roof would perform poorly in reducing the temperature since the green roof cooling effect reduces by distance, which would be identified based on the macro scale. Figure 2.20 further displays the study's findings (Rajabi & Abu-Hijleh, 2014).

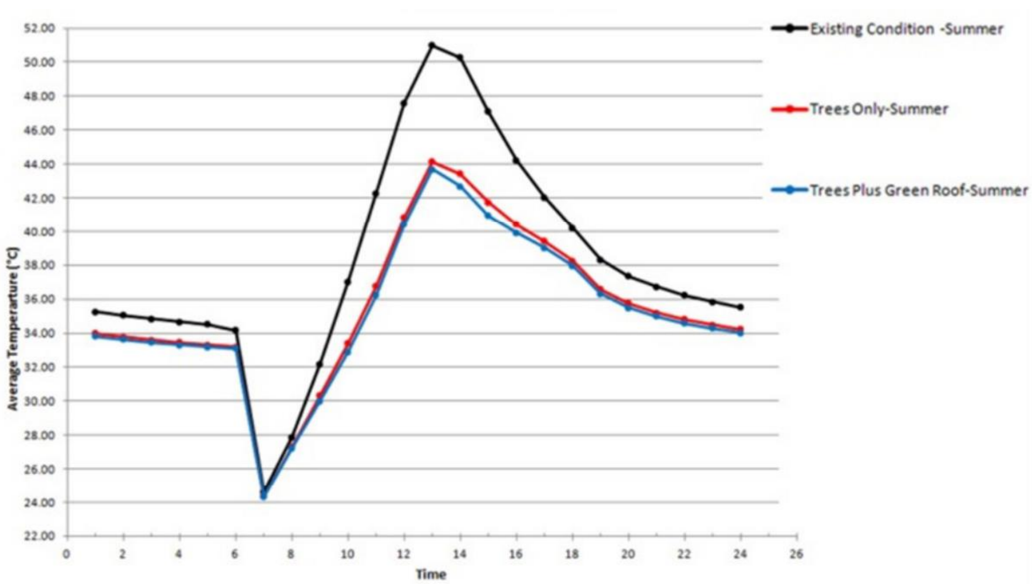


Figure 2.20: the temperature variations based on the simulated area in Dubai (Rajabi & Abu-Hijleh, 2014).

2.8 Dubai weather overview

Geographically, Dubai is positioned at 25.2697°N 55.3095°E and covers an area of 3,893 square kilometres, which includes the developed areas and farm land, but excludes the lands beyond the coastal zone of Dubai. Due to the proximity of Dubai to the Tropic of Cancer, Dubai has a tropical desert climate. In the summer, the average temperature reaches 41°C during the day and 30°C during the night, while in winter, the temperature reaches 23°C during the day and 14°C during night. Throughout the year, the skies are sunny and the annual accumulated rain reaches 150 mm per year, mostly between December and April. The relative humidity mean reaches its peak on December at 65% and the minimum mean relative humidity is in May at 49% (AlRustamani, 2014). Details of the climate data of Dubai are further explained based on the National Centre of Meteorology and Seismology's historical data collected from 1977 until 2016 in Table 2.2.

Solar radiation:

Solar radiation is the electromagnetic radiation that is emitted by the sun. As noted in Figure 2.21, the direct solar radiation reached 6900 wh/m^2 during May, i.e. the highest sun exposure.

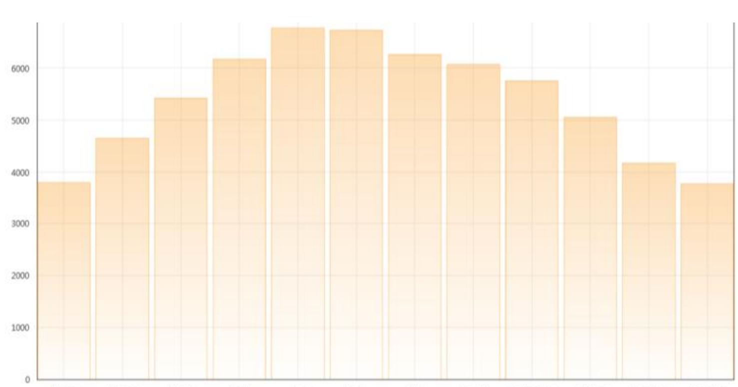


Figure 2.21: Solar radiation monthly mean of daily totals wh/m2 (NCMS,

Wind speed and direction:

The average wind speed in Dubai is 20 km/h during most of the year. It reaches its peak in April, when the maximum wind speed reaches 73 km/h. As shown in Figure 2.22, wind blows from all the directions throughout the year. The prevailing winds approach from the north-west direction due to the flow of sea breeze.

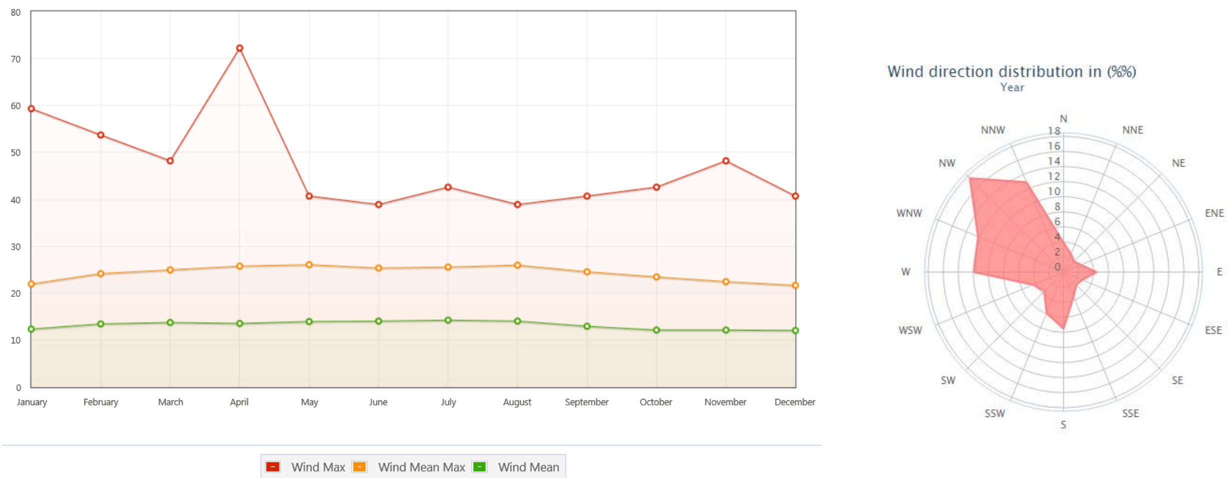


Figure 2.22: (L) wind speed in km/h (R) wind direction (NCMS, 2016)

Air temperature:

The highest temperatures recorded are in July, when temperatures reach a maximum of 49°C, while the minimum is 25°C, during the night. The temperature varies based on the season as well as based on the time of the day in relation to the solar radiation and wind speed.

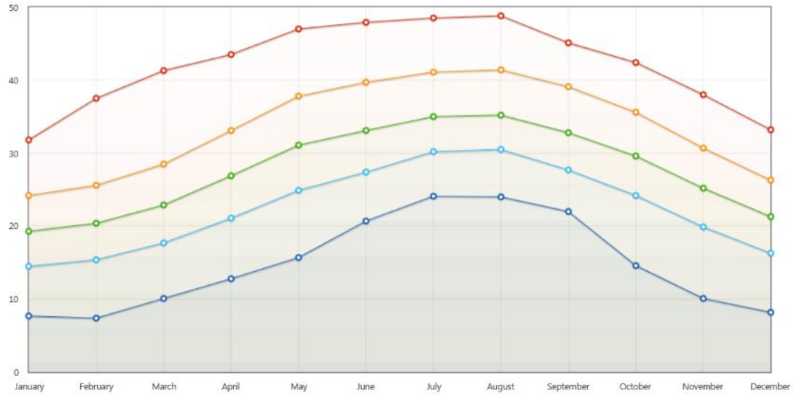


Figure 2.23: air temperature in ℃ (NCMS, 2016)

Table 2.2 shows the increase of the solar radiation and how it would increase the speed of the wind flow. This would decrease the humidity overall and can be observed between March and August (NCMS, 2016).

Table 2.2: data table of temperature, humidity and wind (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

3. Methodology

3.0 Chapter overview

In the previous chapter, the literature surrounding criteria about the heat island effect is analysed to understand a complex phenomenon taking place based on the inputs. Many methodologies were examined in the recent chapter due to the complexity of the parameters used and investigated for their effect on thermal comfort, based on several urban areas. In this chapter, a detailed explanation of the procedures, tools and techniques are considered and justified for the current study. Several analytical programs and software are surveyed. The most suitable program is used to study the urban configuration and each parameter is studied separately, yielding the most effective model with the highest impact. As noted in the literature review, the building form and orientation affects the air velocity within the urban form, in which the air velocity impacts the heat island effect. There were many recent contributions from researchers to study the heat island effect, which allows the current study to delve further into the subject to reach a stage, in which the aims are achieved through the settled goals, which define the objectives.

3.1 Methodologies used for similar studies

Through recent investigations conducted to enhance thermal comfort and walkability, several parameters impacted thermal comfort depending on the study location and its resources. It is important to analyse the methods used by other researchers to achieve similar goals and ensure a certain quality of knowledge to be added in the urban walkability field. Based on the literature review in chapter 2, various parameters and configurations affect the outdoor thermal behaviours, in which there was two essential steps conducted to investigate the interaction between the urban form and thermal comfort. The first step conducted in recent research was the observation approach, which includes the field measurements that consist of several inputs, such as air speed, temperature and humidity. The other conducted approach was simulation, which was used extensively by the researchers. The simulation has a magnificent impact in analysing the different configurations that is applied to determine the influence of configurations and its results that would influence human thermal comfort. Other methodologies were presented by different researchers, which include surveys and experiments.

3.2 Methodology literature review

This section presents a literature review of different research methodologies that are relevant to the topic of the heat island effect and investigations based on different configurations affecting the thermal comfort. Advantages and disadvantages of each methodology are discussed and the selected methodology is justified as the best tool for this study.

3.2.1 Field measurements

The field measurement is the most widely used approach for validation to review location and specific measurements. This is simply a reading of the existing situation of an area, which is converted into data that is utilized for another study, in which the felid measurement studies the interaction between the environment and the urban form through the usage of different tools. The field measurement can state a certain theory after it is analysed. The accuracy of this type of methodology depends on the preciseness of the measurement tool, as it is not a completely reliable method due to its manual measurements. Field measurement methodology has several limitations for which it needs specific tools for measurements, data loggers and monitoring devices that should be placed with high accuracy. Another limitation is the time factor, which is one of the main obstacles of field testing as the data differs based on the season, the timing of measurement and location. Generally, when field measurement is considered, the tools records the thermal data during various climate conditions of the year, which requires a longer time to study the same phenomenon. Another obstacle in field measurement is that the tool should test the exact data. For example, if the required weather conditions did not occur, the data collection should be postponed until the requirements meet the research criteria. The lack of published data in terms of air velocity and temperature variation across various parts of Dubai is one of the main obstacles that may affect the accuracy of the selected study location, which is also considered one of the limitations for this study.

There are several studies that use field measurement as an additional or supportive tool to their main methodology, simulation. The simulation requires measurements and inputs from the field measurements. For example, the study undertaken by Doherty, Nakanishi and Meyers (2009) uses field measurement to evaluate different criteria, shaping the density of the urban form. Moreover, the researchers used fixed measurements to validate the result obtained from the main methodology tool which was a computer modelling simulation. The researchers conducted their monitoring during the day when there was high pedestrian activity and during the night when activities tended to decrease. Other measurements used were total open spaces, green areas, land zoning and land cover, as well as the building heights of each zone within the community (Doherty, et al., 2009).

Field measurement is also used in the study of the behaviour of materials that are exposed to the natural environment, which might be a good methodology to obtain real measurements. Al Sabbagh, Yannas and Cadima (2016) also use field measurements in addition to the study of other factors in several areas in Dubai, including air speed, temperature, humidity and sun radiation. The researchers used observation as the main methodology to evaluate the pedestrian movement in the selected area of the city across several different times of the day as a daily process. The field observation is presented in Figure 3.1, analysing pedestrian thermal comfort, based on the available utilities in the urban form, as well as the main measurement factors considered. Specifically, they concluded that in shaded areas with higher wind flow, people use the outdoor pathway instead of walking in a closed area (AL SABBAGH, et al., 2016).

Figure 3.1: field observation of the pedestrian movement (AL SABBAGH, et al., 2016)

3.2.2 Simulation approach

Computer simulation is widely considered the best methodology for urban forms due to the flexibility of replicating several situations by controlling several variables that affect the output of the simulation. A simulation approach makes tests easier for the researcher, which leads to a clearer investigation scenario. The simulation approach solves the limitations of other approaches, such as the duration of investigation, the climate condition based on the simulated area and the size of the simulated scenarios. The lack of validation may be considered a negative aspect of this approach due to the absence of a natural setting. The three main urban planning simulations are presented below with its pros and cons.

STEVE

Screening Tool for Estate Environment Evaluation (STEVE) is a mapping tool, which is a plug-in for sketch up. STEVE stands for Screening Tool for Estate Environment Evaluation, to simulate through STEVE there are two required inputs: the 3D model from sketch up with the layers description, such as greenery and materials used on building facade, and secondly, the climate data should be imported to the tool for accurate analysis outputs. Moreover, the tool uses geographical information system to present the temperature maps. After the analysis of several components, including urban glare, energy consumption, urban pollution and urban thermal comfort. The tool transforms the analytical data into graphical presentation through the UCMap approach. The STEVE model is based on trial and error to predict the air temperature based on each city's climate conditions and urban characteristics. STEVE is considered a user-friendly tool for urban planners in terms of analysing the master plan and its impact on the microclimatic conditions of the area. Furthermore, the simplicity of the tool's usage and minimal time required for analysis and benchmarking between several design configurations, means urban design would not to suffer additional temperature disparities, which would eventually worsen the thermal comfort (Karyono, et al., 2017).

ENVI-met

ENVI-met is a three-dimensional non-hydrostatic microclimatic model designed to analyse air, ventilation, building and vegetation interactions, which is used in several fields including architecture, bioclimatology, building design, urban climatology and environmental planning. It can also be used to calculate the heat exchange at building skin, ground surface and other surfaces. Ali, Toudert and Mayer (2010) used ENVI-met to study the outdoor thermal comfort in Ghardaia, Algeria through the simulation of the microclimatic conditions within the urban environment, in which it was concluded that the selected method was most suitable due to its low cost and speed (ALI-TOUDERT & MAYER, 2010). Another study mentioned in literature review by Rajabi and Abu-Hijleh (2014) evaluated the vegetation effect on reduction of the urban heat island effect in Dubai. The main study approach was software validation, simulation and data analysis. The researchers used ENVI-met due to its capabilities of modelling greenery and urban simulations. In their study, several variables were inserted to analyse the different configurations of their studies, includes the green roof, trees and grass, while the other input variables were defined through ENVI-met variables, including the wind speed and direction, average humidity and air temperature. The researchers concluded that this methodology gave them the freedom to derive the thermal comfort during summer and winter, while also showing them the variation of wind speed and air temperature based on the timing, allowing them to analyse and discuss the case with accurate results (Rajabi & Abu-Hijleh, 2014).

Urban Sim

Urban sim is an open source simulation system, which was developed to support and analyse urban development, transportation, metropolitan land uses and environmental planning. The simulation program is designed to support the three sustainable pillars of economy, environment and society. It explores the effect of development and infrastructure on communities through accessibility, green house emission, affordable housing, preservation of open spaces and green areas. The urbanism modelling is built based on the data available for each metropolitan area, the parameters used are the urban form and statistical details that reflect actual conditions. Once the inputs are placed and the model is built based on the available land use plans and transportation plans, the output will clearly be defined by the inputs and the model through the representation of the development capacity. Moreover, the program offers the flexibility to change the inputs to propose different urban scenarios that are suitable for the metropolitan development.

Once the model is built and calibrated, the simulation inspects the transportation method and encodes the travel networks that are modelled by the user transportation model. The model network is congested based on the travel time from one zone to another, which can be used to propose changes in the transportation system in different simulation years, based on the development and economic growth. Once the simulations are complete, several indicators can be created to obtain a better analysis of the result through the evaluation of the available scenarios based on policy perspective. There are multiple pros in this type of simulation, such as the ease of use and visual analysis of different scenarios that are presented as 3D maps, chart and Tables that clarify the indicators. In addition, the simulation is carried out through the cloud, which speeds up the analysis (UrbanSim, 2016). The need for several input variables and statistics is considered one of the main disadvantages of this methodology, due to the lack of accessibility for the needed information, such as local statistics and surveys.

3.3 Methodology selection and software justification

The aim of this research is to investigate the impact of walkability and thermal comfort by analysing of three different urban configurations in the CBD of Dubai. Based on the analysis of pros and cons of the methodologies presented above, and the limitations of each, the most appropriate methodology for this research is the computer simulation approach. The computer simulation covers the limitations of the research, which is also considered a suitable alternative to other methodologies, such as field measurement and observational method. This type of methodology offers a method to explore large urban areas, in addition to flexibility of studying different scenarios derived from the base case, and design optimization. Another benefit of the simulation is that it gives a higher level of control for the factors that may affect the environmental results. The other main limitation of this research is the time frame, as the time is limited for investigation.

Given that the increase of concerns of the international scientific community towards measuring the microclimate and outdoor thermal comfort, several software's were initiated to simulate thermal conformability, such as Integrated Environmental

Solutions (IESVE). This program allows the researcher to simulate indoor spaces and individual buildings. It was used in addition to other software that is capable of simulating urban areas. Some of the software that are able to simulate the urban areas include STEVE, ENVI-met and Urban sim. Other urban simulation tools that was not discussed in this section are CityCAD, CITY SHADOWS and Ecotect analysis. CityCAD is an urban design software that is capable of master planning a site up to 200 hectares in size and carrying out different types of analyses, including city design, sustainability, liveability and viability. The sustainability criteria include energy consumption and budgeting, and carbon rates and emissions, presenting charts of total built areas and open spaces. While this tool lacks the ability to model wind variation and temperature (Holistic City Limited, 2015). CITY SHADOW is used as a tool to simulate the solar exposure. Like CITY SHADOW, Ecotect determines solar radiation on a building. It has been integrated as part of the Revit product family and has limited capabilities. It is not the appropriate choice for this research. Therefore, the selected software for this research is ENVI-met (envi-met.com). This is a holistic microclimate system that can calculate microclimatic dynamics of urban structures. The software calculates radiation fluxes, PET values, relative humidity, air temperature and wind speed. It also has the flexibility to add geographical location and vegetation, and change surface materials on buildings and floorings. The availability of climate data in ENVI-met is considered as one of the positive aspects for the selection of the location for the research site. The software analyses the location and considers the available information in the database, which includes wind speed and direction, relative humidity and solar orientation and radiation. This software is free and easily obtained with no limited time and fee (ENVI-MET, 2016).

3.4 Methodology validation

Based on the literature review, some studies tested the validity of ENVI-met software by comparing the simulation results created by the software against measured values for the same time and date of the year as well as the location of the study. A recent validation of ENVI-met software was conducted by Rajabi and Abu-Hijleh (2014). Actual thermal images of Dubai were selected to compare with an ENVI-met model that was created under similar conditions as the actual urban block. The researchers compared both thermal images and concluded that the simulation of microclimates of urban areas in Dubai using ENVI-met is validated. The configurations would yield results similar to the real conditions (Rajabi & Abu-Hijleh, 2014).

Furthermore, the software's capability of evaluating outdoor thermal comfort cross-examined with results from field measurements. Elnabawi, Hamza and Dudek (2013) evaluated the validation of ENVI-met model for two different urban forms in Cairo, Egypt through field measurements. The researchers placed small scale micrometeorology measurement in the urban form in which the measurements were taken between 26 June and 2 July 2012, representing the summer season and the related wind speed, air temperature, relative humidity and solar radiation through the usage of the Kestrel 400 heat stress tracker. Based on the researchers' observation of the available data, the simulation for the dry air temperature was in an appropriate approximation during the peak hours between 11:00 and 13:00. The actual measurement of air temperature was between 33℃ and 33.69℃, compared to ENVI-met, in which the air temperature was between 31.27℃ and 30.95℃. The relative humidity showed a good similarity between the site measurement and the ENVI-met. The Relative Humidity reached the maximum during morning hours between 6:00 and 10:00 as shown in Figure 3.2. According to the file measurement, the humidity was 72% and 50%, while through ENVI-met it was estimated a humidity of 66% and 58% at the same times (Elnabawi, et al., 2013).

Thus, the researchers concluded that this was a reliable tool for simulation as well as analysis of different urban scenarios and configurations. The researchers advise the use of ENVI-met for any planning process that considers microclimate conditions. Therefore, it is the applicable methodology for the present study.

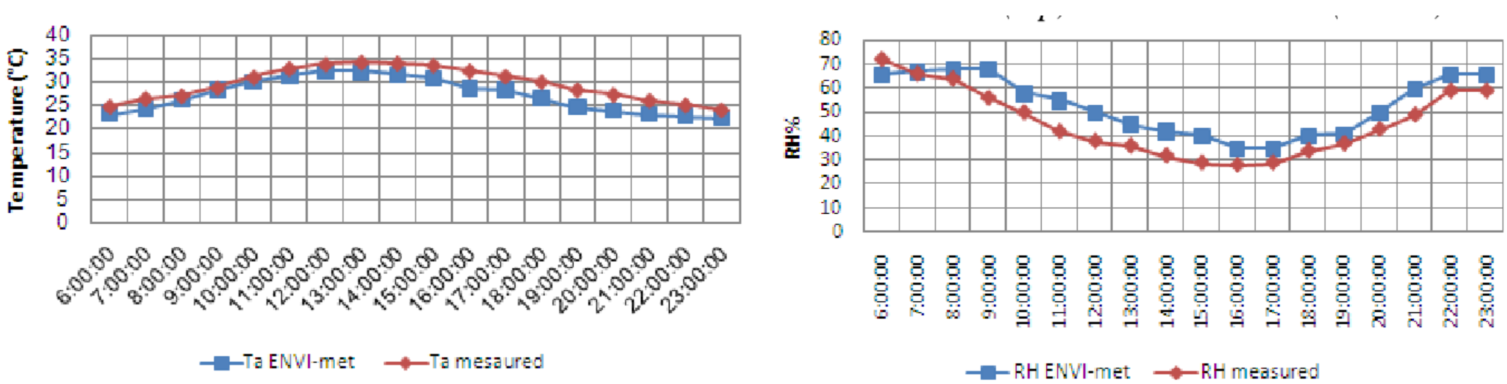


Figure 3.2: temperature and humidity validation (Elnabawi, et al., 2013).

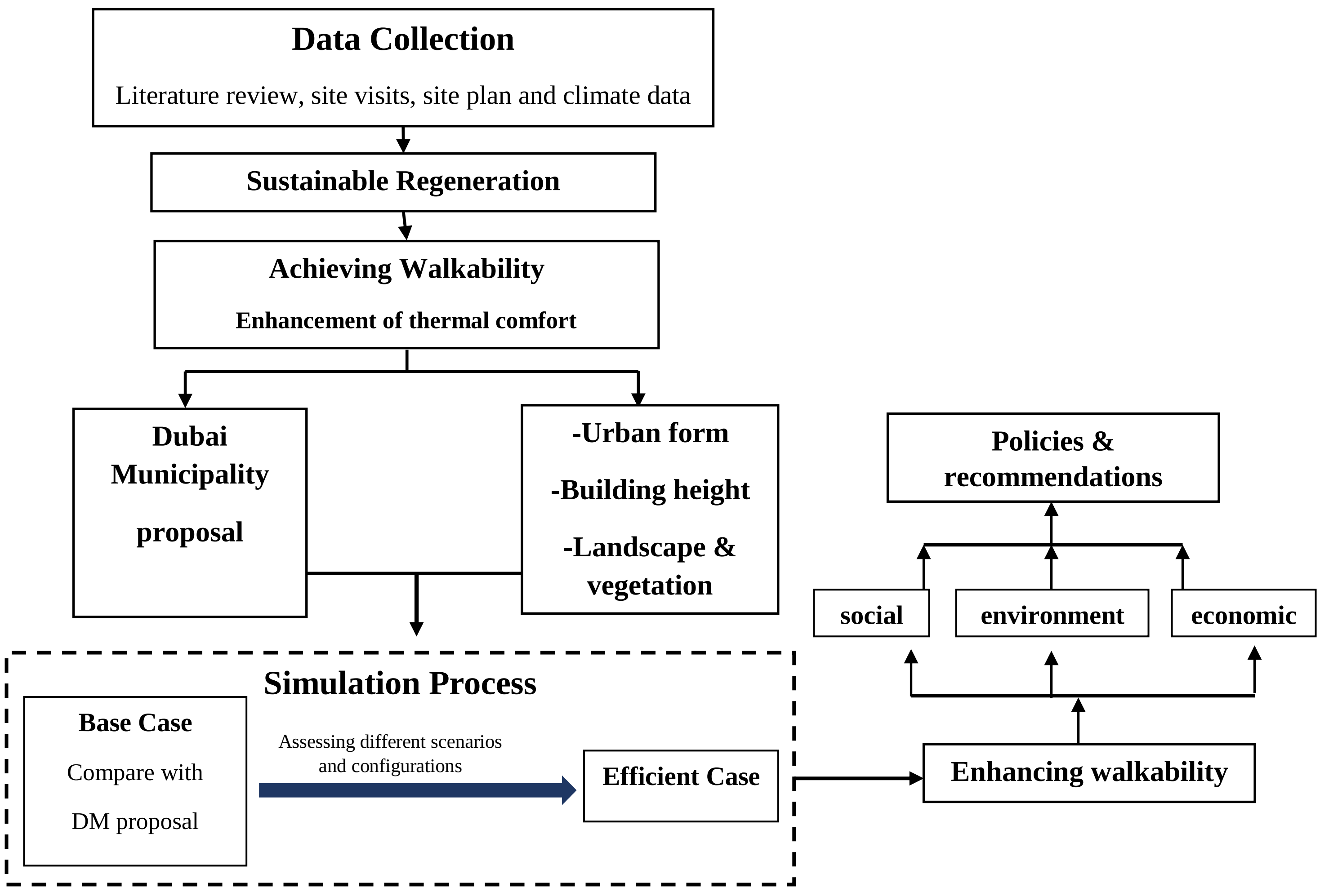
3.5 Site selection

The selected area for this research is in Dubai. Al Rass CBD is located at the northern part of the Dubai creek. Figure 3.3 shows the location of the CBD in Dubai, as well as the case study site specifically.

Figure 3.3: study site location and boundary (google earth)

The selection of the site was based on its historical background and economic strength. The district has several traditional buildings, such as Al Ahmadiya school, the fort, the gold Souq and several mix use buildings. The district is partially renovated and preserved, while the overall urban fabric has stayed the same since its development during the early 20th century, with narrow alleyways and *sikkas,* as well as more natural and organic configurations based on the historical settlement. The buildings in the study area are low to medium-rise buildings. The buildings consist of commercial spaces in the ground floor and residential spaces in the upper floors. Yet, it has been noted that the uses of the upper floors turn to storage spaces serving the commercial spaces. Most of the residents in the selected area shifted to other places in the city, due to the high rental prices, difficult accessibility to the buildings due to the high traffic and the noise pollution from the car traffic in the area. The width of the roads in the selected area do not exceed seven meters, while the pedestrian walkways vary from three to five meters narrow sidewalks. There are very few open spaces and no green areas available. The parameter that is studied for the selected site includes climatic data, such as humidity, air temperature, wind speed and direction. The following chapter includes the research methodology and the parameters and variables. Section 3.6 presents the methodological map of the research.

3.6 Methodological map



4. Computer Model Application

4.0 Chapter overview

To create a walkable community in CBD, Dubai, the investigation in this chapter studies the impact of urban configurations on thermal comfort. The research was conducted in two main parts. The first part considers the simulation of the base case, as well as the Dubai municipality proposal, while the second part studies various optimizations divided into three phases. The first phase investigates three urban configurations with varying building forms and courtyard proposals, while taking into consideration that other parameters are constant. The second phase uses the optimum configuration result of the previous phase to determine the most preferable building height in terms of thermal comfortability, in which three different height proposals are identified and simulated, based on Dubai municipality height regulations. Finally, the third phase examines the impact of landscaping and vegetation, using the optimal configurations identified in the second phase. In the following sections of this chapter, a quick trial validation of the software is presented, alongside a detailed explanation of the simulation methodology and the climate variables.

4.1 Trial validation

As mentioned in the previous chapter, ENVI-met is the most preferable tool for investigation based on the recommendations of the researchers with similar studies. Before running the simulations for the current research, a trial verification was preformed to ensure the capabilities and the outputs of generating valuable results. The trial was preformed to study different urban configurations from 11:00 to 14:00, with fixed climate data. Figure 4.1 represents the simulation results at 12:00. The two main parameters that where are examined is the wind speed and air temperature. The simulation findings showed the difference in the wind speed and air temperature, based on different building height configurations. The trial verified that the software takes the building height into accounts in thermal and wind calculations.

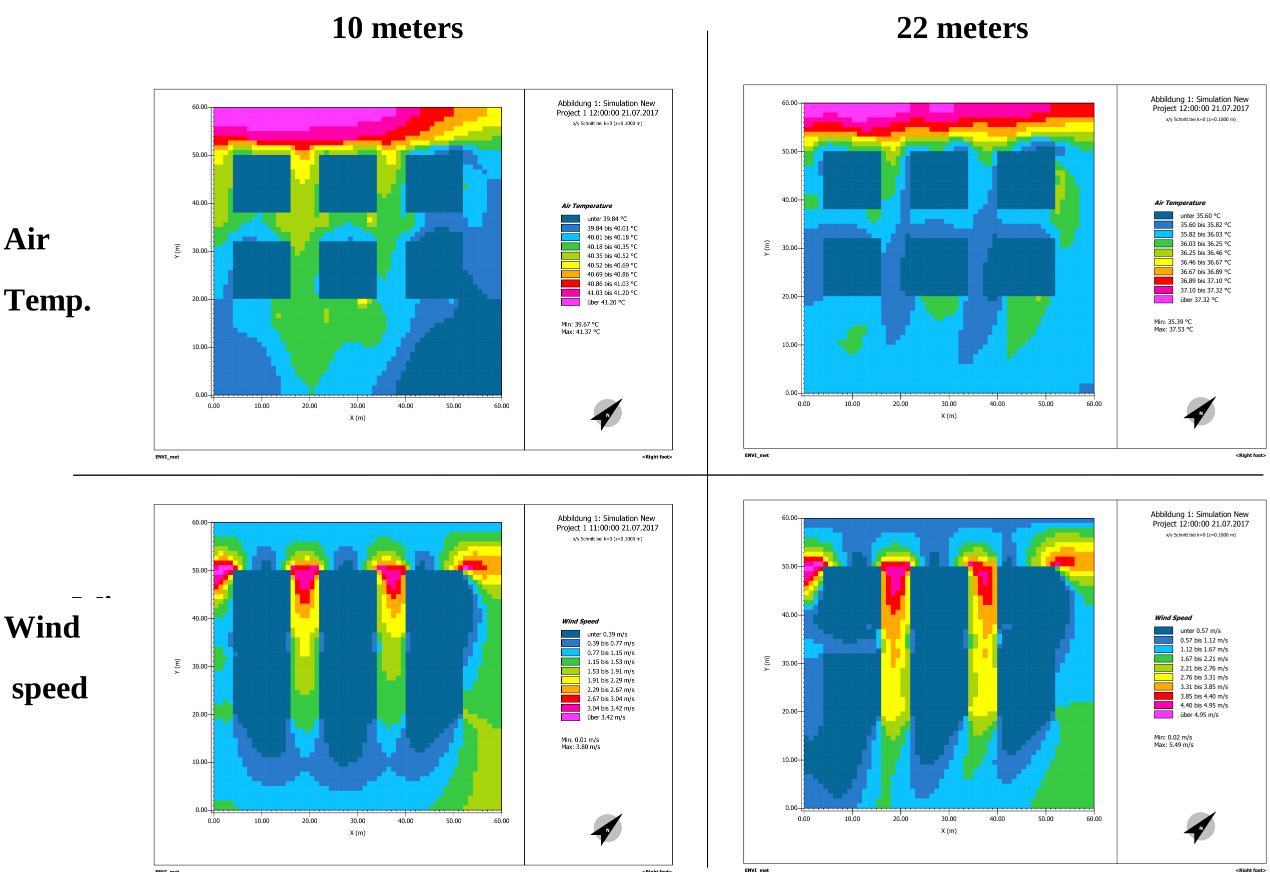


Figure 4.1: ENVI-met results for different height optimization

Another simulation was conducted for two sets of model applications for a U-shape configuration and linear shape, proposing a courtyard between the buildings. The result presented in Figure 4.2 show that there is a different result of thermal comfort based on the building forms, which verifies that the software accounts the different building width and different enclosure sizes.

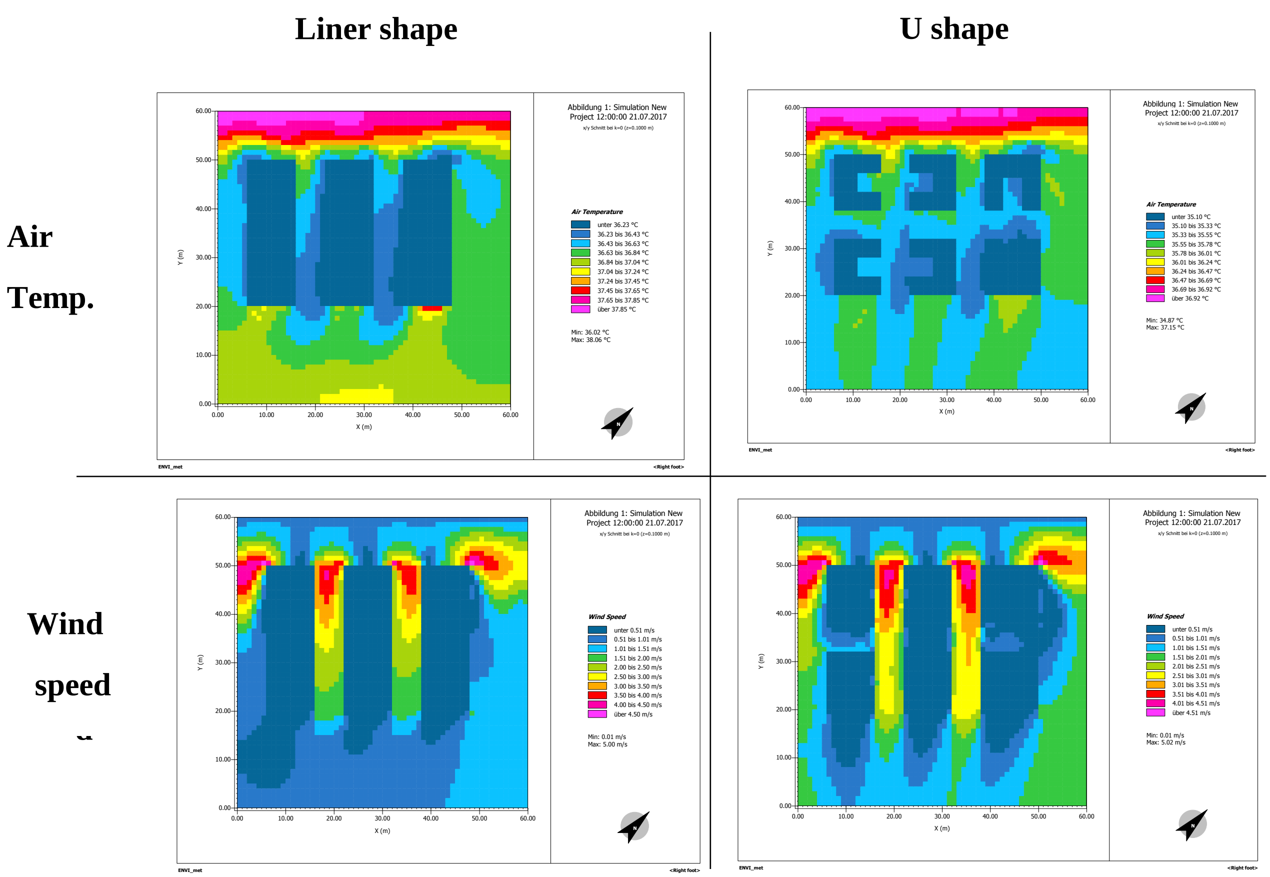


Figure 4.2: ENVI-met results for different form optimization

Based on the literature review with similar methodology, the researchers recommended a finger grid in ENVI-met of 1:1 scale model to obtain an accurate numerical result in terms of wind flow and temperature readings. In which the ratio 1:1 means that the scale is 1-meter actual to 1-meter simulation modelling, in which it was used in the validation of trial. Some researchers used the 1:2 and 1:3 scale mode due to the large area coverage of the study. According to the selected research study in Dubai CBD, it is preferred to use the scale 1:5 due to the large coverage of the selected study area. The passageway, or *sikka,* was measured with a minimum width of 5 meters, so the optimum 1:5 grid size is used.

4.2 Simulation methodology

The simulations for the current research are delivered through parametric analysis. Several simulations run through several urban configurations to examine a single parameter, while considering other parameters as constant. The outdoor thermal comfort conditions are investigated by studying one variable at a time. With reference to the climate conditions, the results of the configurations may vary based on the variables' modification. Based on the variety of the results throughout the simulation, the best configuration is selected to move to the next phase.

To achieve walkability and outdoor thermal comfort in this research, three parameters are investigated and divided into base case, Dubai municipality proposal and optimizations that are divided into three phases listed in Table 4.1. The first parameter is building form; this is the most important parameter that creates the base of the study. The second parameter is building height and the last parameter is the presence of landscaping and vegetation. The parameters mentioned are simulated through the three phases using ENVI-met simulation software, the research phasing and configurations is illustrated in Table 4.1.

Table 4.1: selected parameters and variable optimizations

Parameters	Base case	DM proposal	Variable optimization
1- Building form			- developed linear blocks with rectangular courtyards. - proposed different forms with square courtyards. - creating wind channel
2- Building height			-four stories (12 m). -Six stories (18 m). -Different stories (variation from 6-30 m).
3- landscaping &vegetation			-Grass -Grass and Trees -Grass, trees and water elements

Phase 1 investigates the building form, in which the building size, orientation and dimension change, while the floor area ratio, gross site coverage and gross floor area remain constant. The configurations were specified based on the literature review analysis of similar cases. Table 4.1 lists the urban configurations for phase 1.

A: The existing urban form

B: Dubai municipality proposal

C: Developed linear blocks with rectangular courtyard

D: Proposed different forms with square courtyards

E: Wind channel created

The optimum result acquired at the end of phase 1 is selected for the phase 2 base case. Furthermore, investigation is then carried out to simulate three different building heights of two stories, six stories, and different stories based on each plot GFA. In phase 3, the impact of greenery, vegetation and water elements is tested bases on the most favourable urban configuration selected in phase 2. In each phase, there is one variable parameter, while the other two parameters are fixed, allowing for a more accurate simulation through the measured variable parameters. The tests that are applied and the measured parameters for each phase is shown from Table 4.2 to Table 4.4.

Table 4.2: Phase 1: Trials investigate the building form

Trail	P1- Variable parameter: Building form	P2- Fixed parameter: Building height	P3- Fixed parameter: Landscaping & vegetation
P1-1	The existing urban form		
P1-2	Dubai municipality proposal		
P1-3	Developed linear blocks with rectangular courtyard		
P1-4	Proposed different forms with square courtyards		
P1-5	Creating a wind channel		

\ **Table 4.3:** phase 2: trials investigate the impact of building height

Trail	P2- Variable parameter: Building height	P1- Fixed parameter: Building form	P3- Fixed parameter: Landscaping & vegetation
P2-1	Four stories (12 m)		
P2-2	Six stories (18 m)		
P2-3	Different stories (variation from 6-30 m)		

Table 4.4: phase 3: trials investigate the impact of landscaping and vegetation

Trail	P3- Variable parameter: Landscaping & vegetation	P1- Fixed parameter: Building form	P2- Fixed parameter: Building height
P3-1	Grass		
P3-2	Grass and trees		
P3-3	Grass, trees and water elements		

Researchers such as OKE (1988), Ali, Toudert and Mayer (2010) and Shishaegar (2013) have linked the building form and height as the essential configurations in enhancing the outdoor thermal comfort in a new development, while other researchers such as Doherty, Nakanishi, Bai and Meyers (2009) considered the landscaping, vegetation and shading as the most important configuration in enhancing outdoor thermal comfort in a developed community. In this study and based on the objective of sustainable regeneration, the selected parameters were placed based on the properties of urban settlement in which the three parameters are considered important. The parameters' phasing was placed according to the priorities and their expected results throughout the urban redeveloped area.

4.3 Variables

There are many variables that affect the intensity of the heat island effect and thermal comfort, in which there are different variables interconnected. In this study, defined variables remain constant, while others are modified based on the changes. According to the recent literature review, the variables are separated into two types, which include microclimatic variables and urban texture variables, which are identified in the following section.

4.3.1 Microclimate variable

As mentioned, many variables are interconnected and these variables are either fixed or changeable, affecting outdoor thermal comfort. To simplify the methodology of simulation, some variables were set as constant. Generally, based on the modelling variables, the variables were categorized into three groups: fixed, independent and dependent. The dependent variable changes based on the independent. At the start of the simulation process, it is important to identify the three types of variables.

The fixed variables remain constant and do not change throughout the simulations. To highlight the importance of the three main variables that affect the urban configurations, these variables are not necessary factors that are fixed in all the phases of urban configurations. For example, hardscaping and landscaping properties remained constant for the first two phases of urban configurations, which includes building forms and height, while they are still changeable at the third phase. Other constant variables that remain fixed throughout the simulation that are considered part of the input data that do not change in any of the simulations are wind speed and direction, relative humidity and temperature. However, these can vary based on the simulation study location, date and seasons. These fixed variables are kept ensuring that the results of the simulation are the base of the selected independent variables, without the intervention of other varying circumstances. The dependent variables are the fixed variables of the simulation, which is presented in Table 4.5.

Table 4.5: Fixed variables for all simulation runs

Wind speed at 10 m	Wind direction	Initial temp (℃)	Relative Humidity in 2m
3.0 m/s	315 degrees	Min. 32 max 48	Min 32 max 75

The independent parameters are the parameters that are manipulated through several scenarios to achieve the goal of the research. The three main variables, mentioned as phases, listed in Table 4.2 to Table 4.4, play a key role in the interface between the outdoor thermal comfort and the urban configurations. ENVI-met software is capable of considering the interconnected variables that contribute to the interface.

Based on the selected parameters for simulation, it is important to mention that all the scenarios are simulated for 21 July, which is considered the hottest day of the year. The result is recorded from 12:00 until 15:00. As presented in Figure 4.3, the model domain was adjusted for all simulations, in which the grid measurement of 60x, 60y, 30z and the selected grid cell size was adjusted to be 5 m (dx), 5 m (dy) and 5 m (dz).

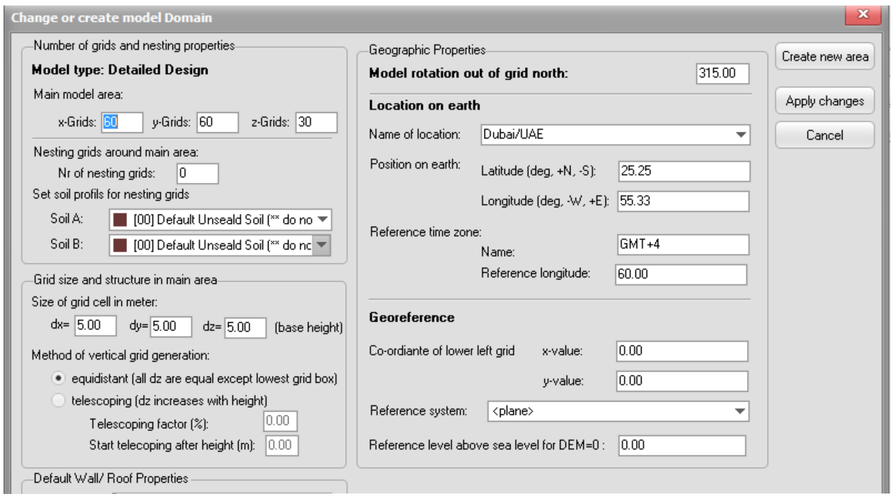


Figure 4.3: the model domain of all the simulations

4.3.2 Urban texture variable

Due to the many factors that influence the physical parameters within the urban space, the building forms and density of the urban form is characterized by several urban texture variables. These variables are listed in Table 4.6, in which the parametric design was selected. Setting the floor-area ratio (FAR) constant at 2.9 complies with Dubai municipality regulations for the high density. Meanwhile the total GFA is 72,366 m^2 for the total number of buildings in the study area. For the first phase of the simulation, the GFA remains constant, while the building height may vary based on the three configurations. In the second phase, the plot coverage may change partially due to the height configurations, while the focus is in keeping the GFA as the maximum floor area restriction, through the creation of compact buildings with more courtyards and open spaces, which eventually cause the total building surface area to become smaller.

Table 4.6: Urban texture variables

Block area	Total GFA	FAR
24,947 m^2	72,366 m^2	2.9

4.4 Model setup

After running the validation trial simulation, the selected grid scale was 1:5. This scale was found to be the most suitable scale for the selected study site due to the approximate of the urban form, building, roads and *sikka* sizes. The x and y axis represents the length and width of the urban form, respectively, while the z-axis represents the building height, kept at 1:1, due to the different building heights within the studied area. The standard floor height was modified as 3 meters per floor, while some buildings had a ground floor with 4 meters height. So, each building was measured separately based on Dubai municipality urban planning regulations. Figure 4.4 shows the building height within the study area, the study area boundaries and the buildings surrounded by the study area.

Figure 4.4: the white buildings are the studied area represented by the building heights in meters (Author)

Due to the difficulty of drawing the tilted and rotated building in ENVI-met, as shown in the previous figure, the model was rotated to 45 degrees to have an approximation of parallel and perpendicular buildings and open spaces to simplify the tracing of the model through the available grid, while considering the north orientation modified, based on the actual site accurate orientation. The first model presented in Figure 4.5 is the original configuration (base case) of Al Rass area, in which the study site is presented. The surrounding buildings are part of the simulation to analyse the effect of the surrounding buildings on the studied area. According to the base case configuration model presented below, the model appears to be organic and centralized, hence this configuration is referred as Al Rass configuration from here on.

Figure 4.5: the base case 3D model (Author)

4.5 Phase 1 – Simulation run to investigate the impact of the building form

The study investigates the test of three urban configurations along with the existing configuration and DM proposal configuration to analyse the thermal comfort within an existing site in a hot, arid climate. A total of five configurations are tested in this phase to assess the three main parameters affecting outdoor thermal comfort through parametric analysis. The three main configurations were selected based on the literature review analysis on the effectiveness of each configurations.

The study scope is to identify the potential proposal of the three configurations that are simulated and identify the optimal urban configuration that provides the best outdoor thermal comfort. The conceptual design of each configuration is created in Sketch up 2017 and simulated in ENVI-met as the core simulation software. The required data from the Sketchup software are the GFA and FAR, due to the flexibility and ease of the software, while the core software is used for simulation and data analysis such as wind direction, air temperature and relative humidity analysis is still ENVI-met. The two software's are used throughout the study to analyse the potentials of each configuration mentioned.

Based on the literature review, three main forms for urban configurations are recommended in many papers and implemented in this study. This comprises of developed linear blocks with rectangular courtyard, in which this configuration is named proposal C and proposes different forms with square courtyards, named as configuration D, creating wind channel within the urban form, which is configuration E. Configuration A is the base case of the site, in which the plot size and road width as well as other dimensions were requested from Dubai municipality. Configuration B is considered one of the main proposals by the Dubai municipality, urban planning department. The department's aim is to achieve sustainability and walkability in Al Rass District. The Dubai municipality divided the project of walkability into several phases. Some of the phases in Al Rass area were implemented, while others are still under study. In the selected site, Dubai municipality developed some proposals that are not yet implemented, so in configuration B the simulation will run on the proposal delivered by Dubai municipality.

Once the simulation of all configurations from A to E is completed, the three essential parameters affecting walkability are considered, which include wind speed, air temperature and relative humidity. These are used to determine and select the best urban configuration. The five main configurations of phase 1 have constant parameters, which include the building height (P2) and landscaping and vegetation (P3), while there are a fixed number of trees and vegetation, based on the base case, despite the difference in the building forms and open spaces due to the requested configuration methodology. Generally, the results obtained from the three parameters are investigated based on the peak hours.

4.5.1 Existing urban configuration (form A)

The base case or the existing urban configuration is referred as form A is the first configuration to be tested. The selected site as shown in the Figure 4.6 is shaped like a parallelogram, in which the sides length varies 127m, 192m, 172m, 141m. The selected site consists of 27 mixed use buildings and two historical buildings, which include Al Ahmadiya school and the heritage house. Figure 4.6 presents the historical buildings as well as the mix use buildings, along with the building heights in the study site.

Figure 4.6: the plot heights and uses (Author)

To simplify the modelling through ENVI-met, as shown in Figure 4.6, the site was rotated 45 degrees to have regular shapes rather than organic curves in the actual site. The model area was also selected for this study as grid of 100x100, in which each point represents five meters in the actual site. The existing urban texture, as well as the grid composition, remain standard for all the configurations and phases to have accurate measurements. Moreover, the buildings' material was standard for all the configurations, while the roads, parking and pathways have albedo of asphalt, which is according to the actual site cover.

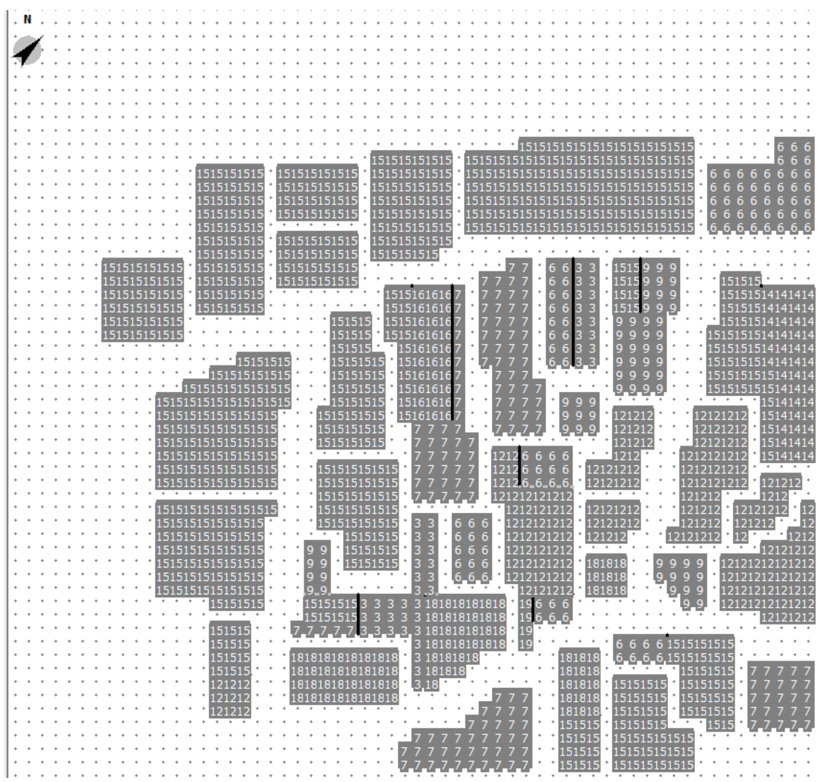


Figure 4.7: screen shot of the base case Envi-met model

The model was placed according to the actual model in the space of ENVI-met. The next step was to adjust the ENVI-met (project wizard) with all the fixed variables, including location, timing, input and output information. Figure 4.8 shows snapshots from the ENVI-met configurations that are set as fixed variables.

Figure 4.9 shows the setting of the meteorological data, which includes the local conditions such as wind speed and direction, atmospheric temperature and the relative humidity. After filling all the basic settings, the model is ready for simulation at the peak hours from 12:00 until 15:00 (a timespan of three hours). In this research, the peak hour is presented at 13:00 in accordance to the known peak hours in Dubai, presented in the literature review. The other simulation timing is presented in Appendix A.

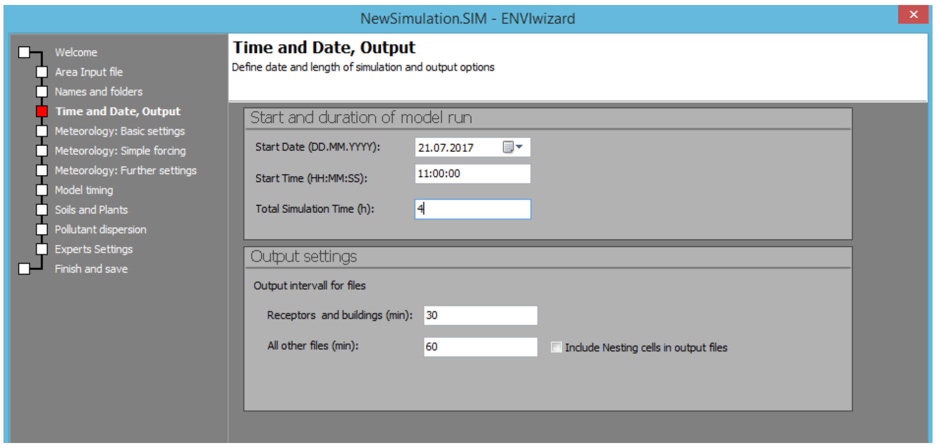


Figure 4.8: time and date fixed variables

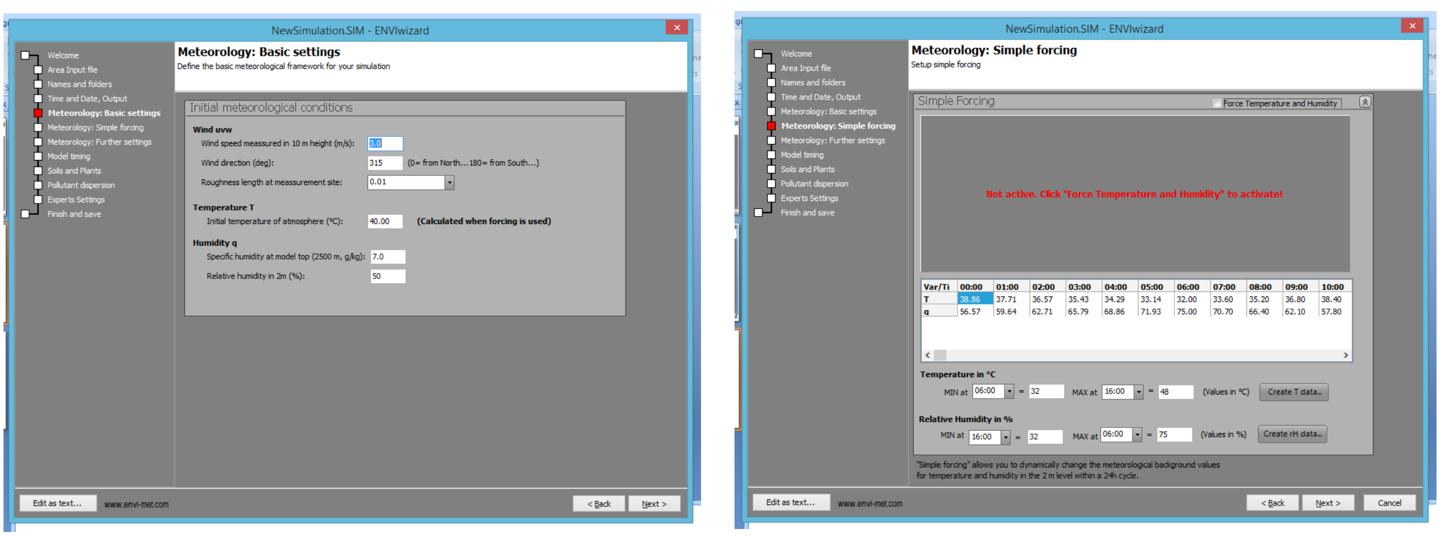


Figure 4.9: meteorological data inputs

4.5.2 Dubai municipality proposal (form B)

The urban configuration referred to as form B is part of the Dubai municipality's proposal to enhance walkability in Al Rass area. The proposal was presented by Dr. Khaled Nasef, urban planning expert in the Dubai municipality (2016). The project was divided into several phases. The first phase that was implemented in the gold souk, in which walkability was enhanced through the addition of shaded areas for pedestrians, as well as the natural ventilation to promote the walkability. Another part of the project was to create more open spaces and underground car parking, as well as solar shading and water elements, such as fountains and ponds. In this study area, the planning department proposed another configuration to enhance walkability, named the CBD beautification, which is referred to as form B in this study. Figure 4.10 presents the Dubai municipality's optimization.

Figure 4.10: DM proposal of pedestrian walkway

Based on the urban planning department analysis of the site and the traffic information system TIS it was analyzed that Al Ahmadiya street is a one-way road with total Right Of Way 11 meters that includes the pedestrian walkways and the car parking in which in their study it was preferred to do a road conversion from Al Ahmadiya street to be shifted to Al Rass street, as it can be seen in figure 4.11. The conversion of the road will help to increase the mobility in which it will decrease the traffic on Al Ahmadiya street as well as it enhances the walkability pathway from Al Rass metro station which is 60 meters away from Al Ahmadiya street. The road shifting tends to decrease the traffic to the inner part of the study area while the traffic is sifted to the outer road which it can handle the traffic due to its capability in increasing vehicle mobility capacity in which the outer part is measured as 20 meters ROW which includes 2 lanes for each side. The inner road which is named as Al Ahmadiya street is converted to a pedestrian open space connecting the metro station to Al Rass District.

Figure 4.11: (left) road conversion proposal (right) actual setting out

According to the municipality's proposal, the building forms changed slightly in the northern part of the study area, in which an open space or courtyard was proposed, as seen in the Figure 4.12, to segregate the road and pedestrian movement. The proposal delivered by the municipality was to create a semi-gated community to the Al Rass area, as a private pedestrian space. In their proposal, the gate includes several commercial spaces, car parking and *Barjeel*, which is considered a historical natural ventilation object with added vents to increase the functionality for pedestrian cooling in the walkable areas.

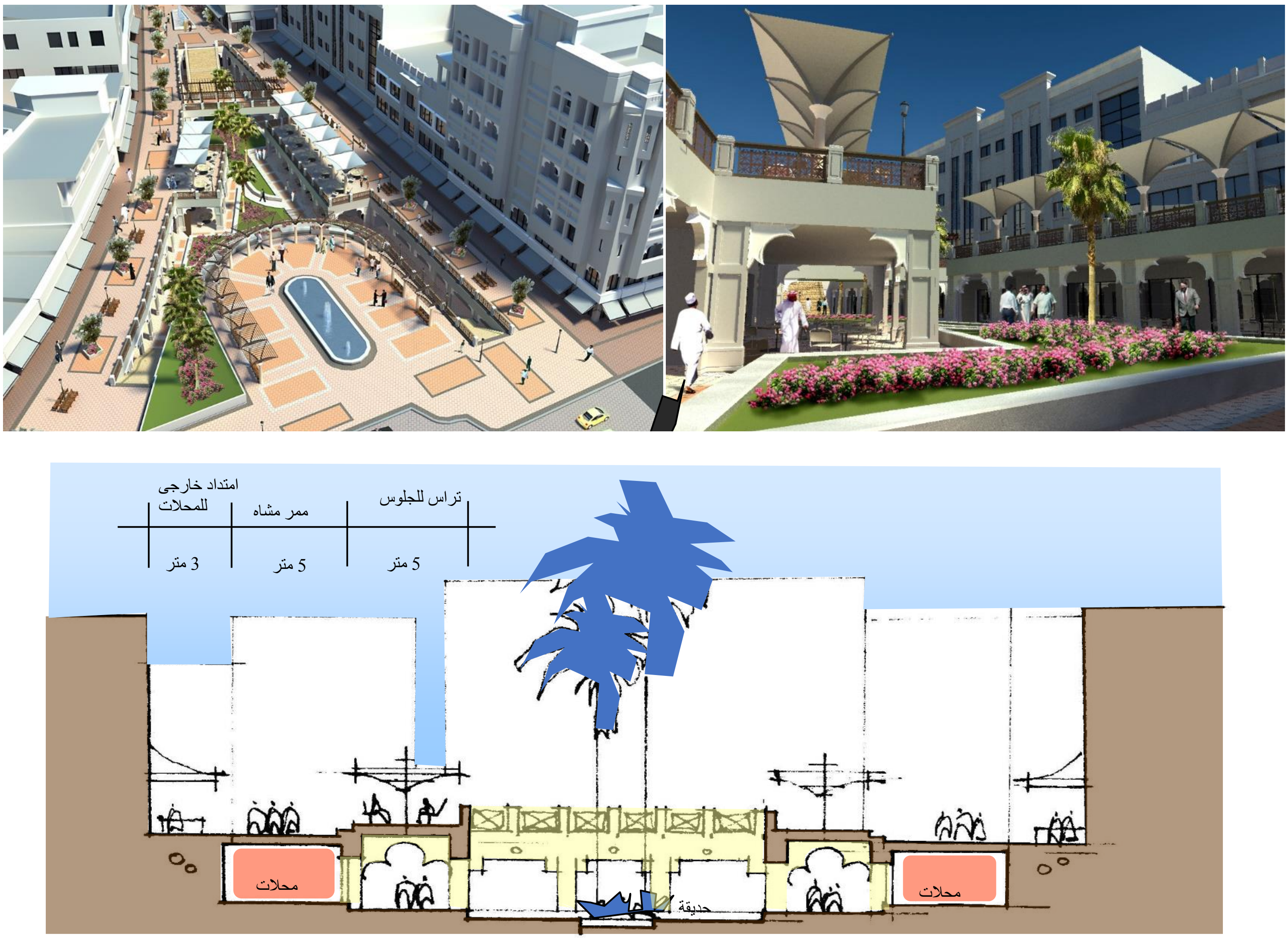


Figure 4.12: east proposal (Dubai Municipality, 2016)

As presented in Figure 4.13, the open space that was proposed includes an open theatre and social space to enhance the social sustainability of the area. The pedestrian movement is shaded by wood and palm leaves to decrease the direct sun radiation during the peak hours of the day. The semi-private pedestrian space increases the pedestrian safety and enhances the urban acoustics due to the conversion of the vehicle noise to the outer part of the district. The logistics of product drop off from the cars to the commercial space was solved through the placement of a car park for cars and trucks, where the goods are shifted easily from the parking area to the commercial spaces via trollies.

Figure 4.13: west road proposal (Dubai Municipality, 2016)

Configuration A and configuration B share similar building form and height, while configuration B has several sustainable measures, which includes the focus on open spaces and the enhancement of walkability and public safety. Configuration B also changes the road material and texture for existing roads, pedestrian spaces and shared spaces for pedestrian and cars. It can be assumed that configuration B is a more sustainable choice to entertain. The next chapter presents the most sustainable configuration in addition to the importance of walkability to select the most preferred configuration.

4.5.3 Developed linear blocks with rectangular courtyard (form C)

Based on the previous forms, A and B, the best form is selected after the simulation of the final three configurations, C, D and E. Urban configuration proposal C was considered because Ali, Toudert and Mayer (2010), and other researchers, concluded that courtyard configuration led to a more favourable outdoor thermal comfort. The thermal comfort in hot, arid climates has been studied deeply. Open spaces and courtyards play a significant role in enhancing the passive design strategy along with the provision of shade and ventilation. There are different uses of the courtyard depending on the climate in which the courtyard is used. In hot climates the courtyard provides shade, while in cold climates, the courtyards are used to protect the pedestrians from direct wind. In humid climates, courtyards provide greater better air movement and ventilation.

In the Figure 4.14, several urban configurations were examined by Taleghani et al. (2015), in which several courtyard sizes and shapes was studied for courtyard proportions and orientations. The outcome revealed that the main two orientations and dimensions that are most favourable for thermal comfort were the rectangular courtyard with an east to west orientation or north to south orientation.

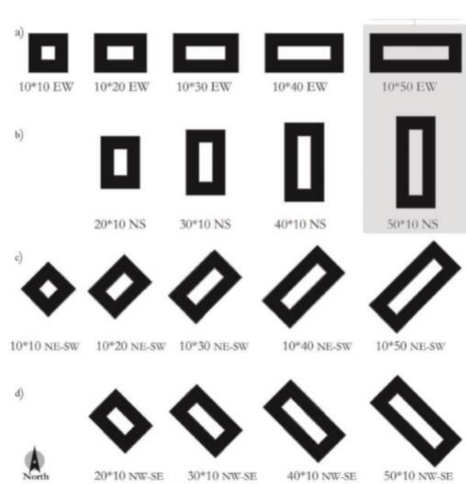


Figure 4.14: Different orientations and proportion for the examined courtyards (Taleghani, Tenpierik & Dobbelsteen 2015)

In the selected study site, it is preferred to examine the north to south orientation, due to the site orientation and the preserved, historic buildings that are oriented in the same way. Figure 4.15 shows the form in which the courtyards were placed, based on their importance and location based on the accessibility from the site to the urban fabric surrounded by the study site. The courtyard configuration was defined based on the urban form in which it is considered a part of the urban design. While it is difficult to consider the configurations of courtyard within the building, due to the ownership of these buildings by different people, the configuration should be conducted within the urban space. These courtyards are considered open, public spaces, enhancing inner city movement, while also encouraging use by community residents and traders.

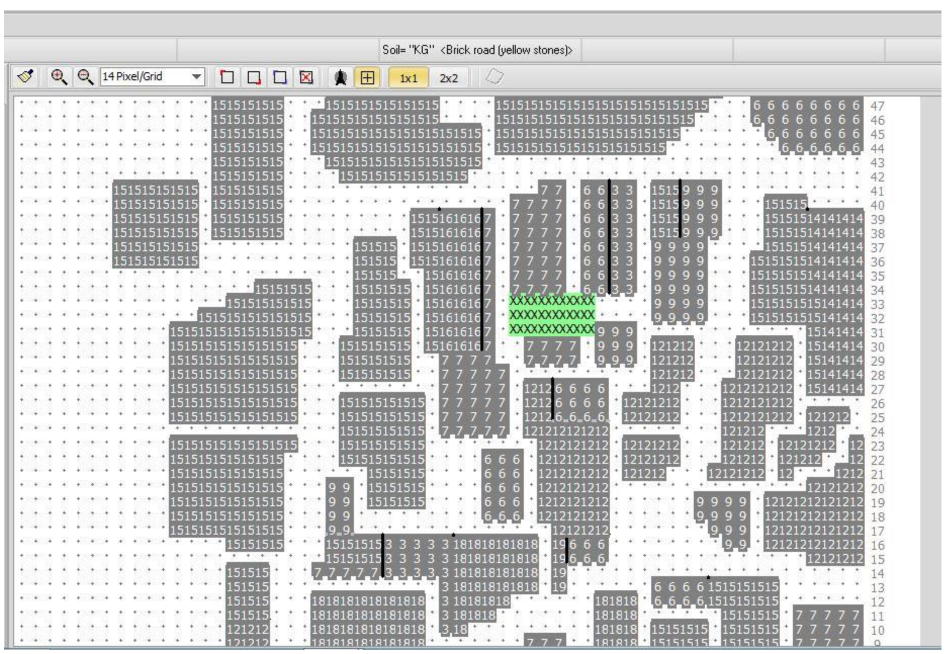


Figure 4.15: form C Envi-met modeling

4.5.4 Proposed different forms with square courtyards (form D)

The proposed urban configuration form D consists of simple rectangular forms that can be considered as extended manipulation forms from the original proposal of the rectangular fortress plans, inspired by research done by Ahmed & Abu-Hijleh (2016) who investigated the best urban form in terms of wind speed and air temperature in Abu Dhabi, which shares similar climate data with the selected study site. The rectangular forms consist of smaller, leaner forms with different orientations to create a semi-open courtyard, in which the courtyards are maintained as rectangular courtyards with different measurements, as represented in the Figure 4.16.

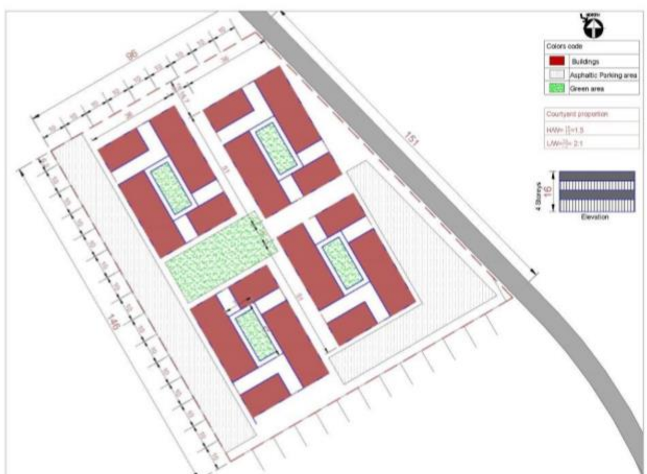


Figure 4.16: The proposed developed linear blocks with rectangular courtyard urban configuration Ahmed & Abu-Hijleh (2016)

4.6 Phase 2 – Simulation run to investigate the impact of the building height

Based on phase 1 results, the second phase investigates the impact of several building heights. Essentially, three different heights are taken into consideration: four stories, six stories and different stories to be tested. As mentioned recently, the building height would vary in each configuration. P2-1 studies buildings of four stories with a total height of 12 meters, while the second configuration, P2-2, studies buildings with six stories, with total height of 18 meters. The third configuration includes different building heights starting from 3 stories up to 10 stories, with different heights from 9 meters up to 30 meters. Tsang, Kwok and Hitchock (2009) studied the effect of building height and building separation and its relationship with the wind environment, through which they concluded that a wider building would block the approaching wind, but it is not recommended to have large blocks to stop the wind resistance and rather, allow the wind smooth movement. They also concluded that higher buildings would increase the wind speed surrounded by the buildings. Moreover, the study added that the higher the height to width ratio, the lower the wind flow (Tsang, et al., 2009). In this part of the study, the investigation considers two main factors that influence wind speed and orientation in the study site: building form and building height. In hot arid climate zones, higher wind speeds lead to lower temperatures and lower relative humidity. The wind speed air temperature and relative humidity are the three main parameters that would be considered in selecting the best building height configuration.

4.7 Phase 3 – Simulation run to investigate the impact of the landscaping and vegetation

The literature review in chapter two concluded that building forms do affect the thermal comfort. Many researchers focused on greenery and vegetation to enhance thermal comfort in regenerated urban forms. Greenery and vegetation does improve the urban climate. Rajabi and Abu-Hijleh (2014) determined that the temperature decreased by 7°C in an urban area, with similar climate data of the study site. Moreover, trees are a better alternative for shading and wind speed. Three different configurations were performed in the third phase, using the best configuration chosen in phase 2. This configuration was optimized to study the impact of landscaping and vegetation in the urban form. The three configurations performed in the third phase include: grass; grass and trees; and grass, trees and water elements to evaluate the impact of vegetation and landscaping on outdoor thermal comfort. The base case of the following configurations is the selected configuration from phase two that guides the investigation of the three landscaping and vegetation configurations. Moreover, the three studied configurations proposed in this research are needed within any urban area while results may vary based on the studied location. After the investigation is conducted, the optimum design is compared to the base case and Dubai municipality proposal. It is important to note that the other parameters are fixed, such as the building materials and forms within the last phase.

A total of 11 simulations are investigated along the three parameters, which are divided into three phases, listed in Tables 4.4, 4.5 and 4.6. The results of wind speed, air temperature and relative humidity are studied and evaluated based on the average of peak hours from 12:00 to 15:00. For each configuration studied, the wind speed, air temperature and relative humidity values are obtained from different simulations and displayed in tables for further analysis and comparison. The next chapter focuses on the analysis of data accrued by the simulation for further discussion of the results.

5. Results and Findings

5.0 Chapter Overview

After running the eleven simulations through Environment for Visualizing Images ENVI-met software, the findings were categorized to analyze the results of each phase. In this chapter the findings in respect of the base case, the Dubai Municipality (DM) proposal, and the phases of different configurations are discussed in further detail. Phase 1 has two parts: The first part is the selection of the best case from the two configurations, namely the base case and the DM proposal. The optimum design selected from the first part of Phase 1 (P1) will be compared with the configurations proposed by the literature review, which includes three different urban forms. The most suitable optimization will be selected, based on the most favourable form, which will be further investigated in Phase 2. Phase 2 studies the impact of building heights (P2), and Phase 3 investigates landscape and vegetation (P3). The proposal of an efficient building form is based on the thermal comfort parameters, which includes air temperature, wind speed, and relative humidity. Later in the chapter a comparison of the three configurations will be presented. The second phase focuses on the investigation of building heights using the simulation of three trails, followed by the third phase which focuses on vegetation and landscaping to analyze their impact on outdoor thermal comfort. It is important to note that the simulation analysis in this research investigated urban design despite the surface temperature of the buildings.

5.1 Phase 1: Results and Discussion

As mentioned in Chapter 4, Phase 1 will include the investigation of the existing configuration (base case) and the DM proposal. After the simulations are analyzed, the best case of the two simulations will be selected for further analysis in Phase 1. Phase 1 configurations include: Developed linear blocks with rectangular courtyard; proposed different forms with square courtyards; and the creation of wind channels. Air temperature, wind speed, and relative humidity will be tested and results will be discussed further to justify the selection of the optimal urban configuration, which will be investigated in the second phase with different height optimizations.

5.1.1 Base Case and Dubai Municipality Proposal

In this part the base case and the DM proposal are simulated to select the best option for further simulations to be conducted in Phase 1. The base case includes the actual modelling of the central business district (CBD) area, in which no vegetation or landscaping was considered. Similar to the base case, the DM proposal had fixed gross floor area (GFA) and building height, while some modifications were considered regarding the building forms of the two buildings, and greenery was taken into consideration in the DM proposal. It is important to compare the base case with the DM proposal in order to gain further clarification on the effectiveness of the DM proposal with respect to the base case. Figure 5.1 presents the temperature comparison between the base case and the DM proposal at 13:00 p.m., with the different colours representing the

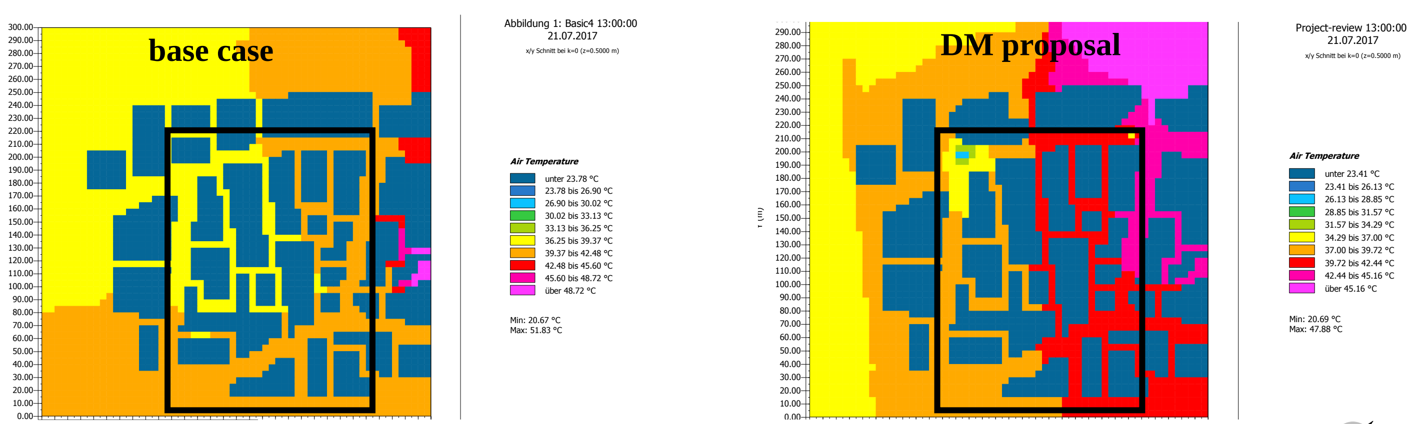


Figure 5.1: Comparison between Base Case and DM Proposal

temperature range in degrees Celsius (°C).

As illustrated in Figure 5.1, the minimum and maximum air temperatures are taken into consideration, as well as the overall temperature of the site and its surroundings. The studied area air temperature is highlighted, i.e., the exact temperature within the boundary of the site itself, excluding the surroundings. As can be seen in Figure 5.2, the DM proposal has higher wind speeds in the northern part, as well as lower humidity, compared to those of the base case at the peak hour, 13:00 p.m.

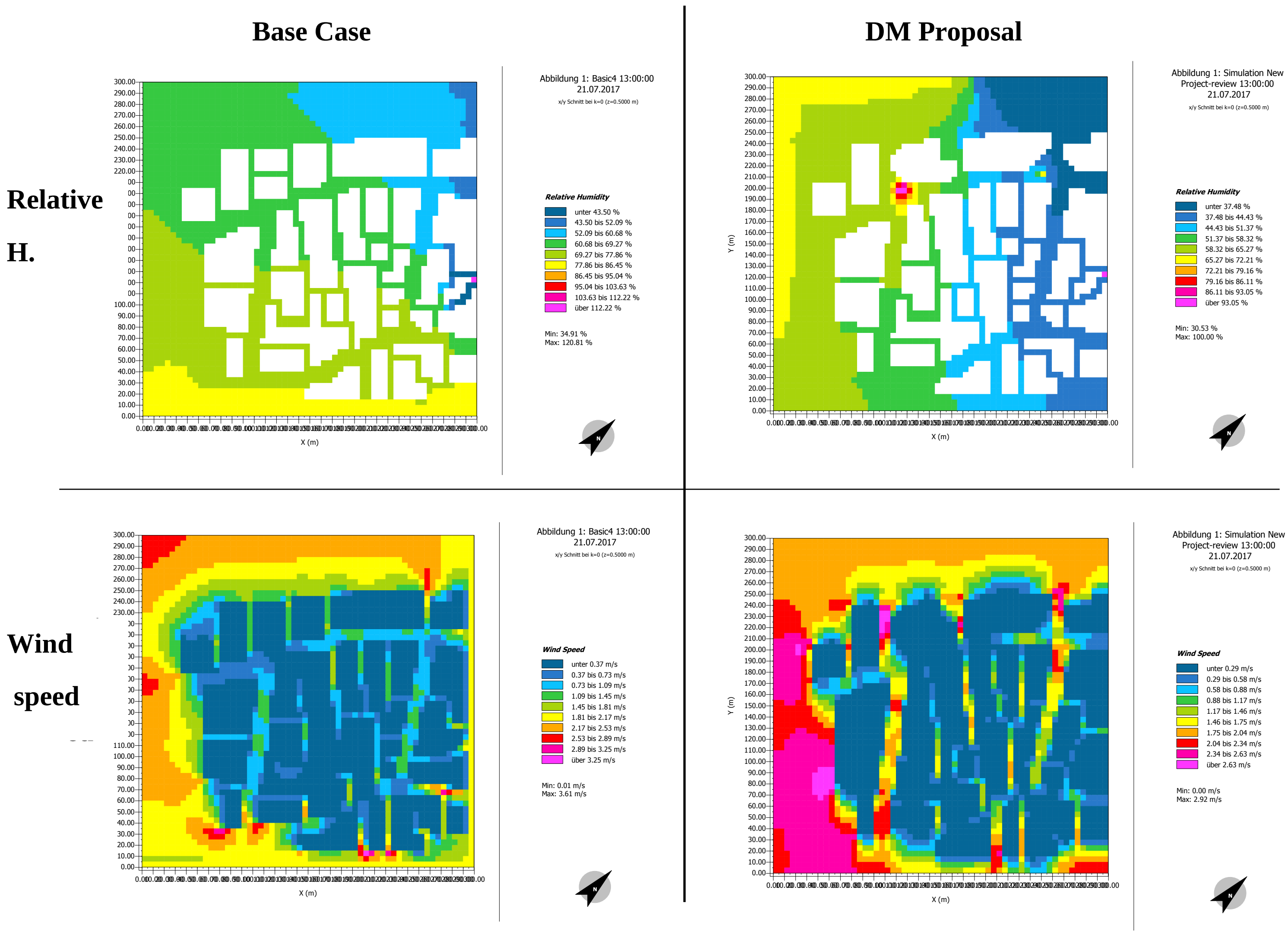


Figure 5.2: Comparison between base case and DM proposal of Relative Humidity and Wind Speeds

Table 5.1 presents the recent simulation result of the base case and the DM proposal, with DM optimization averages of air temperature, wind speed, and relative humidity from 12:00 p.m. to 15:00 p.m., which represent the peak hours of the day. The simulations are presented in Figure 5.1 and in Figure 5.2, are at 13:00 p.m., while the rest of the simulations are presented in Appendix A.

Table 5.1: Comparison of Numerical Data Extracted with Average Air Temperature, Average Wind Speed and Average Relative Humidity.

Form	Average air temperature	Average wind speed	Average relative humidity
A: Base case	39.35	1.05	62.5
B: DM proposal	38.34	1.09	50.66

Comparing the two simulations with regard to the DM proposal and the base case from 12:00 p.m. to 15:00 p.m., Table 5.1 illustrates that the DM proposal has higher average wind speeds, lower average air temperatures, and lower relative humidity. The difference in the average air temperatures was 1.01 ℃, and the average wind speed difference was 0.04 (m/s), while the average relative humidity recorded the highest difference of 11.84%, due to the DM proposal optimization of adding shading and greenery, as well as optimization of the two building forms in the northern part of the studied area, in which the northern buildings were partially removed to add streets, allowing car accessibility to the outer road. After the selection of the DM proposal as the best case, the first phase simulated the following configurations: Linear blocks with rectangular courtyards; different forms with square courtyards; and the creation of wind channels. The configurations already mentioned were based on the DM proposal building form heights and landscaping.

5.1.2 Phase 1: Results of Investigation into the Impact of Building Forms – P1

Three different urban configurations and their variables were considered in this part of the investigation. As clarified in Chapter 4, there are three proposed configurations of building forms, while there are several fixed parameters to be considered, such as the building height, fixed GFA of a total area of 72,366 m^2, and no vegetation or greenery to be added, except the actual greenery space mentioned in the best case. Table 5.2 presents the three different optimized configurations, along with the considered parameters.

Table 5.2: Phase 1 Configurations

Trail	Form	P3: Fixed parameter
P1: 3	C: Developed linear blocks with rectangular courtyard	
P1: 4	D: Proposed different forms with square courtyards	
P1:5	E: Creating wind channels	

Based on the site analysis, it was decided that the historical buildings would be conserved, and the challenge was to integrate the historic buildings with the proposed urban configurations. Figure 5.3 shows the visualization of the air temperatures of the three different configurations at the peak time, which is at 13:00 p.m. on July 21st, 2017. Figure 5.3 demonstrates that configuration C had a lower air temperature on the western site of the study, while in configuration D temperatures decreased in the central area of the study, due to the form change produced by the squared courtyards. Configuration E had the lowest air temperature, due to the focus on enhancing wind channeling, the greatest optimization of wind flow was also achieved in this configuration.

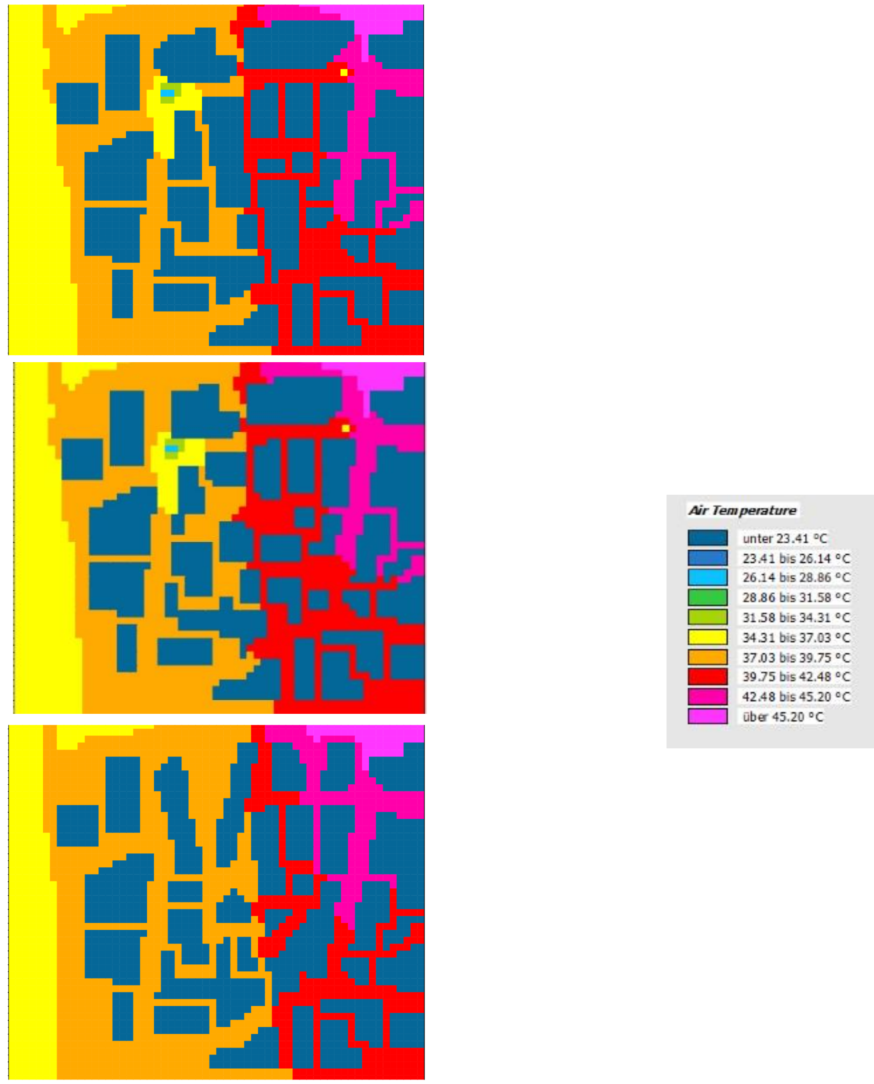


Figure 5.3: Air Temperature for Proposed Urban Configuration C (top), D (middle), and E (bottom) at 13:00 on July 21st, 2017.

Table 5.3: Air Temperature Averages for Proposed Urban Configurations C, D and E

Time	(P1-3) C	(P1-4) D	(P1-5) E
12:00	39.65	39.95	36.06
13:00	40.1	40.48	39.78
14:00	39.12	39.21	39.1
Average temp.	39.62	39.88	38.31

As presented in Table 5.3, the average air temperatures did vary based on the urban configurations. The variation in air temperature demonstrate the effectiveness of the urban forms proposed for Phase 1. The limitation in conserving the historical buildings caused some deficiency in the model, due to the preservation of the site, which lead to a slight difference in air temperatures between the three simulations. As can be seen in Table 5.3, the highest air temperature between the peak hours is at 13:00 p.m., and therefore it was concluded by many researchers that the peak hour in Dubai is at 13:00 p.m. It can be concluded that configuration E, the creation of wind channels, is the best optimized proposal, and is due to the shape and orientation of buildings. The second most efficient proposal is configuration C, which consists of leaner buildings and rectangular courtyards. The least favourable configuration is form D. As can be seen, landscaping was removed from the simulation of the design proposal, due to the aim of focusing on the building form as the priority. As mentioned before, the landscaping will stay in the same space according to the DM proposal, or be overlapped by the building, since the core analysis for Phase 1 is building forms.

Figure 5.4 presents further analysis of Phase 1 at the peak hour of 13:00 followed by the other parameters of the project, including wind speeds and relative humidity. Figure 5.4 reveals that configurations C and D had similar relative humidity and wind speeds during the peak hour at 13:00 p.m., while configuration E had a higher wind speed, due to the change in the urban form and courtyard layout. Further analysis is presented in Table 5.4 and Table 5.5 for the three configurations at peak hours from 13:00 p.m. to 15:00 p.m., and for the other two parameters of average relative humidity and average wind speed.

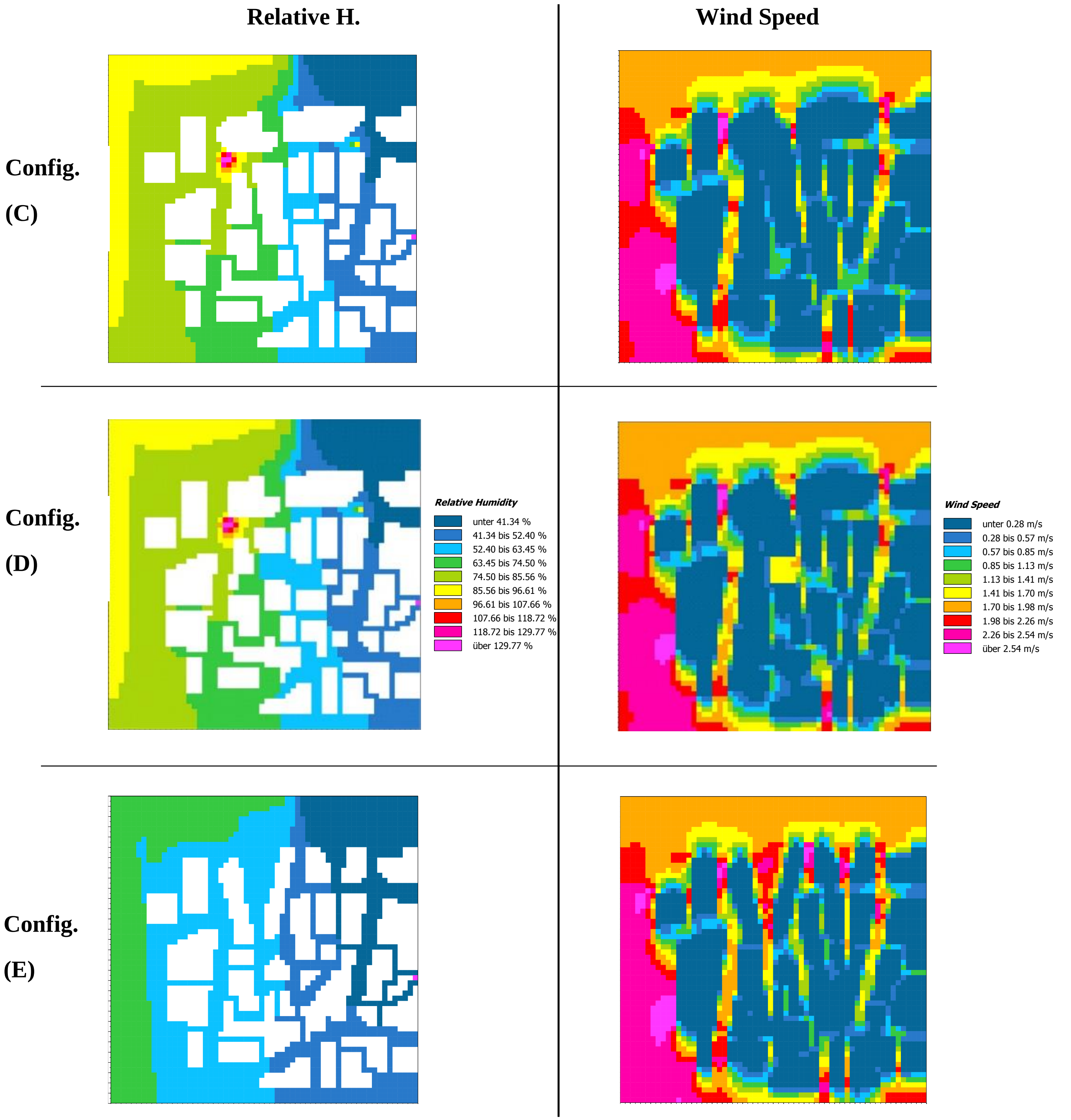


Figure 5.4: Comparison between Configurations C, D and E in terms of Relative Humidity and Wind Speed.

Table 5.4: Relative Humidity Average for Proposed Urban Configurations C, D and E.

Time	(P1-3) C	(P1-4) D	(PI-5) E
12:00	55.6	57.52	52.58
13:00	51.38	49.61	45.34
14:00	50.09	47.27	41.45
Average RH	52.62	51.46	46.45

Table 5.5: Wind Speed Average for Proposed Urban Configurations C, D and E.

Time	(P1-3) C	(P1-4) D	(PI-5) E
12:00	1.50	1.70	2.03
13:00	1.60	1.75	2.26
14:00	1.47	1.52	2.18
Average wind speed	1.52	1.65	2.15

It can be seen in Table 5.4, that configuration E has the least humidity at the peak hour at 13:00 p.m., namely 45.34%, as well as the lowest average, namely 46.45%. The second best configuration in terms of relative humidity was configuration D, which had 49.61% at its peak time, while its average relative humidity was 51.46%. The least favourable configuration in terms of relative humidity was configuration C, which had 51.38% at the peak time, while its average relative humidity was 52.62%. Table 5.5 reveals that configuration E had the highest wind speed at the peak hour of 13:00 p.m. which reached 2.26 (m/s), with an average of 2.15 (m/s), which is the highest wind speed due to the optimization of the form with respect to courtyards and open spaces.

5.1.3 Selection of Optimal Building Form and Courtyard Proportion

Table 5.6 summarizes the simulation outcomes of the first phase, taking into consideration the main parameters, which include air temperature, wind speed and relative humidity.

Table 5.6: Average Air Temperature, Wind Speed and Relative Humidity of the Optimized Configurations.

Form	Average air temperature	Average wind speed	Average relative humidity
C: Developed linear blocks with rectangular courtyard	39.62	1.52	52.62
D: Proposed square forms with square courtyards	39.88	1.65	51.46
E: Creating wind channel	38.31	2.15	46.45

As can be seen from Table 5.6, form E had the best average air temperature of the proposed forms of urban configuration presented in Figure 5.3, which demonstrates that the wind channel resulted in the lowest air temperature. Comparing the temperature of configuration E with the best case proposed by Dubai Municipality, it can be seen that the average air temperature is 38.34°C, which is 0.03°C lower, which makes the DM proposal the second most favourable configuration in terms of air temperature averages. Meanwhile, it can be seen that configurations C and D have similar air temperatures, due to the minimal changes of the urban forms of the configurations, because of the limitation of form control considering the conservation of the historic buildings.

As can be seen in Table 5.6, comparing wind speed and relative humidity in the three configurations, the wind channel form results in the highest wind speed and the least relative humidity, as well as the lowest average air temperature. Comparing the DM proposal with the best configuration in Phase 1, it can be seen that the DM proposal has the lowest wind speed and second lowest relative humidity after the wind channel optimization. The results of the simulation confirm the theory of Al-Sallal and Al-Rais

(2012) that creating buildings with a north-south orientation in Dubai will lead to a higher wind speed, which will consequently decrease the air temperature.

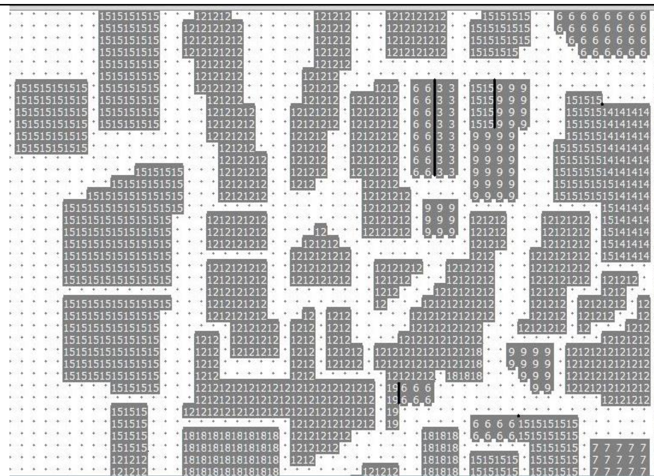
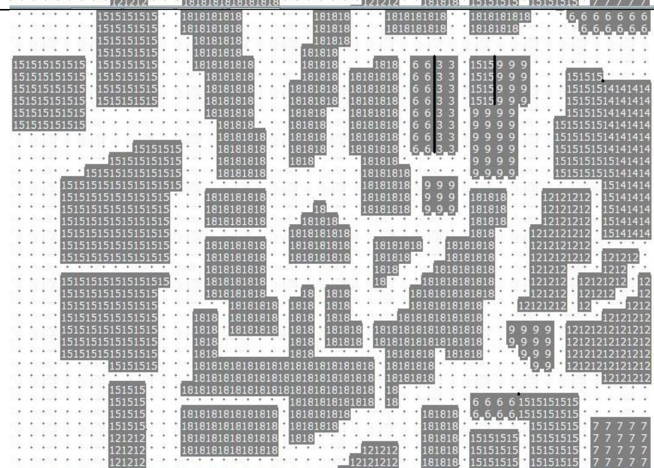
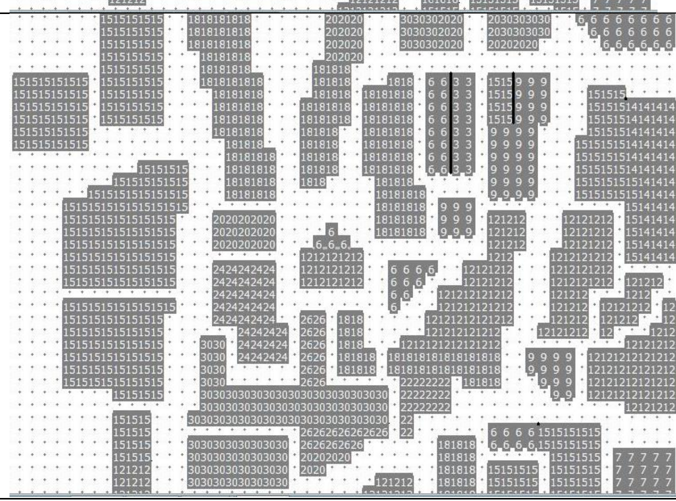
The comparison undertaken by Taleghani et al. (2015) did conclude that courtyard shapes and orientation affect the overall thermal behavior. The simulations clarify that courtyards that have depth and have a north-south orientation provide better results than square courtyards. To conclude, form E offers the best thermal comfort of the configurations analyzed, due to the record of lowest average air temperature, lowest average relative humidity, and highest average wind speed at the peak time of 13:00 p.m..

5.2 Phase 2: Results and Discussion

The second phase consists of three different urban configurations, as listed in Table 5.7, which focus on building heights in terms of an analysis of air temperature, wind speed and relative humidity. The three different heights investigated are four storeys (12 m), six storeys (18 m), and different storeys (variations between 6 m and 30 m) derived from the optimal form configuration E, which was recommended in Phase 1.

It is important to mention that the building heights took into consideration the preservation of the historical buildings located within the studied area, as well as the building heights surrounding the site relative to its actual height. The main focus was to simulate the building heights within the studied area. Vegetation and landscaping were removed from this phase to focus on building height optimal configuration.

Table 5.7: Phase 2 Optimizations and Building Heights

Trail	P2: Variable parameter - building height	ENVI modelling
P2-1	Four storeys (12 m) - The optimization took into consideration the conservation of the historic buildings in which the optimized height was for the study site, excluding the surrounding buildings' height.	
P2-2	Six storeys (18 m) - The optimization took into consideration the conservation of the historic buildings in which the optimized height was for the study site, excluding the surrounding buildings' height.	
P2-3	Different storeys (variation from 6 m to 30 m) - This optimization considered the variety of building heights as presented, excluding the historical buildings and buildings surrounding the site.	

5.2.1 Results of Investigating the Impact of Building Height – P2

In this section, the building height configuration is analyzed by focusing on the three main parameters of air temperature, wind speed, and relative humidity, taking into consideration the recent literature review on building height configuration. Second, the outcomes of the simulations of this phase will be compared to identify the optimal building height configuration based on the peak hour of 13:00 p.m. and averages. The optimal urban configuration will be examined in later sections.

Figure 5.5 demonstrates the air temperatures on July 21st, 2017 at the peak hour of 13:00 p.m. for the three configurations, followed by another simulation conducted on the same day from 12:00 p.m. to 15:00 p.m., presented in Appendix A. Figure 5.5 shows that the air temperature for configuration 3 differs from the air temperature for configurations 1 and 2. Configurations 1 and 2 share similar results in terms of air temperature at the peak hour of 13:00 p.m., using uniform building heights, where configuration 1 had a uniform height of 12 m for all buildings and configuration 2 had a uniform height of 18 m for all buildings on the studied site, excluding the historical conservation area.

It can be seen from Figure 5.5 that air temperature at 13:00 p.m. for configuration 3 was lower compared to the same timing for the other configurations, due to the optimization of building heights based on their location. For an overall view of all air temperature averages, Table 5.8 presents the three configurations with their average air temperatures.

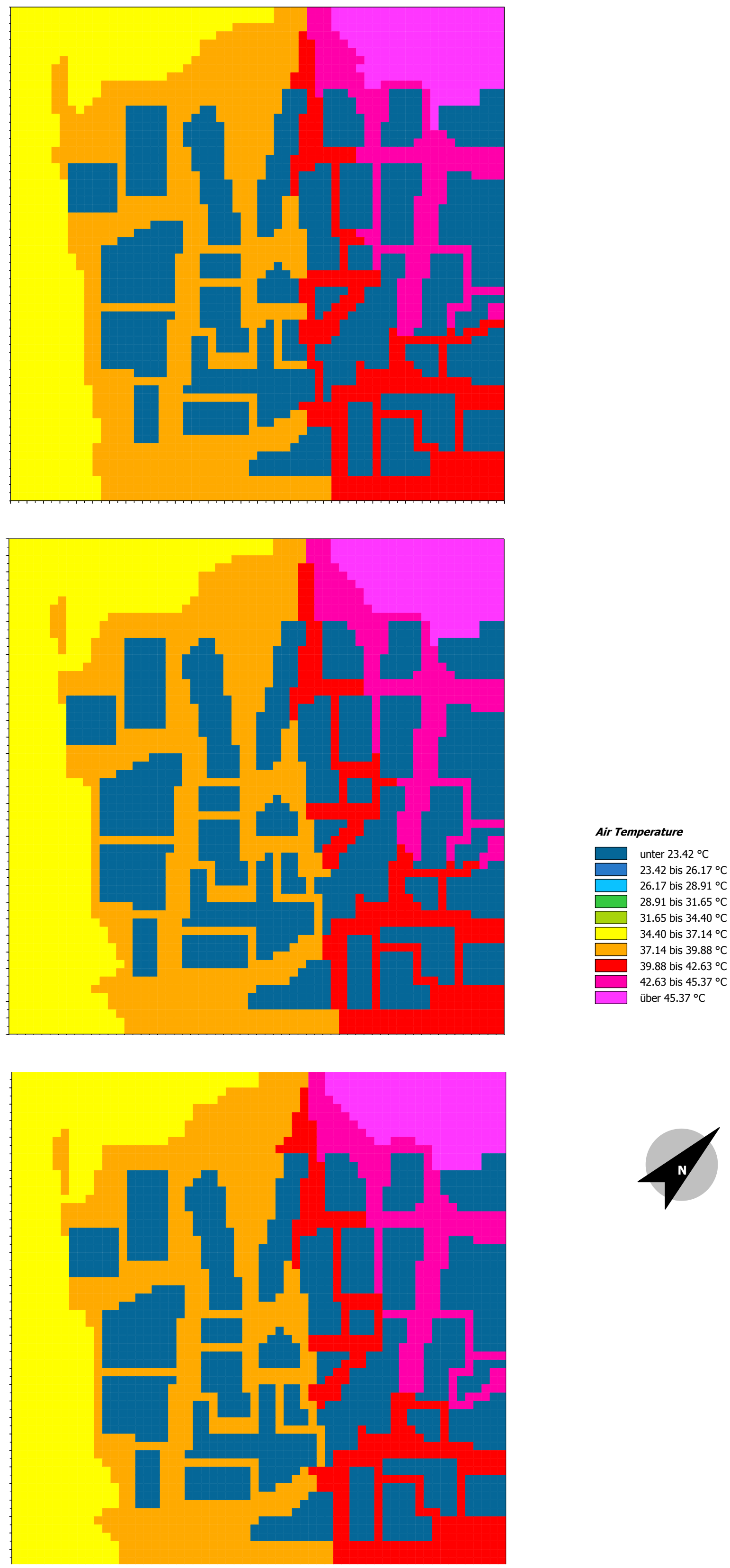


Figure 5.5: Air Temperature of Three Configurations: (top left) Configuration 1, (top right) Configuration 2, (bottom) Configuration 3.

Table 5.8: Average Air Temperature of the Three Optimizations.

Time	(P2-1) E	(P2-2) E	(P2-3) E
12:00	35.51	35.28	35.01
13:00	39.69	39.83	37.50
14:00	38.10	38.17	38.09
Average temp.	37.7	37.76	36.86

According to Table 5.8, the urban configuration optimizations 1 and 2 did have similar average air temperatures, while the third optimization revealed lower average air temperatures. The research was concluded at the peak hour of 13:00 p.m. The third optimization had the lowest air temperature: It consists of mixed building heights with medium-rise buildings at the edges of the studied site and low building heights in the centre. The other two configurations share similar average air temperatures throughout, while there was slight variation at the peak hour, where configuration 1 had an air temperature of 0.14°C lower compared to configuration 2's peak hour temperature at 13:00 p.m. The first optimization was simulated with a height of 12 meters, uniform in all buildings except the historical building conservation area and the buildings surrounding the studied site. Similar to the first optimization, the second optimization simulated the building height of six-storey buildings with a consistent height of 18 meters, in which the height was limited on the studied site, excluding the surrounding and historic buildings. It is important to note that the heights used for this phase were based on Dubai Municipality building regulations and the air aviation authority height regulations.

Figure 5.6 presents further analysis of the parameters obtained in this investigation, including wind speed and relative humidity at the peak hour simulated at 13:00 p.m. Configuration 1 had the highest relative humidity at the peak hour, namely

57.36%, while the relative humidity in configuration 2 was 53.56%, which means it decreased by 3.8%. The best scenario was configuration 3, where the relative humidity reached 47.52% at the peak time.

Wind speeds showed variations between the three configurations at 13:00 p.m., where configuration 1 had a wind speed of 2.01 (m/s), with the highest wind speed of 2.36 (m/s) at the northern part of the studied area. Configuration 2 had an overall wind speed of 1.96 (m/s) at the peak time, due to the increase of building heights. The third configuration had the highest wind speed of 2.21 (m/s), where the highest speed reached 2.25 (m/s) at the northern part, while the central area had a uniform wind speed estimated between 1.47 (m/s) and 2.06 (m/s).

A comparison table was drawn up to compare the average wind speeds and relative humidity of the three configurations presented in Table 5.9 and Table 5.10. Table 5.9 reveals that the highest relative humidity was during the peak time at 13:00 p.m. Configuration 1 had the highest relative humidity at the peak time, as well as in terms of averages, while configuration 3 had the lowest relative humidity at the peak time and in terms of averages. Table 5.10 shows that the highest wind speed recorded for all configurations was at 14:00 p.m., with the highest average wind speeds of 2.08 (m/s) for configuration 3 and the lowest average wind speeds of 1.97 (m/s) for configuration 2.

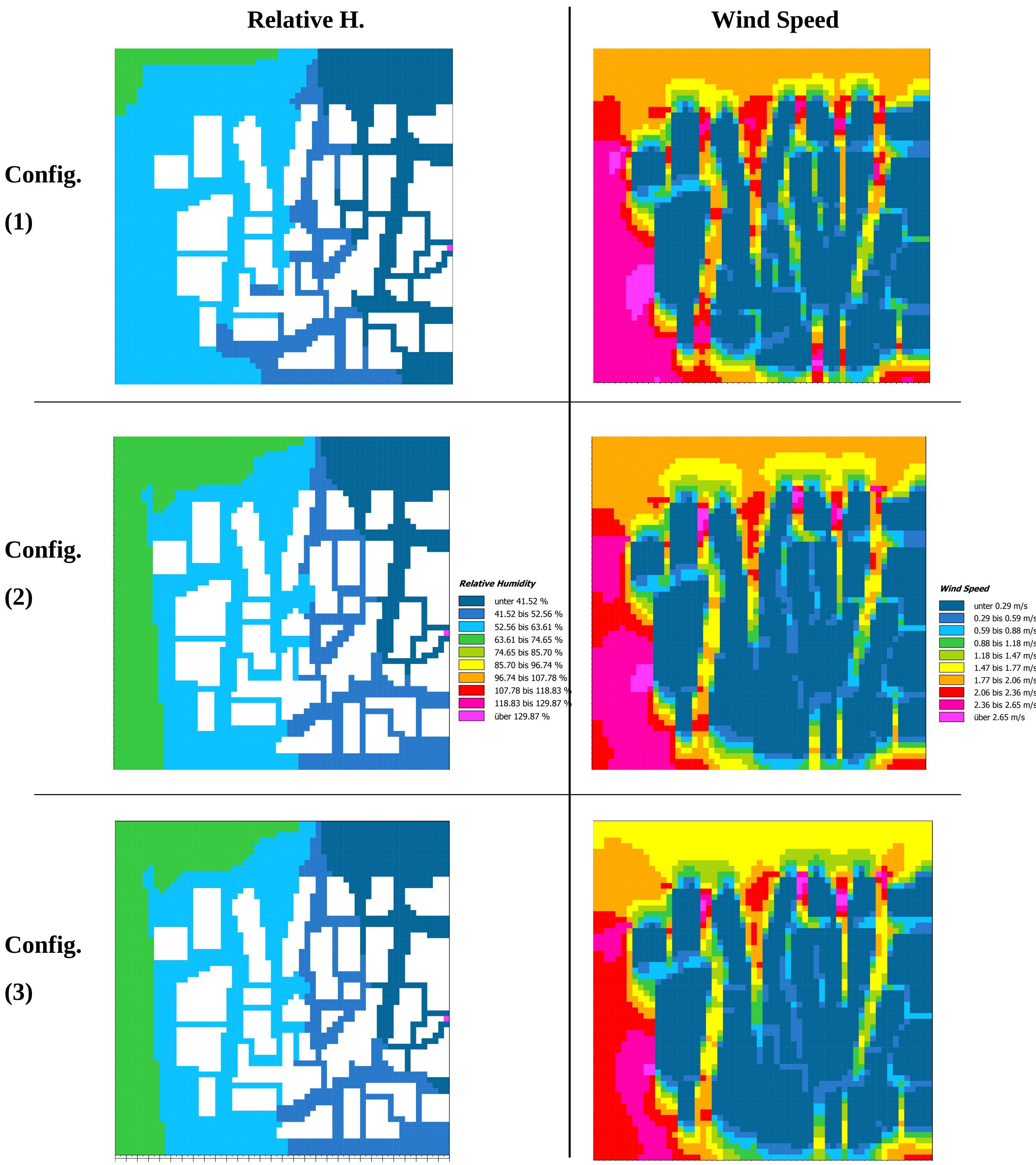


Figure 5.6: Comparison between Configurations 1, 2 and 3 in terms of Relative Humidity and Wind Speed.

Table 5.9: Relative Humidity Average for Proposed Urban Configurations 1, 2 and 3.

Time	(P2-1) E	(P2-2) E	(P2-3) E
12:00	52.27	50.21	50.25
13:00	57.36	53.56	47.52
14:00	55.11	51.38	48.90
Average RH	54.91	51.65	48.89

Table 5.10: Wind Speed Average for Proposed Urban Configurations 1, 2 and 3.

Time	(P2-1) E	(P2-2) E	(P2-3) E
12:00	1.96	1.74	1.80
13:00	2.01	1.96	2.21
14:00	2.11	2.20	2.25
Average wind speed	2.02	1.97	2.08

5.2.2 Selection of Optimal Building Height

Table 5.11 summarizes the simulation outcomes of the second phase, taking into consideration the average results of simulations presented in Appendix A. The outcomes presented by the three main parameters include air temperature, wind speed and relative humidity for further comparison of the outcomes.

Table 5.11: Average Air Temperature, Wind Speed and Relative Humidity of the Optimized Configurations.

Heights	Average air temperature	Average wind speed	Average relative humidity
1- Four storeys (12 m)	37.7	2.02	54.91
2- Six storeys (18 m)	37.76	1.97	51.65
3- different storeys (variation from 6 m to 30 m)	36.86	2.08	48.89

Table 5.11 reveals that height proposal 3, which consists of a different number of storeys, presented the best average air temperature of the various configurations. In

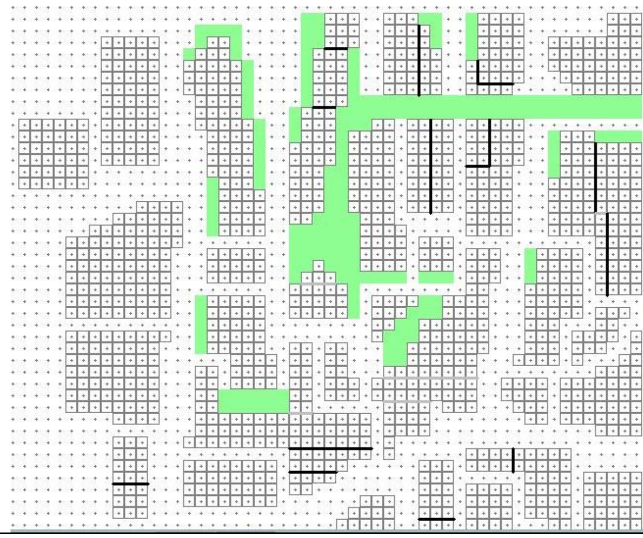
comparison to the best case, namely the DM proposal, the average air temperature was 38.34°C, while the optimized configuration presents 36.86°C, where the average temperature difference is 1.48°C, which is considered a good outcome in the second phase.

Comparing the air temperature, wind speed and relative humidity in the three configurations, the different storeys optimization resulted in the highest average wind speed and lowest relative humidity. In comparison to the Phase 1 best case, in the second phase the air temperature difference is 1.45°C. Following Ali-Toudert and Mayer (2010), who investigated building heights in Algeria, the researchers investigated the effectiveness of different building heights on urban form. The results revealed that midrise buildings can be considered as optimizing wind speeds within urban forms, which supports this configuration as the optimum configuration in comparison to the other two proposed simulations. On the other hand, OKE (1988) concluded that high-rise buildings would block or isolate the air movement of street canyons from the boundary layers. This effect can be noted in the simulation of the southern part of study area, which has the least air movement.

5.3 Phase 3: Results and Discussion

After the selection of different heights as the optimum design in the previous phase, Phase 3 includes three different landscaping and vegetation configurations. Table 5.12 presents the three proposed configurations, in which each optimization is built based on the previous optimization. To test the proposed configurations, the three main parameters, namely air temperature, wind speed and relative humidity, are going to be analyzed in order to make the best configuration selection.

Table 5.12: Phase 3 Optimizations of Vegetation and Landscaping.

Trail	P3: Variable parameter: Landscaping and vegetation	ENVI modelling
P3-1	Grass - The optimization took into consideration the enhancement of greenery in the studies area.	
P3-2	Grass and trees - The optimization took into consideration the previous trial in which the trees are added based on the previous proposal of grass.	
P3-3	Grass, trees and water elements - The optimization took into consideration the previous trial in which the water elements are added based on the previous proposal of grass and trees.	

5.3.1 Results Investigating the Impact of Landscape and Vegetation – P3

As mentioned previously, the third phase comprises the simulation of vegetation and landscaping. The proposals presented in Table 5.12 list the landscaping designs and configurations, which took into consideration the literature review presented in Chapter 2. In this section, the three configurations will be simulated and analyzed to be compared later, in order to select the optimum landscaping and vegetation configuration. Figure 5.7 below shows the air temperature simulation on July 21st, 2017 at the peak hour of 13:00 p.m.

It can be seen from Figure 5.7 that configuration 1, adding grass, resulted in air temperature of 34.4°C. The air temperature increased in configuration 2, and reached 34.51°C during the peak time of 13:00 p.m., due to the addition of trees within the landscaping. The central location of the studied site in configuration 2 had lower air temperature compared to configuration 1. The best configuration in terms of air temperature was configuration 3, due to the addition of water elements within the landscaping. As it can be seen from Figure 5.7, configuration 3 had lowest air temperatures in the central location, compared to the other two configurations. Temperatures in the central location decreased to 25.79°C in configuration 3, while configurations 1 and 2 were estimated to have air temperature variations between 37.16°C and 40°C.

Further investigations are presented in Table 5.13, summarizing the average air temperatures conducted from 12:00 p.m. to 15:00 p.m., while the simulation of the other timings will be presented in Appendix A.

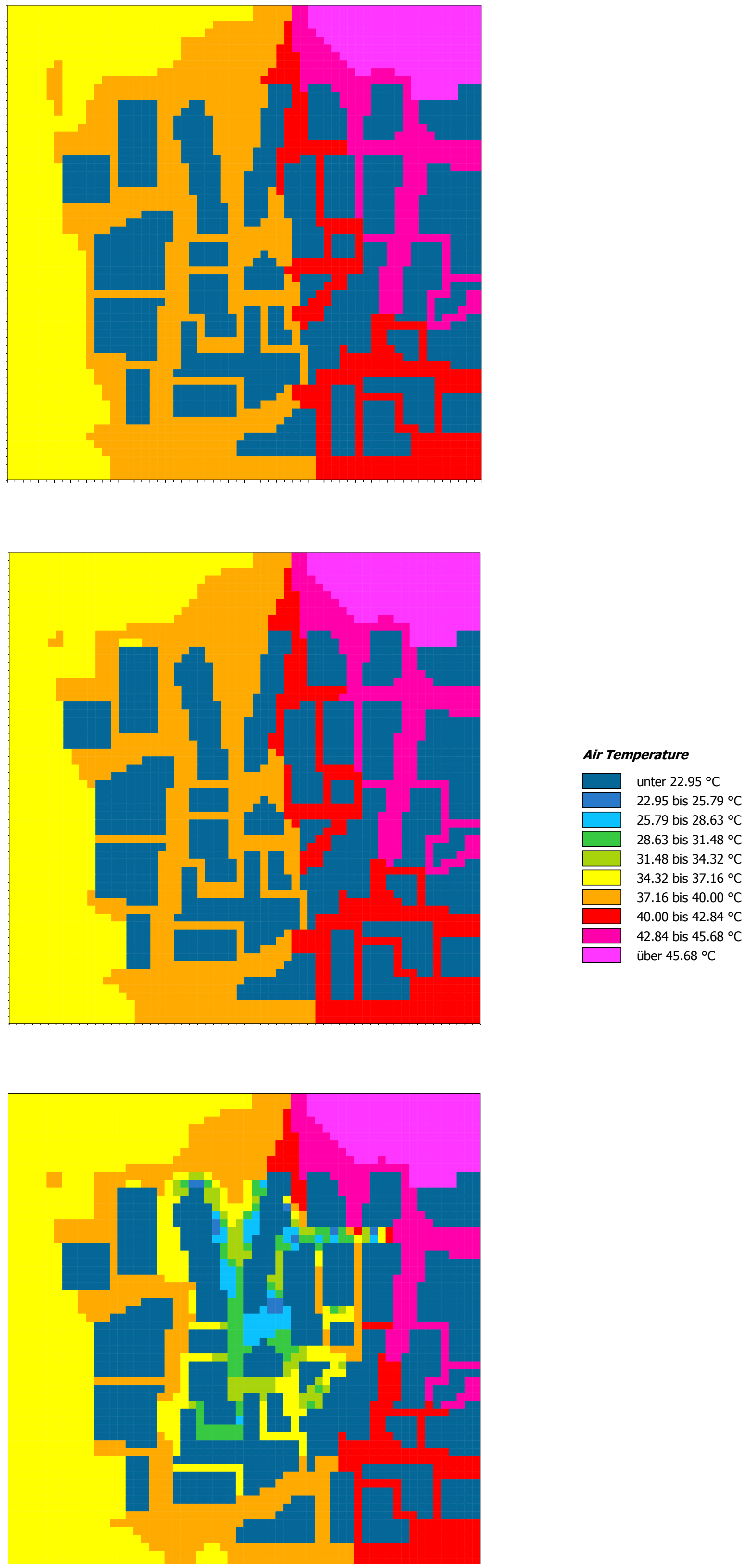


Figure 5.7: Air Temperature of Three Configurations: (top left) Configuration 1, (top right) Configuration 2, (bottom) Configuration 3.

Table 5.13: Average Air Temperature of the Three Optimizations.

Time	(P3-1)	(P3-2)	(P3-3)
12:00	30.90	30.88	29.87
13:00	34.40	34.51	34.32
14:00	34.28	34.64	34.74
Average temp.	33.19	33.34	32.97

According to Table 5.13, the average air temperature in Phase 3 decreased significantly, compared to the previous phases. The first configuration was to add greenery within the urban form, to decrease the heat island effect, as well as to enhance the urban design through the addition of greenery, and the seating area to enhance pedestrian comfort. The second configuration was to enhance the landscaping through keeping the greenery as it is in configuration 2, with the addition of trees. The trees were added based on the wind analysis and air flow movement conducted in Phase 2, in which it was analyzed that wind speed was higher than 2.5 (m/s) in the northern part of the studied area, so trees were added to decrease the wind speed, as well as to add shading to enhance pedestrian comfort. The third configuration took into consideration the configuration which includes grass and trees, while water elements such as fountains were added to enhance the nature acoustics, as well as to have a better comparison to the DM proposal configuration, in which the water element was proposed. As can be seen in Table 5.13, the third configuration resulted in the lowest average air temperature compared to the other two configurations, as well as the lowest temperature at the peak hour of 13:00 p.m.Figure 5.8 presents further analysis of other parameters obtained in this study, including wind speed and relative humidity at the peak simulated hour of 13:00 p.m., followed by comparison tables of wind speeds and relative humidity of the three configurations presented in Table 5.14 and Table 5.15, to conclude the optimal design.

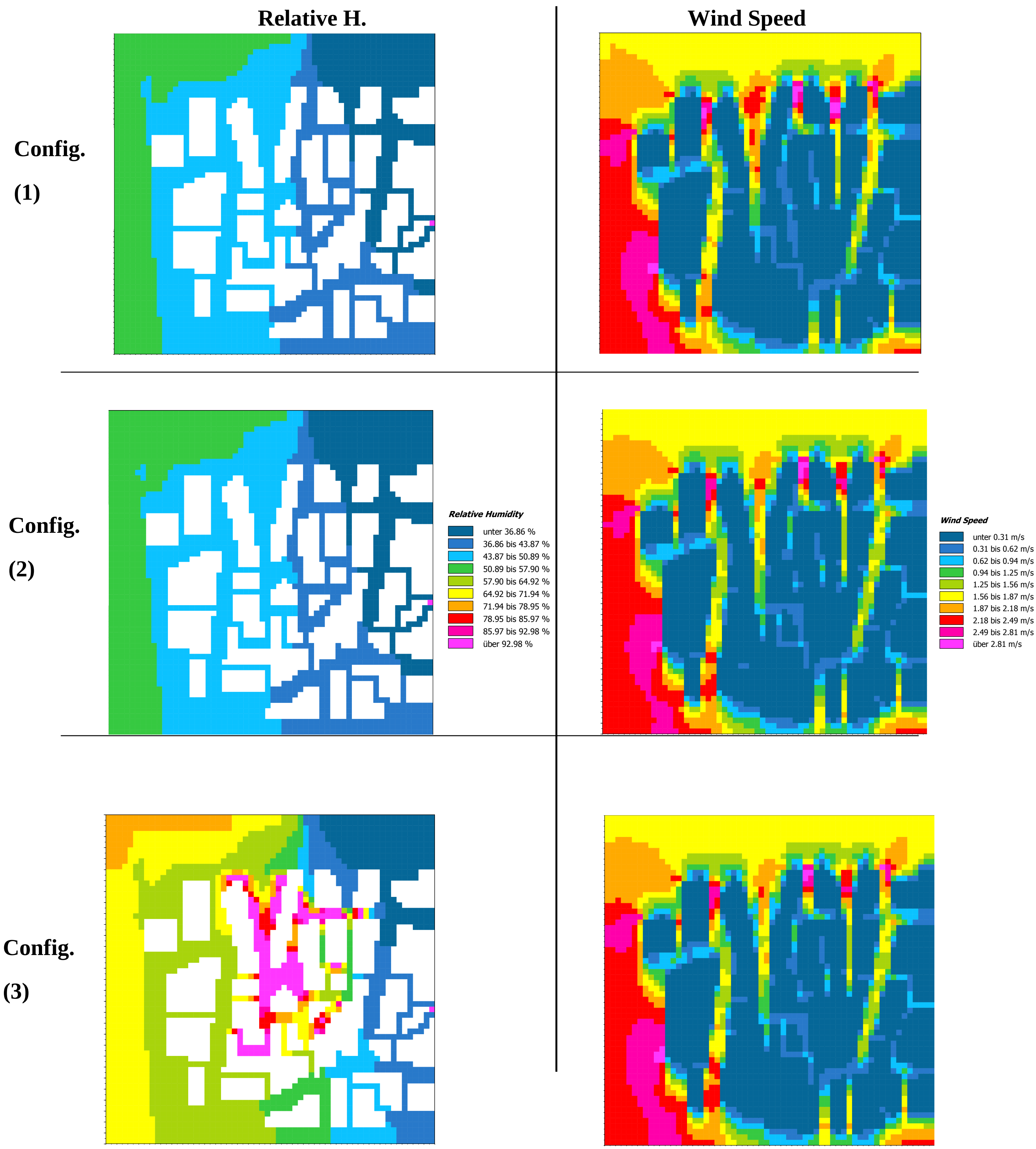


Figure 5.8: Comparison between Configurations 1, 2 and 3 in terms of Relative Humidity and Wind Speed.

Table 5.14: Relative Humidity Averages for Proposed Urban Configurations 1, 2 and 3.

Time	(P3-1)	(P3-2)	(P3-3)
12:00	54.27	50.37	52.9
13:00	52.54	52.32	53.5
14:00	53.90	52.62	52.95
Average RH	53.57	51.77	53.11

Table 5.15: Wind Speed Averages for Proposed Urban Configurations 1, 2 and 3.

Time	(P3-1)	(P3-2)	(P3-3)
12:00	1.81	1.52	1.52
13:00	2.1	1.76	1.61
14:00	1.89	1.65	1.64
Average wind speed	1.92	1.64	1.59

Based on the visualized simulation in Figure 5.8 and the comparison tables of relative humidity and wind speed, Table 5.14 and Table 5.15, it can be seen that relative humidity at 13:00 p.m. was similar in configurations 1 and 2, while the wind speed concentration changed. As can be seen in Figure 5.8, configuration 1 had higher wind load in the northern part, with wind speed varying between 2.18 (m/s) and 2.81 (m/s), while wind speed decreased in configuration 2, due to the addition of trees within the landscaping. Configuration 3 had higher relative humidity at 13:00 p.m., with relative humidity variation from 57.9% up to 85.97%, in comparison to the other configurations that had lower relative humidity, ranging between 36.56% and 57.90%, due to the addition of water elements. The wind speed in configuration 3 was more uniformly distributed in the central location of the studied area.

5.3.2 Selection of Optimal Configuration

Based on the simulations outcomes of the previous section, Table 5.16 summarizes the outcomes of the third phase, taking into consideration that the peak hour of the simulation is presented in the previous section, while the rest of the simulations are presented in Appendix A. The outcomes present the averages of the three main parameters, air temperature, wind speed and relative humidity, for further comparison and analysis of the overall results of this phase.

Table 5.16: Average Air Temperature, Wind Speed and Relative Humidity of the Optimized Configurations.

Landscaping and vegetation	Average air temperature	Average wind speed	Average relative humidity
1- Grass	33.19	1.92	53.57
2- Grass and trees	33.34	1.64	51.77
3- Grass, trees and water elements	32.97	1.59	53.11

Table 5.16 reveal that configuration 3 shows the lowest air temperature and configuration 2 had the highest air temperature, with a difference of 0.37°C between the two configurations. Moreover, configuration 3 shows the lowest average wind speed of 1.59 (m/s), while the highest wind speed was in configuration 1, which had an average wind speed of 1.92 (m/s), due to the addition of trees that partially block direct wind flow and sunlight in the urban form. Configuration 2 had the least relative humidity, with an average of 51.77%, while the average humidity increase in configuration 3 was up to 53.11%, due to the addition of water elements within the landscaping.

Based on the results obtained in this chapter, the following section will provide observations regarding the nine configurations, in comparison to the base case and the DM proposal, with discussion of the causes of these findings. The results analysis focuses on understanding air temperature behavior. The main aim was to increase thermal comfortability through the reduction of air temperature on July 21st during the peak hours. The trials presented shaped the new urban form, in which building heights, forms and landscaping were taken into consideration to maintain thermal behavior in one of the most vital locations in Dubai. Table 5.17 presents the comparison between the optimum design proposed, and the DM proposal and the base case.

Table 5.17: Averages of Air Temperature, Wind Speed and Relative Humidity of the Base Case, DM Proposal and Optimum Design.

Design	Average air temperature	Average wind speed	Average relative humidity
A: Base case	39.35	1.09	62.5
B: DM proposal	38.34	1.05	50.66
C: Optimum design	32.97	1.59	53.11

It can be seen from the previous analysis that the optimum proposed design had the lowest average air temperature, compared to the DM proposal in which there was 5.37°C difference in air temperature, which reached a difference of 6.38°C compared to the base case. In terms of wind speed, which is considered the second most important parameter measuring thermal comfort, Table 5.17 shows that design C, which is the optimum design, has the highest average wind speed, compared to the DM proposal, with a difference of 0.54 (m/s); in comparison to the base case, there is a different of 0.50 (m/s). In terms of the average relative humidity, the DM proposal had the lowest average humidity, while the optimum design had the highest, with a difference of 2.45%, due to the addition of the water element within the landscaping and vegetation form in the optimum design.

In the end, two important results can be concluded, namely that urban form and height play a key role in improving thermal comfort, through improving wind speed, which consequently improves the air temperature. Moreover, landscaping is one of the important factors that should be considered in high-density to medium-density areas, due to its capability of maintaining thermal comfort through the enhancement of microclimatic variables, which include wind speed and direct sun radiation.

6. Conclusion

6.1 Conclusion

It is very important for urban planners to focus on walkability as a major aim to achieve sustainability, since it has social, economic and environmental influences. In Dubai there are several governmental mitigations to enhance sustainable development, while there were very few proposals to enhance walkability within the city overall, due to the high temperatures during summer. On the other hand, Dubai has strong transit structures that can be optimized in order to enhance walkability in the city districts. In this research, the main motivation was to enhance walkability within the urban form, through the reduction of air temperature, to maximize the usage of outdoor spaces within the city. In order to utilize the outdoor open spaces, it was important to analyze previous studies and experiments in order to achieve thermal comfort within the micro level of the CBD area in Dubai.

Different parameters were considered to analyze comprehensively which of the parameters had the most effect in lowering temperatures. The proposed parameters were configured based on the selected study site, where the configurations included the optimization of urban form, the optimization of building height, and the optimization of landscaping and vegetation, to enhance thermal comfort within the walkable area and open spaces. ENVI modelling was used to simulate the air temperature, wind speed and relative humidity for each urban configuration. Several proposals were simulated, based on the previous literature review recommendations in which simulations were investigated and compared with each other, to conclude the optimum design within a specific configuration.

First, a simulation run was to investigate the Dubai Municipality (DM) proposal and the base case, in which it was concluded that the DM proposal had better average air temperature, wind speed and relative humidity than the base case. Second, the DM proposal was compared with the outcomes of three urban configurations on building form, which led to the selection of configuration E that had the lowest air temperature and relative humidity compared to the base case, the DM proposal and proposed configurations. Third, in Phase 2, configuration E was simulated with three different height scenarios to be compared with the DM proposal and the base case.

Finally, landscaping and vegetation was investigated in the third phase, by setting three trials to select the optimum configuration with the lowest air temperature.

Referring to the previous chapter and based on the building form simulation in Phase 1, it was concluded that building form does affect wind speed and relative humidity results directly, showing a difference of 0.5 (m/s) in wind speed between the optimal building form and other proposed forms. Also, there was a difference in relative humidity averages, in which the optimal configurations had the least humidity, showing 5% difference with other configurations. Air temperature showed minor changes between the optimized configuration and other configurations, due to the effectiveness of building form on the macro scale.

The optimal design of the urban form was form E, which focused on creating wind channels to enhance wind speed within the urban form. Urban planners should focus on analyzing the wind orientation, and should consider it as the main aspect in shaping the urban form. The formation of wind channels did enhance the microclimate within the urban form, which resulted in lowering the air temperature and increasing wind speeds compared to other building forms within the same phase.

Several configurations were proposed for building heights in the second phase, which included investigating two uniform heights, and different heights based on the recommendations of previous studies. The simulations revealed that the optimal building height was the configuration of different storeys, which was a variation of different heights between 6 m and up to 30 m. The simulated wind speed was the highest, which caused to a reduction in relative humidity that led to a lower air temperature.

The variation of building height not only affects the air temperature and wind speed, but also affects the shading of buildings on open spaces or on other buildings. For example, if high-rise buildings are concentrated in a high-density area, there will be so little sun exposure at street level, which will cause other issues such as the need for pedestrian lighting, and limiting the use of threes and landscaping.

The third phase revealed the greatest air temperature differences, compared to the first and second phases. Phase 3 concentrated on the implementation of landscaping and vegetation. The third configuration in the third phase provided the best cooling effect in comparison to the other two configurations. Configuration three included the implementation of grass, trees and water elements, with an average air temperature of 32.97°C at the peak hours on July 21st from 12:00 p.m.till 15:00 p.m.

Urban planners and designers in Dubai should focus on landscaping and vegetation to maintain thermal comfort on the micro and macro scale. Landscaping and vegetation play a significant role in enhancing walkability by providing trees for shading, grass for reducing the surface radiation, as well as water elements to enhance the evaporative cooling. Moreover, landscaping and vegetation make positive contributions on the macro scale, including the enhancement of the ecosystem and the environment.

The analysis of the outcomes of Phase 1, Phase 2 and Phase 3 shows that thermal comfort is influenced by building form, height and landscaping. These factors, if achieved, mean that a healthier community will be developed that focuses on the enhancement of walkability within the urban form. The results of this study can be considered as design guidelines for urban planners in Dubai, or cities that have a similar climate to Dubai. The design guidelines include the following:

- Urban planners and designers should focus on analyzing the relationship between urban form, building height, open space proportions, landscaping and vegetation, and their influences on the micro climate.
- Shading should be distributed in open spaces and walkways to maximize the usage of outdoor spaces.
- Landscaping should be considered with a combination of grass, trees and water elements.
- Wind direction should be utilized and oriented towards open spaces.
- Trees act as wind barriers, and so should be utilized in spaces with high wind speed.
- It is essential to simulate proposed developments and analyze outdoor parameters before they are chosen and applied.

6.2 Recommendations for Future Work

The outcomes of this research could be utilized for developing future research which includes:

1. Exploring the effect of different urban forms and heights within the larger urban area to analyze the macro climate difference;
2. Investigating road size and studying orientation to explore the effect of enlarging the road size and its effect on the urban form of the city, as well as to compare the results or road sizes obtained in this research;
3. Extending the duration of simulation to include the coolest day in winter;
4. Investigating the building materials and their effect on the micro climate within walkable districts;
5. Investigating the effects of the configurations mentioned in the research on low- and high-density developments;
6. Studying further regulations to be proposed by the government to enhance the micro climate and thermal comfort to enhance walkability;
7. Investigating wind speed parameters with similar forms proposed in this research to be simulated in other locations with different climate data; and
8. Establishing a research department at UAE that combines environment with urban planning to enhance the linkage between the two fields.

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Appendices

Appendix A: phase 1 configuration (A) simulation from 12:00 p.m. till 15:00 p.m. for the following parameters: wind speed, air temperature and relative humidity.

Appendix B: Phase 2 the three configurations simulation from 12:00 p.m. till 15:00 p.m. for the following parameters: wind speed, air temperature and relative humidity.

Appendix C: Phase 3 the three configurations simulation from 12:00 p.m. till 15:00 p.m. for the following parameters: wind speed, air temperature and relative humidity.

Appendix A: phase 1 configuration (A) simulation from 12:00 p.m. till 15:00 p.m. for the following parameters: wind speed, air temperature and relative humidity.

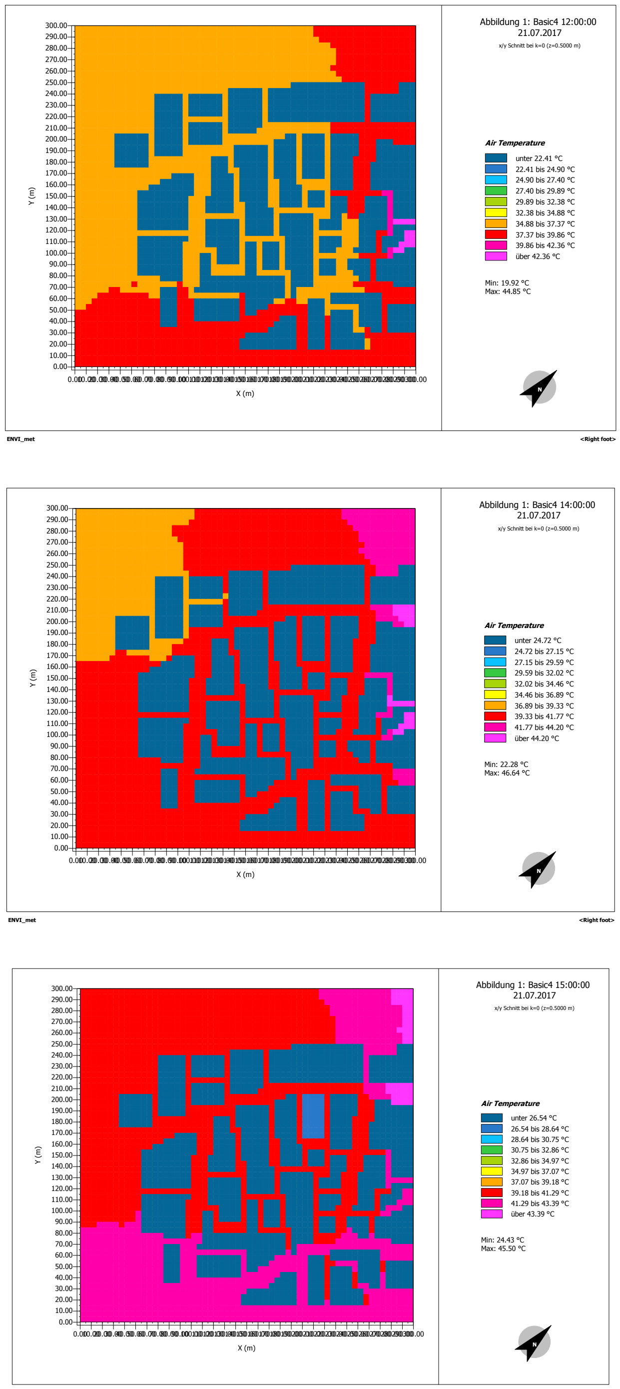
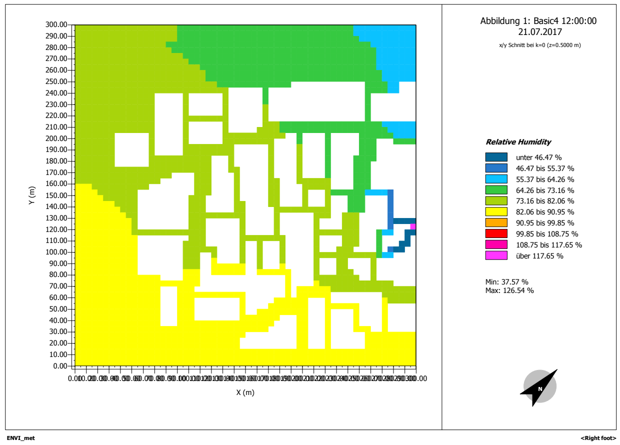
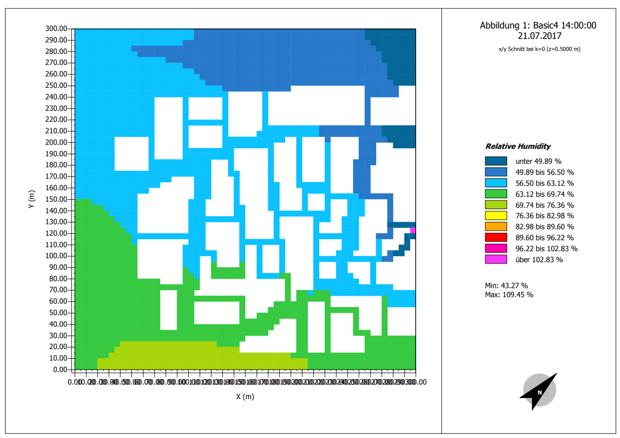


Figure A.1: Air temperature simulation for configuration A.





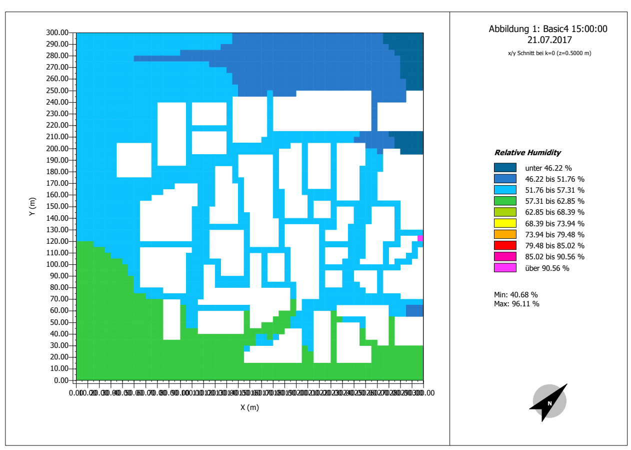


Figure A.2: Relative humidity simulation for configuration A.

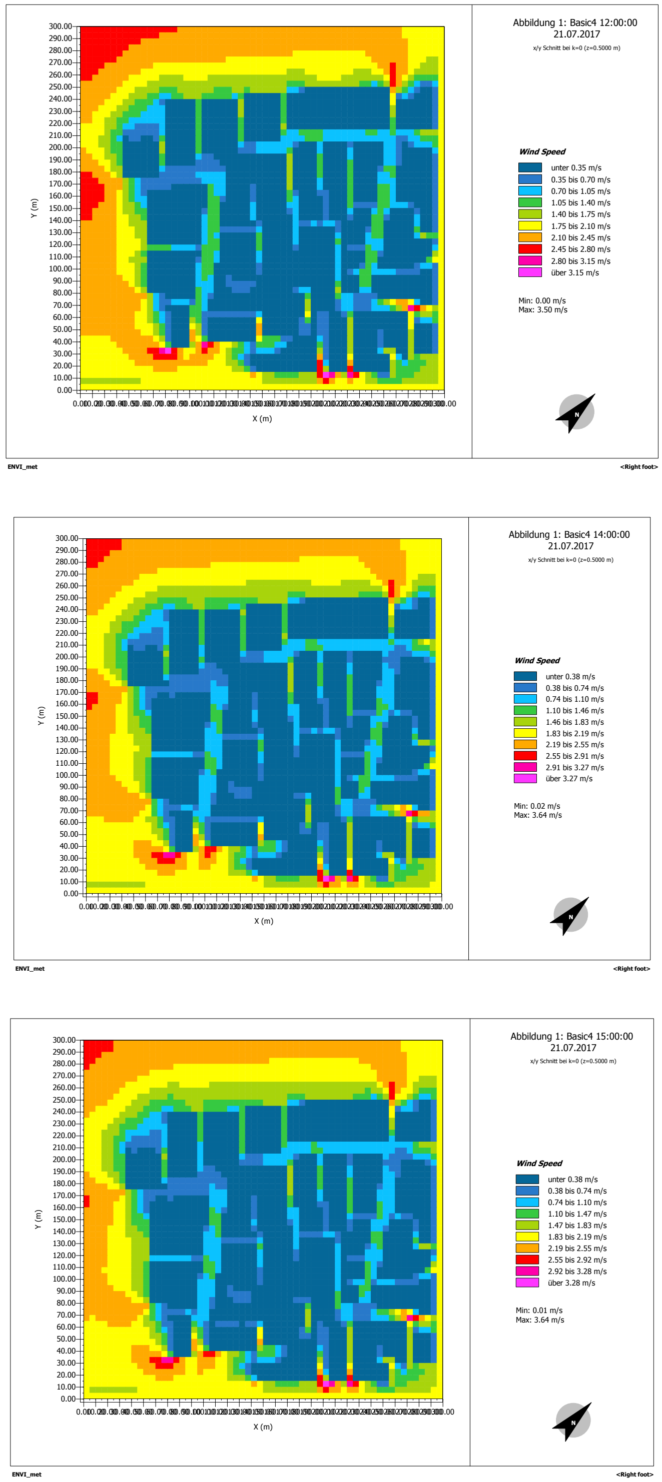


Figure A.3: Wind speed simulation for configuration A.

Appendix B: Phase 2 the three configurations simulation from 12:00 p.m. till 15:00 p.m. for the following parameters: wind speed, air temperature and relative humidity.

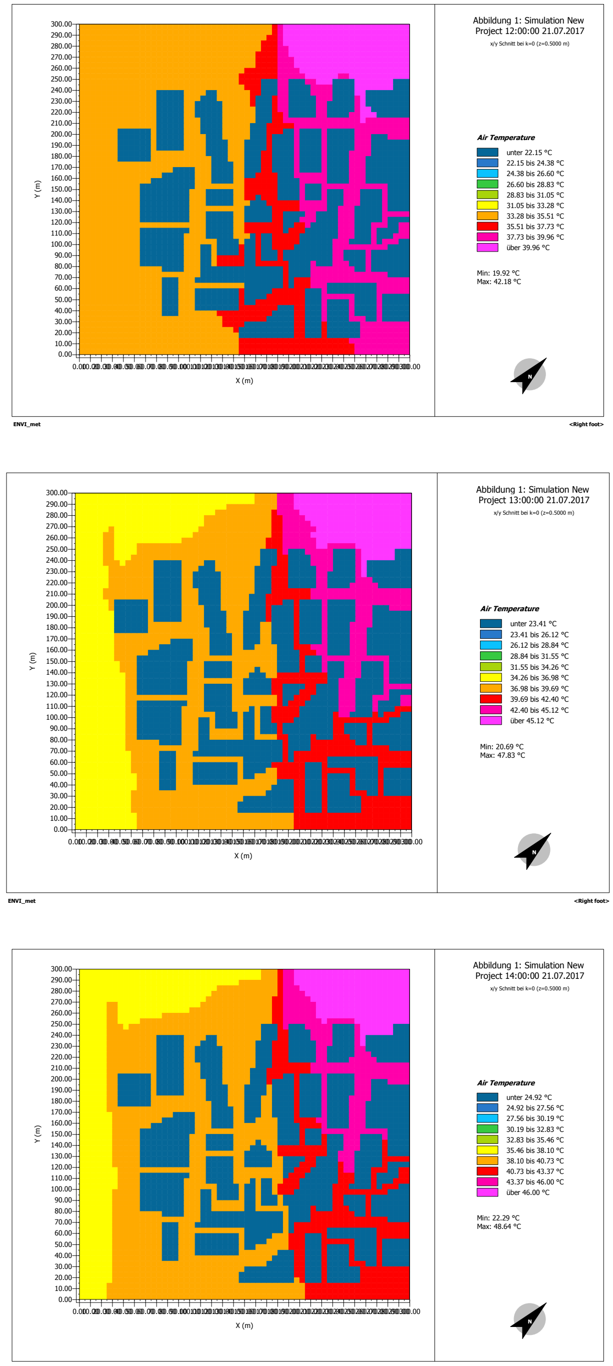
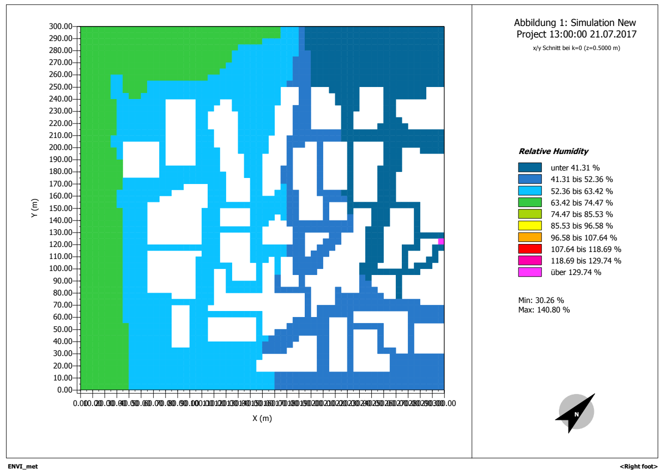
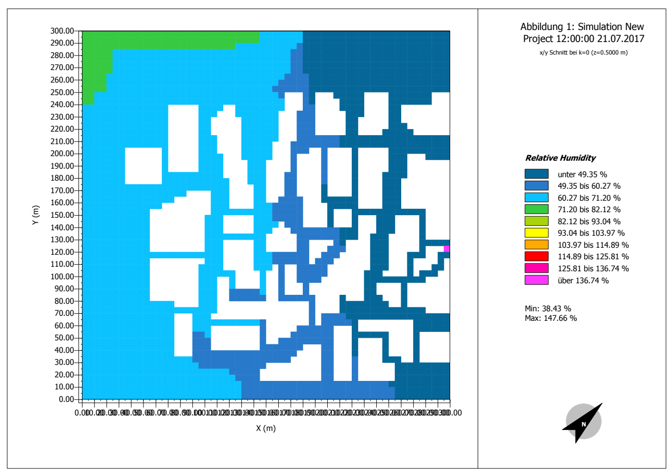


Figure B.1: Air temperature simulation for configuration 1 in phase 2.





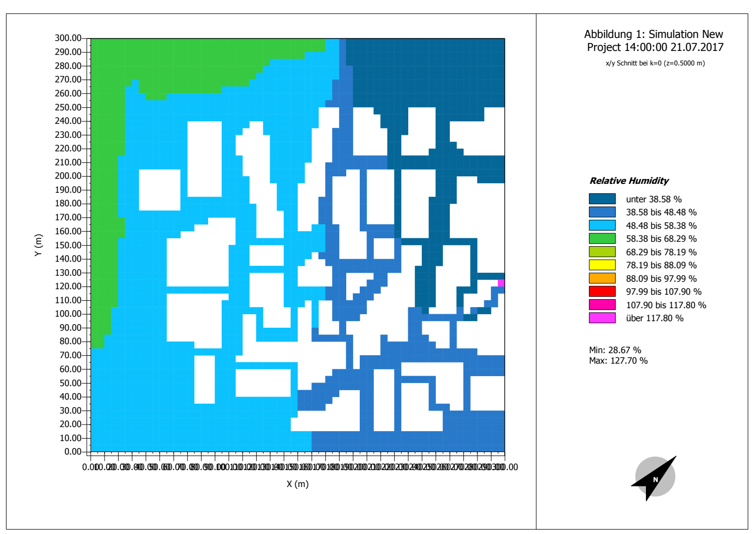


Figure B.2: Relative humidity simulation for configuration 1 in phase 2.

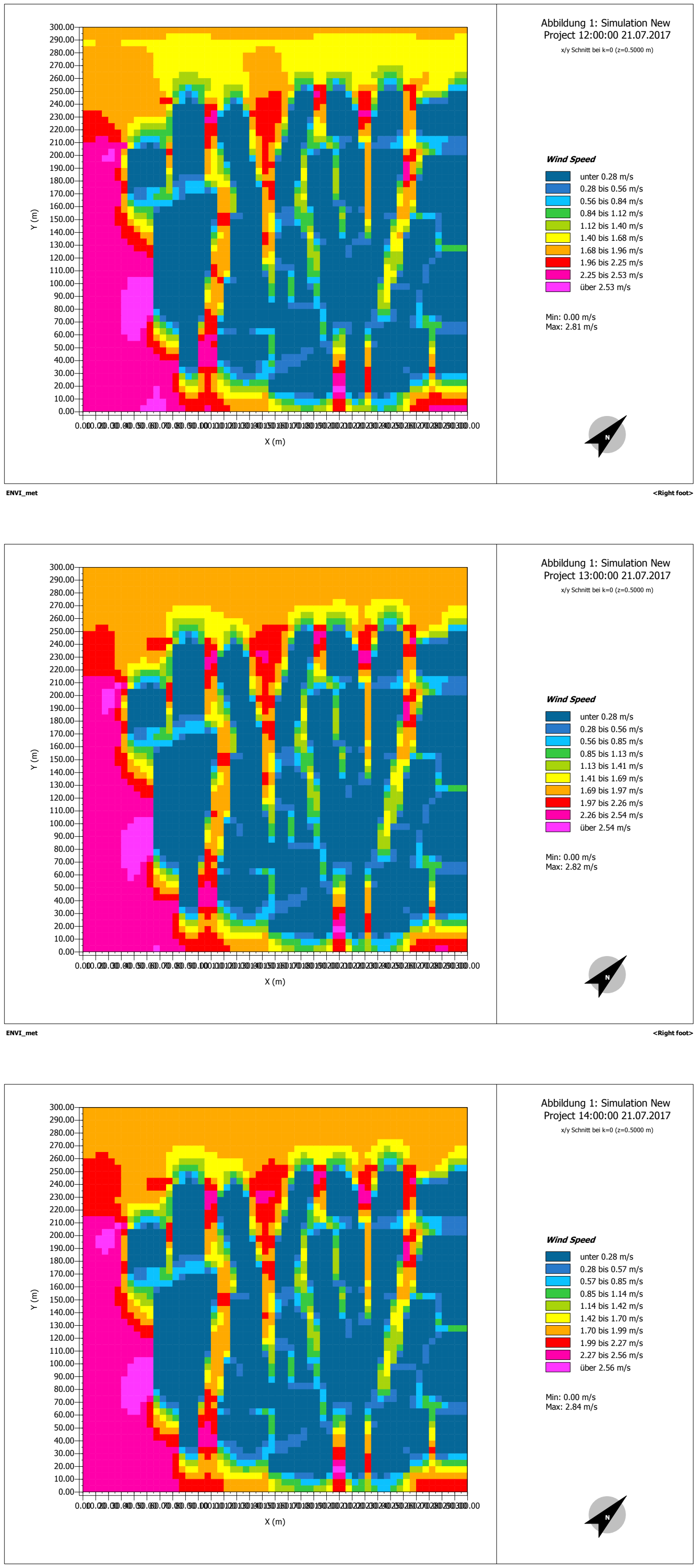
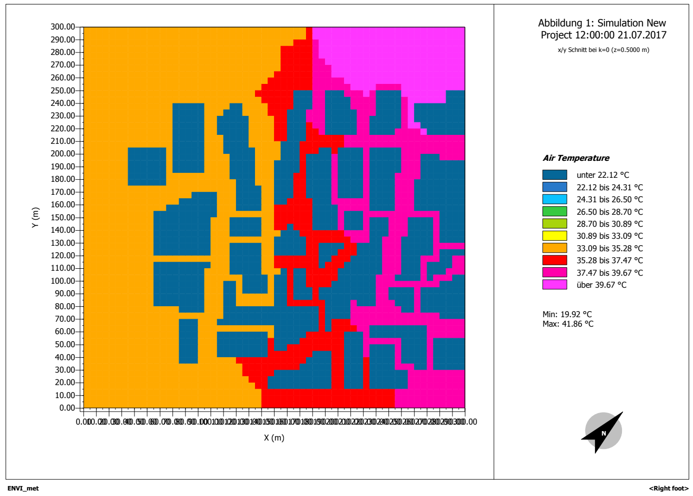
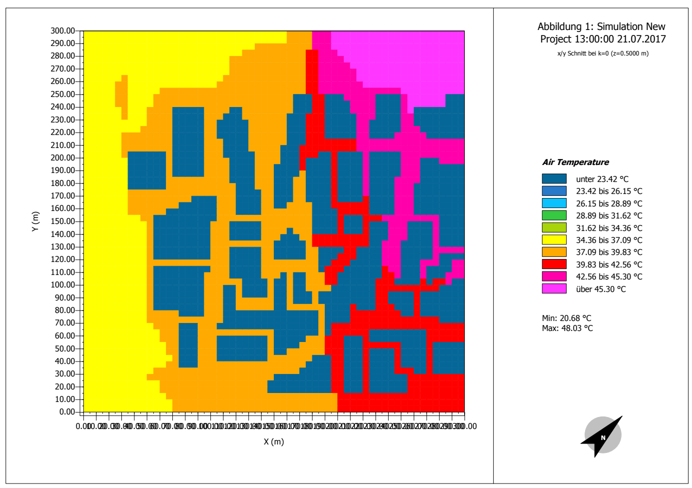


Figure B.3: Air speed simulation for configuration 1 in phase 2.





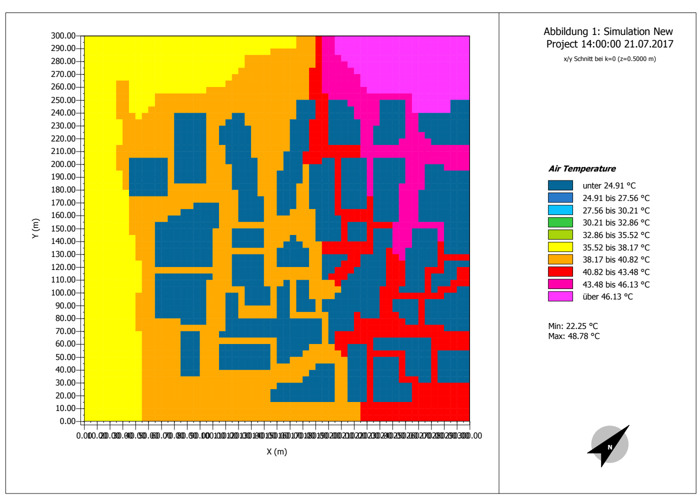
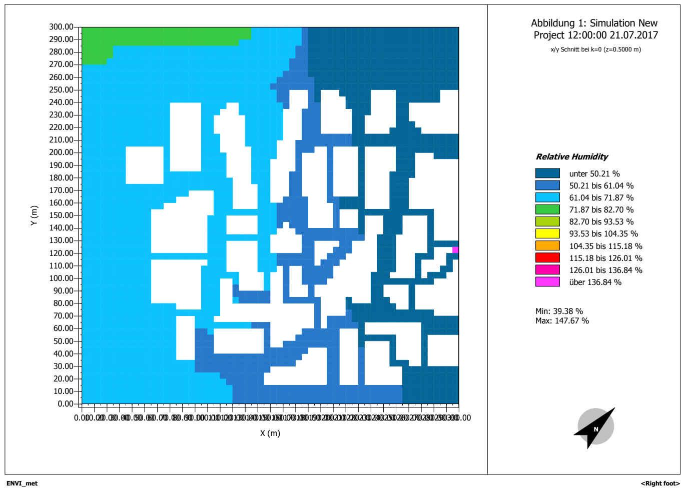
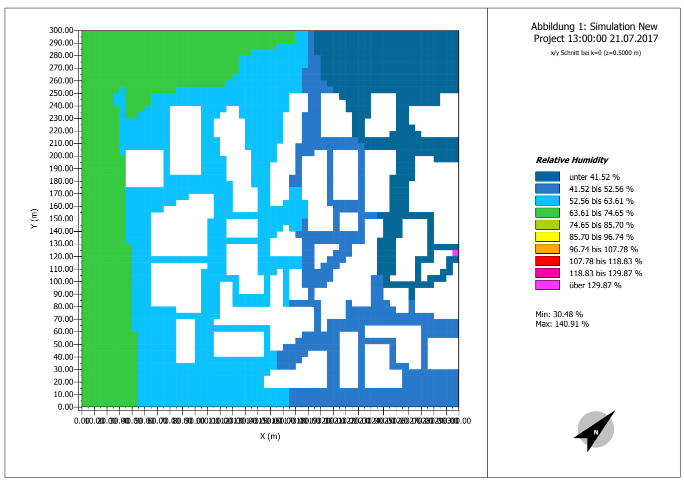


Figure B.4: Air temperature simulation for configuration 2 in phase 2.





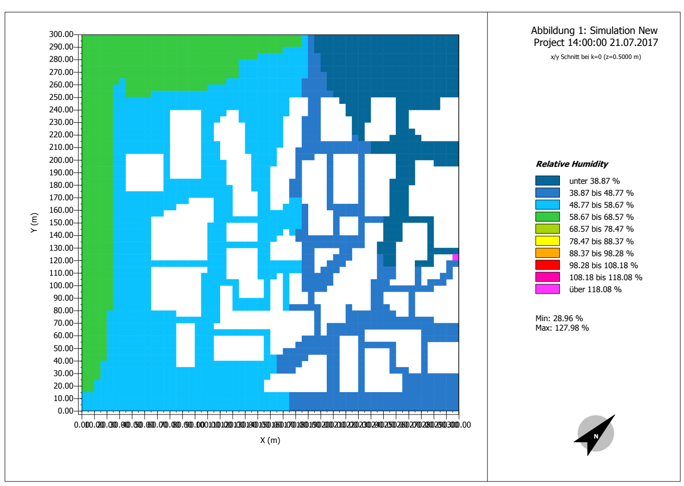


Figure B.5: Relative Humidity simulation for configuration 2 in phase 2.

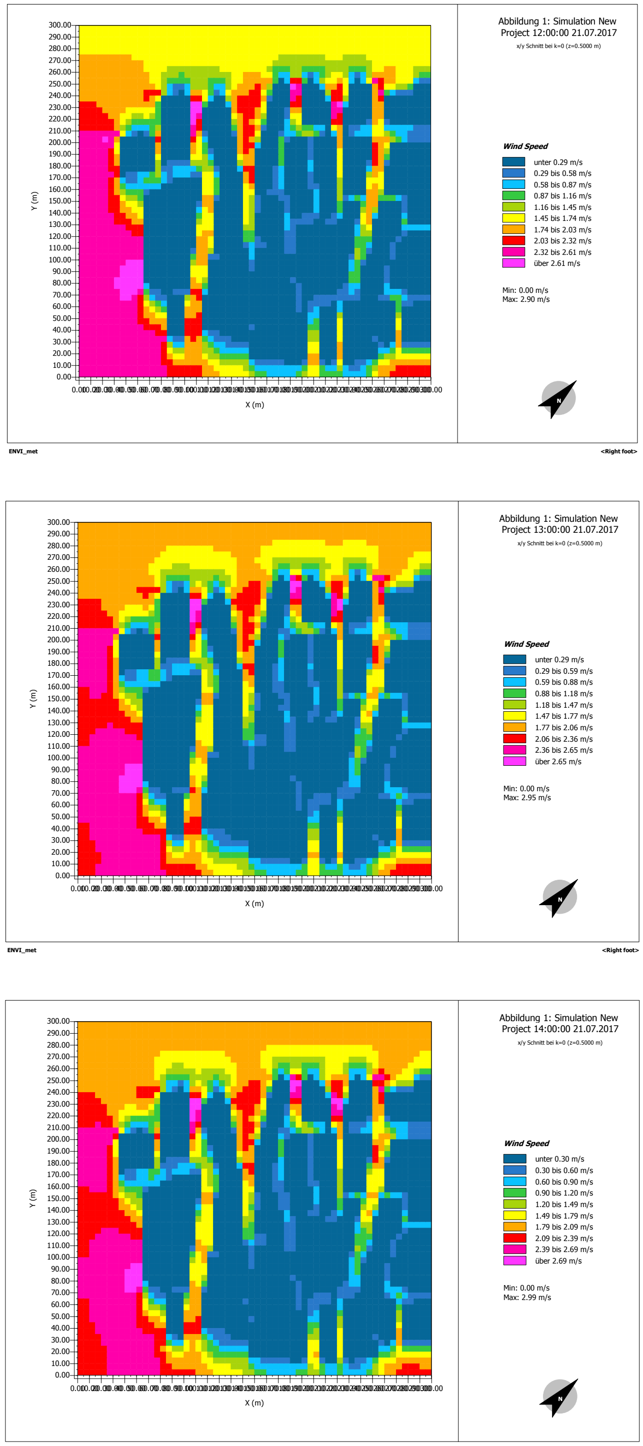


Figure B.6: Wind speed simulation for configuration 2 in phase 2.

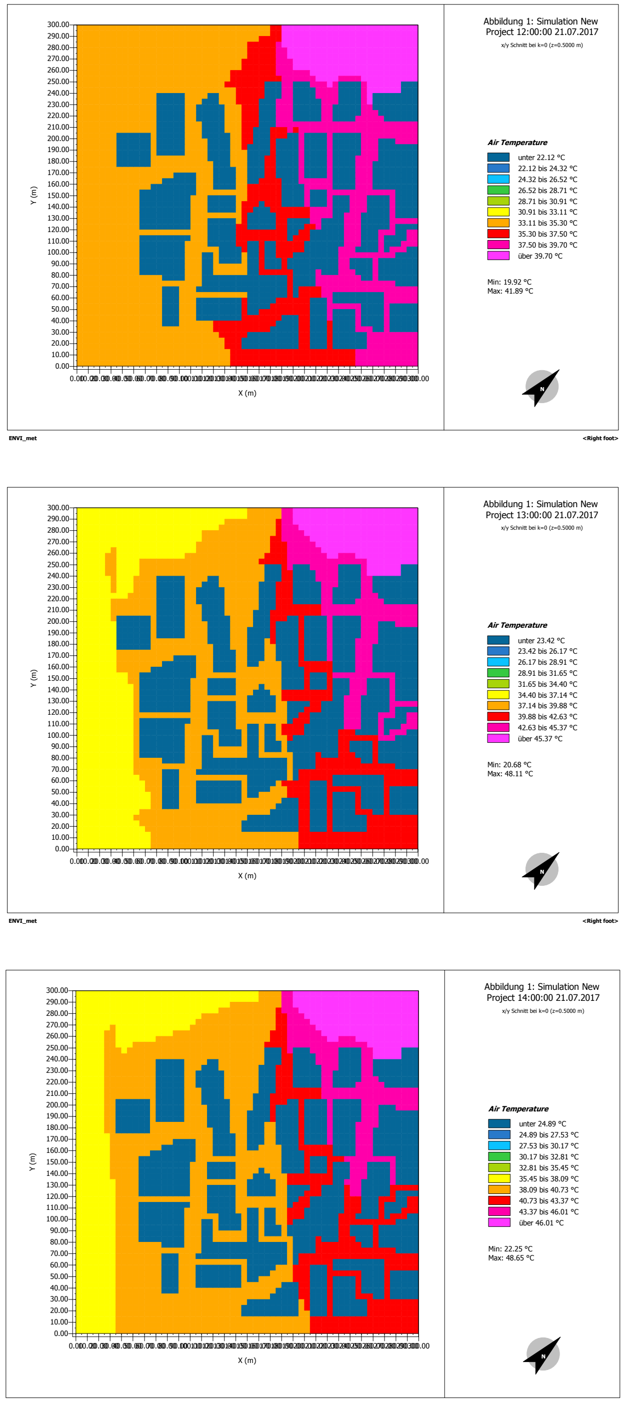
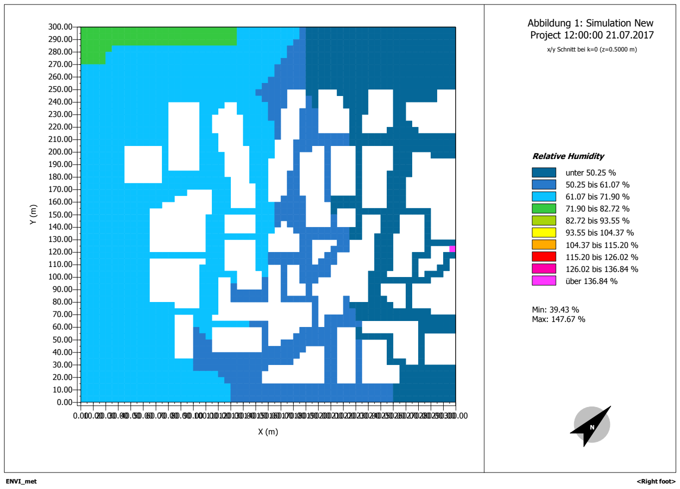
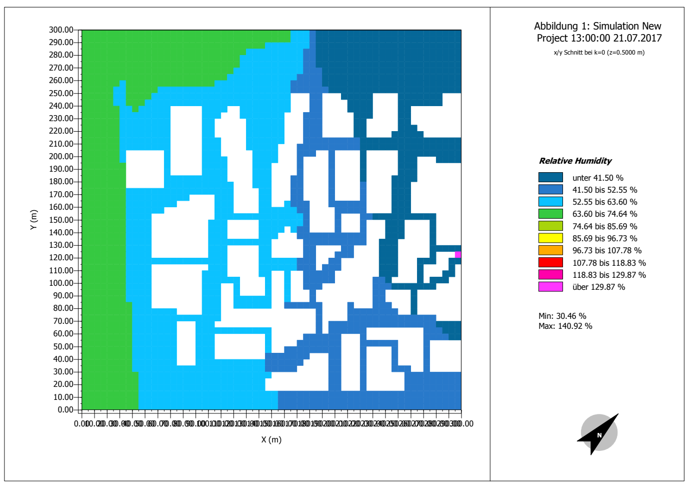


Figure B.7: Air temperature simulation for configuration 3 in phase 2.





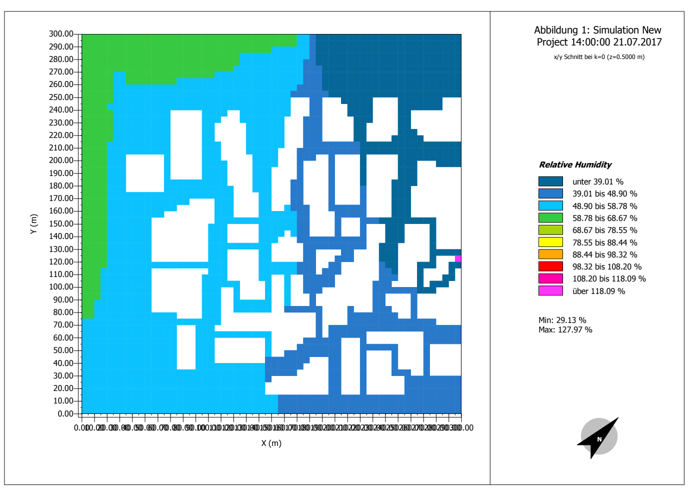


Figure B.8: Relative humidity simulation for configuration 3 in phase 2.

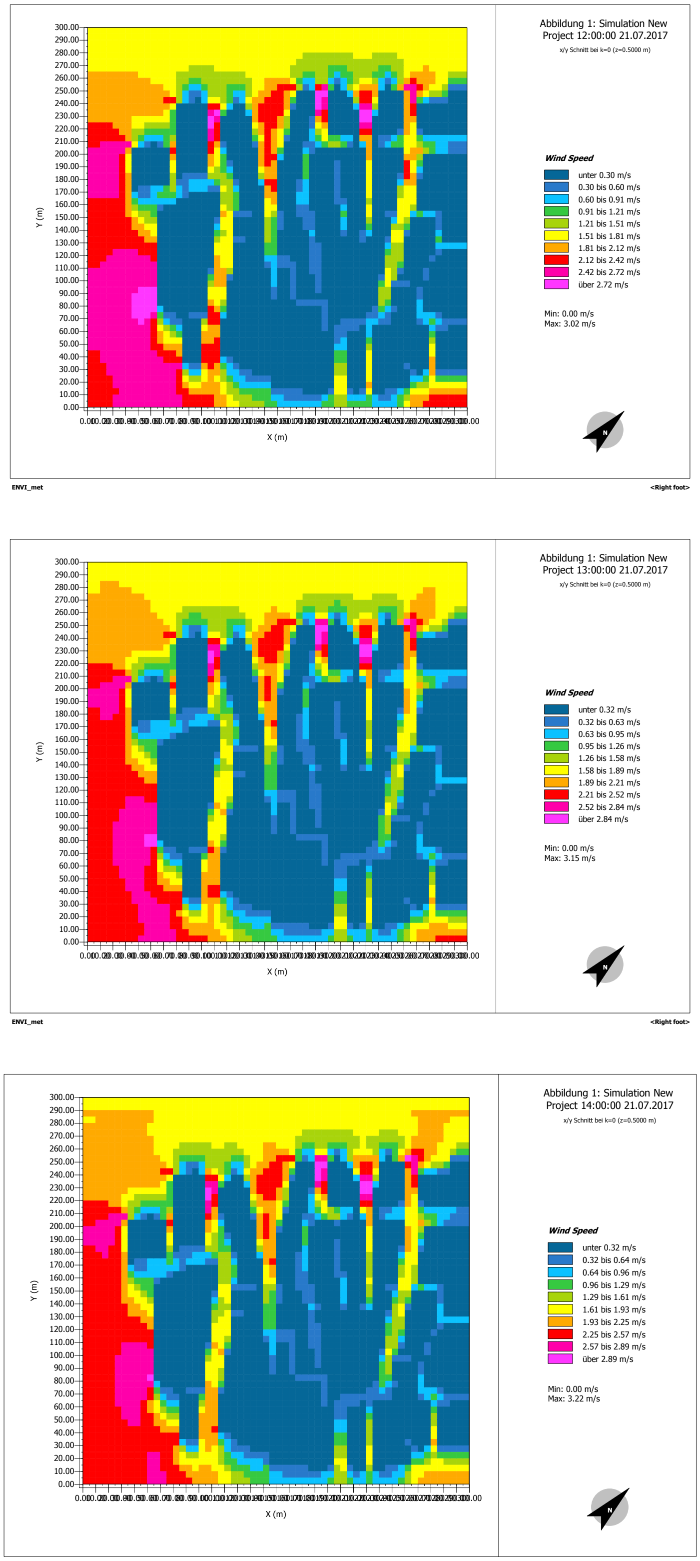


Figure B.9: Wind speed simulation for configuration 3 in phase 2.

Appendix C: Phase 3 the three configurations simulation from 12:00 p.m. till 15:00 p.m. for the following parameters: wind speed, air temperature and relative humidity.

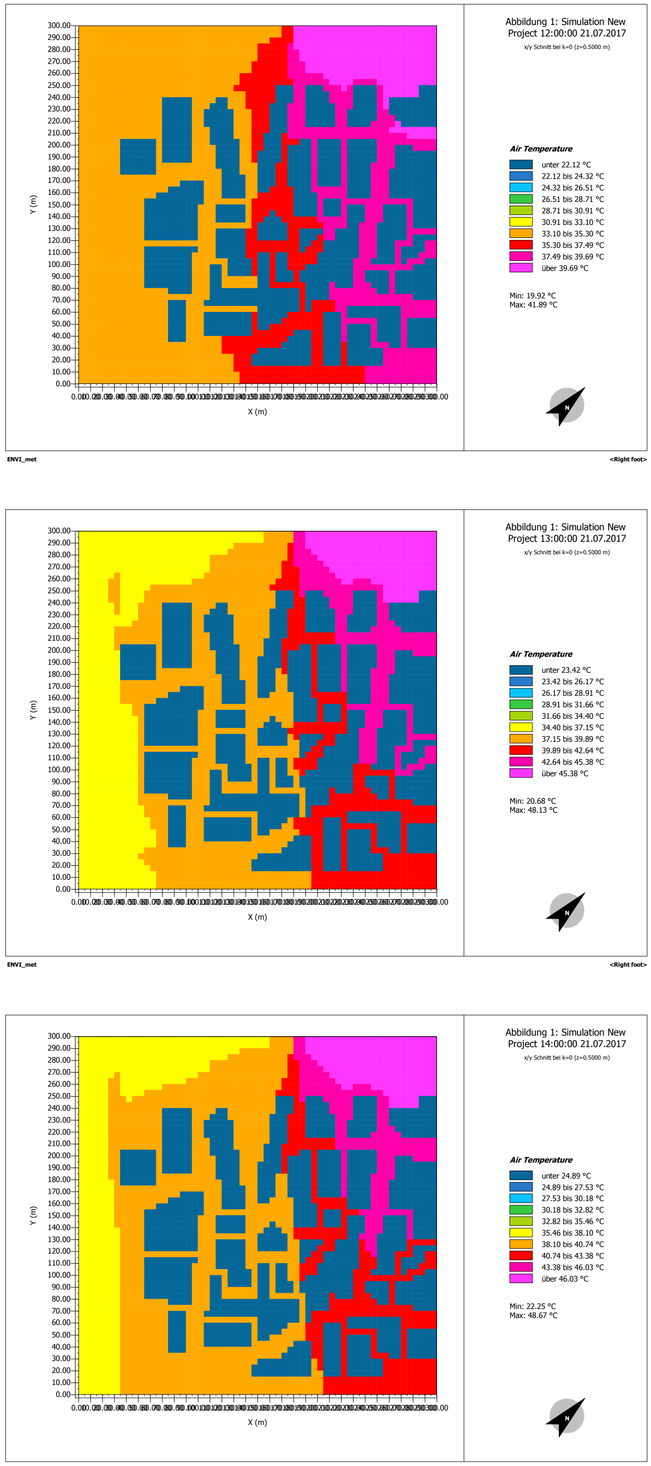


Figure C.1: Air temperature simulation for configuration 1 in phase 3.

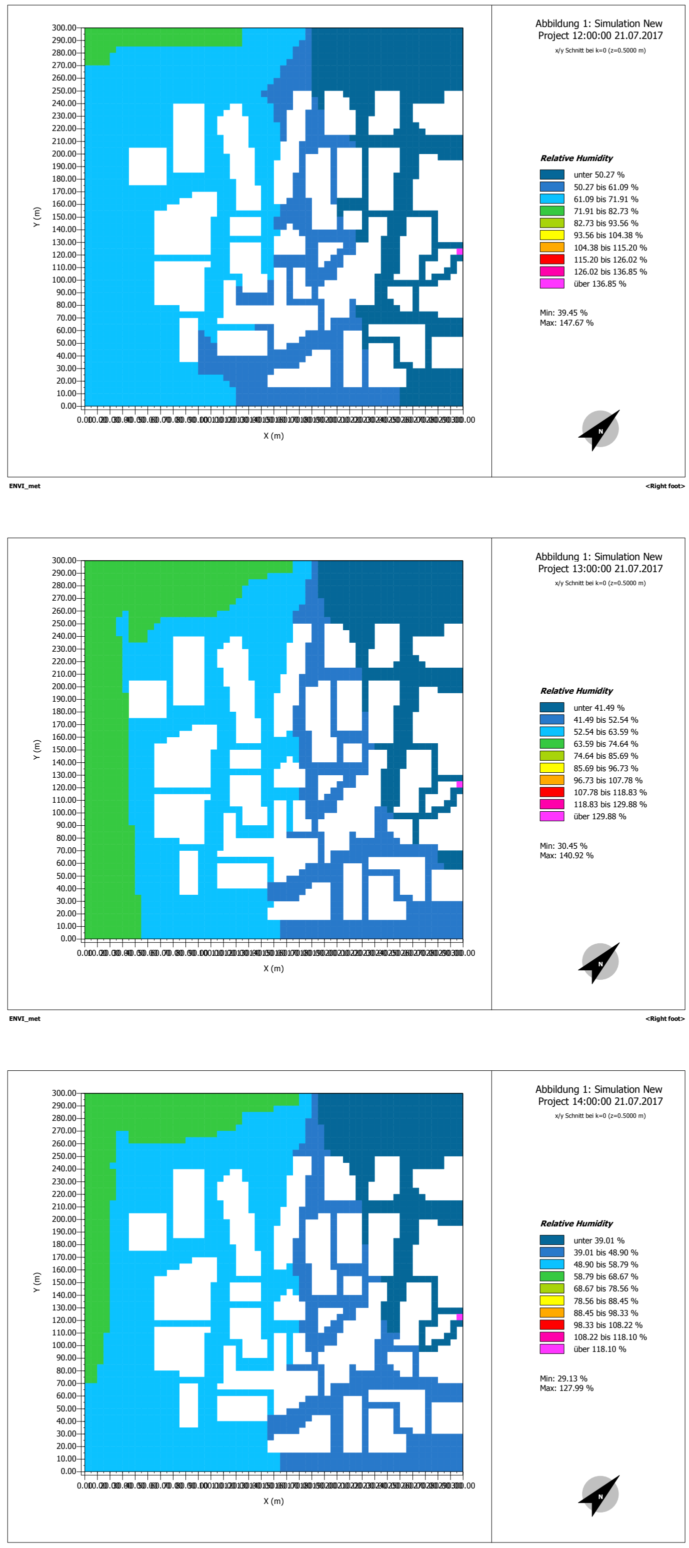
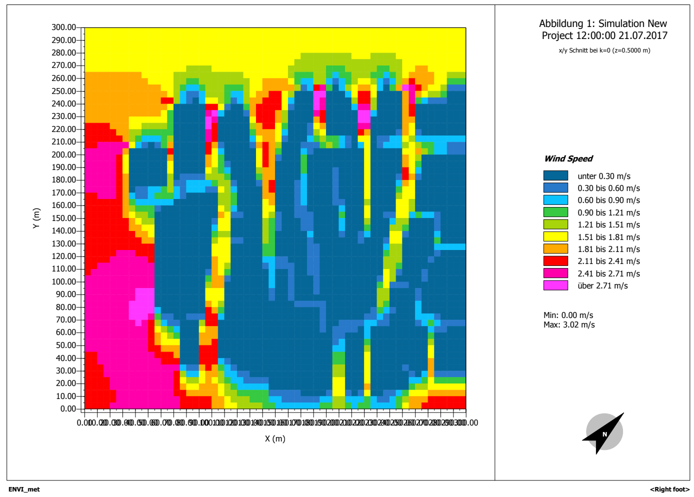
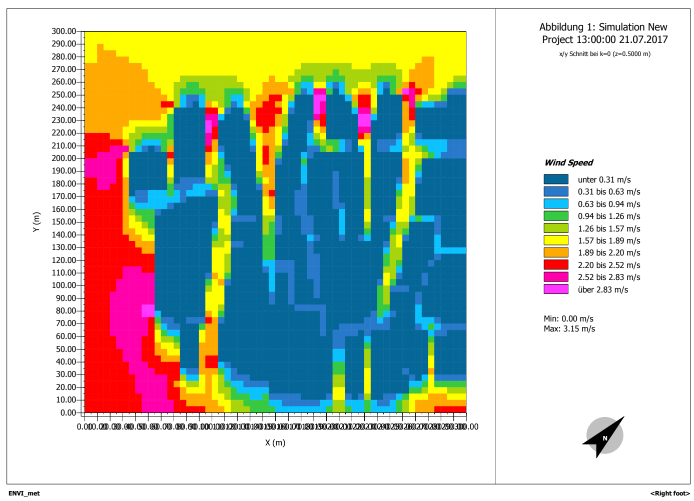


Figure C.2: Relative humidity simulation for configuration 1 in phase 3.





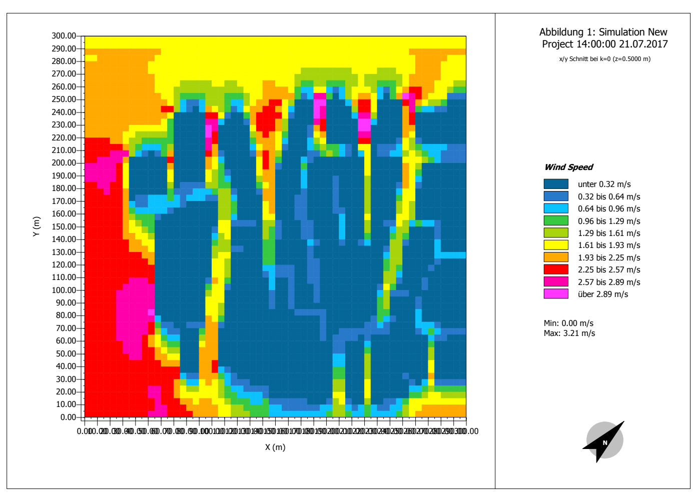
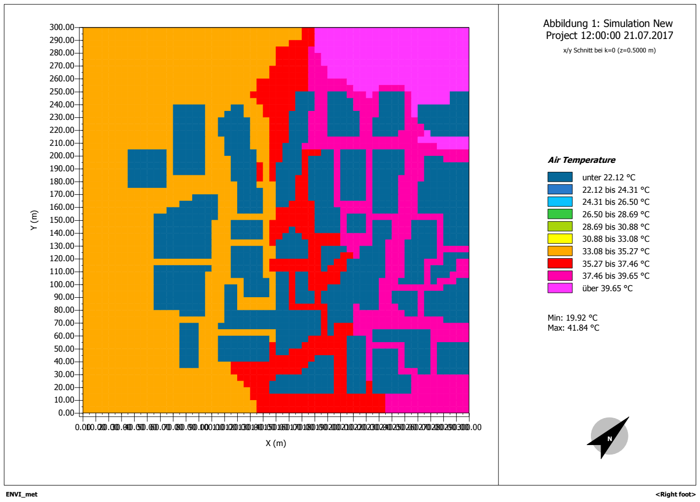
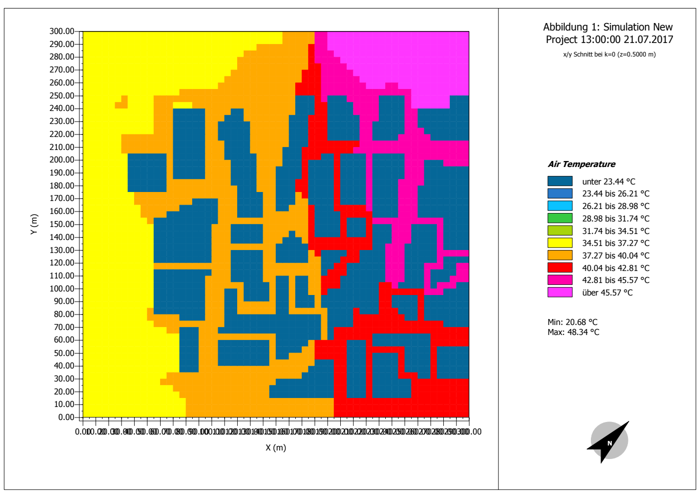


Figure C.3: Wind speed simulation for configuration 1 in phase 3.





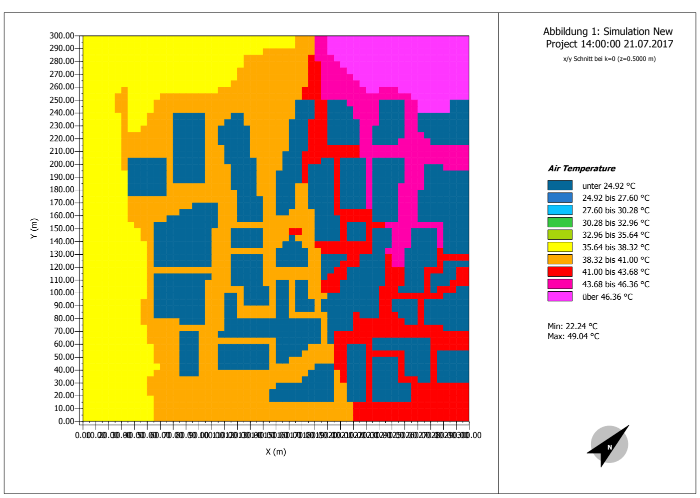


Figure C.4: Air temperature simulation for configuration 2 in phase 3.

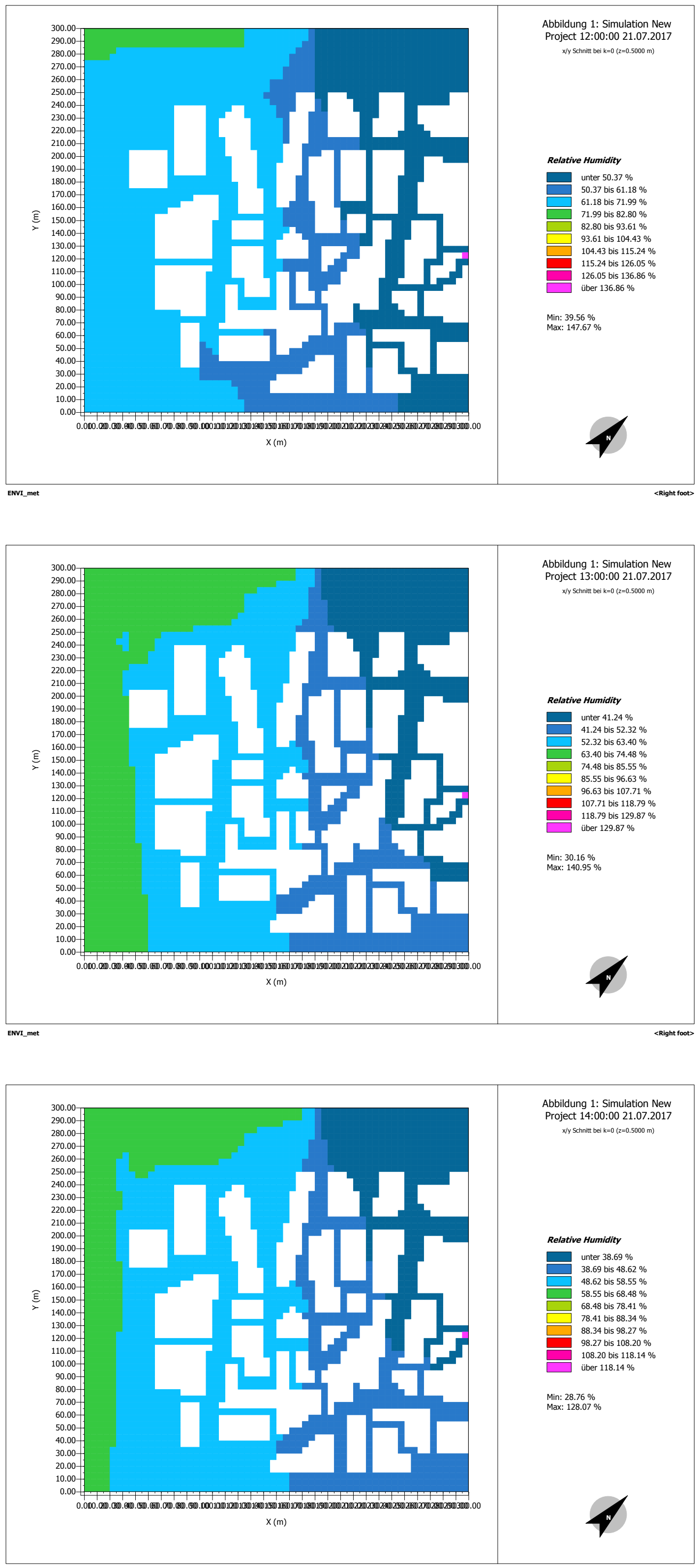


Figure C.5: Relative humidity simulation for configuration 2 in phase 3.

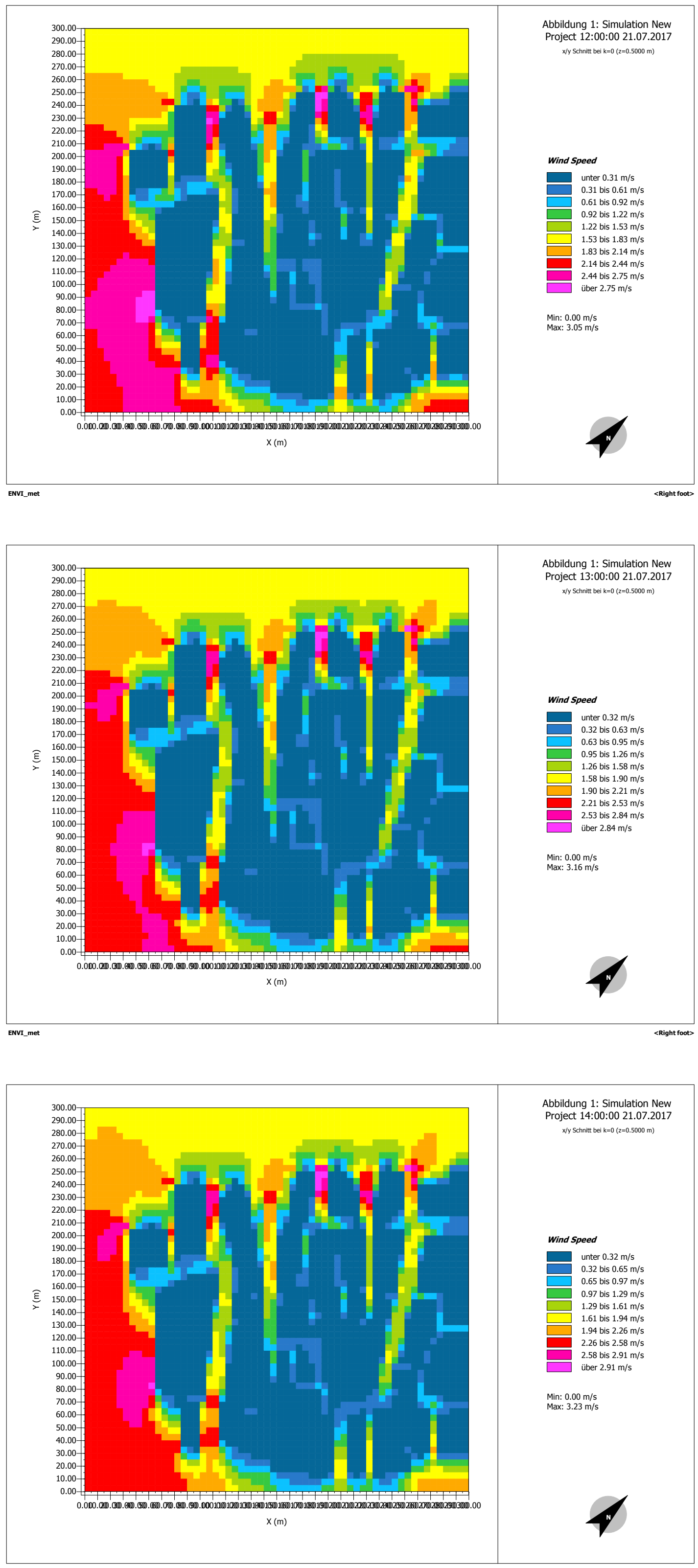
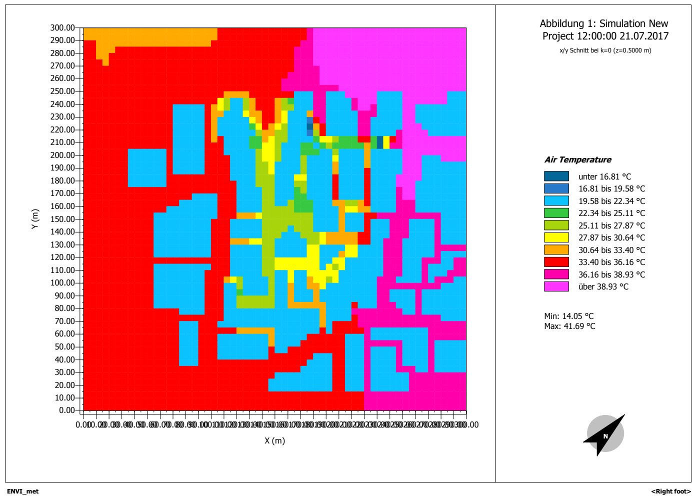
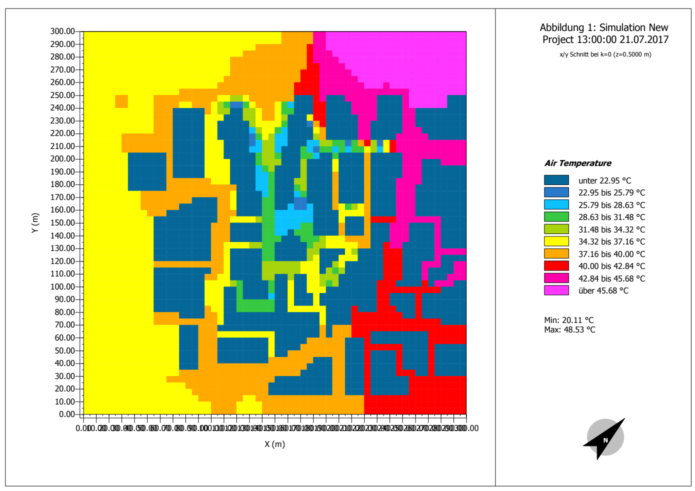


Figure C.6: Wind speed simulation for configuration 2 in phase 3.





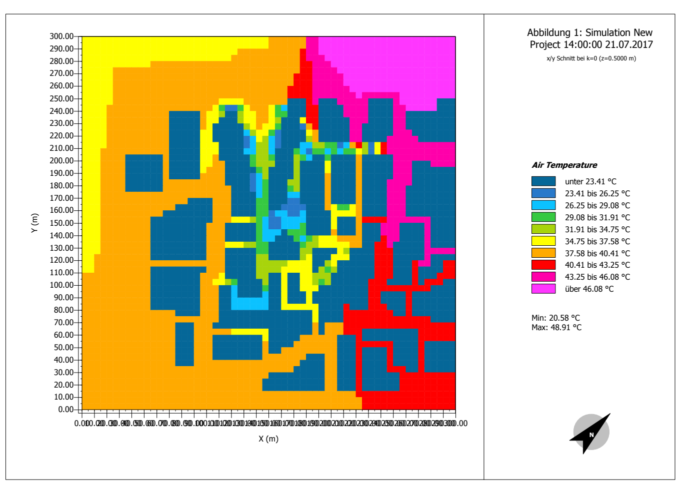


Figure C.7: Air temperature simulation for configuration 3 in phase 3.

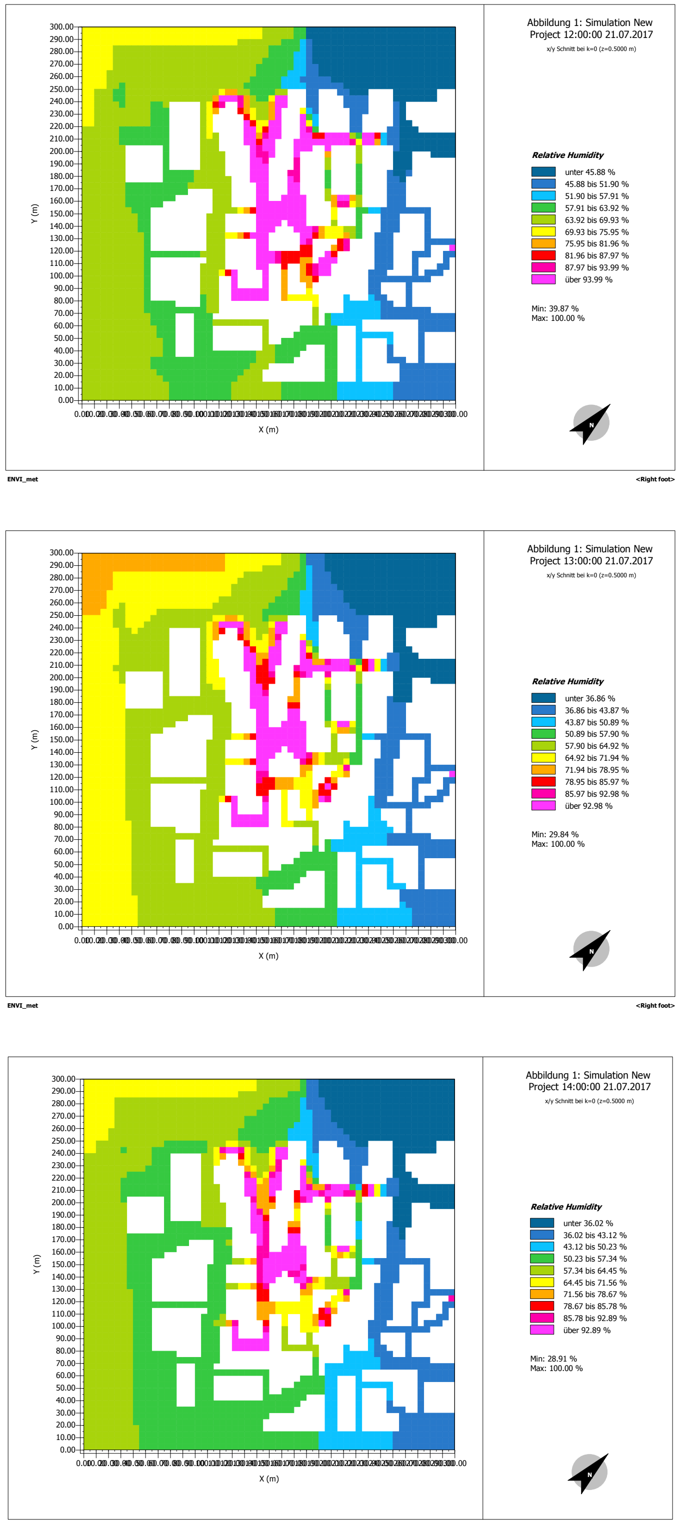


Figure C.8: Relative humidity simulation for configuration 3 in phase 3.

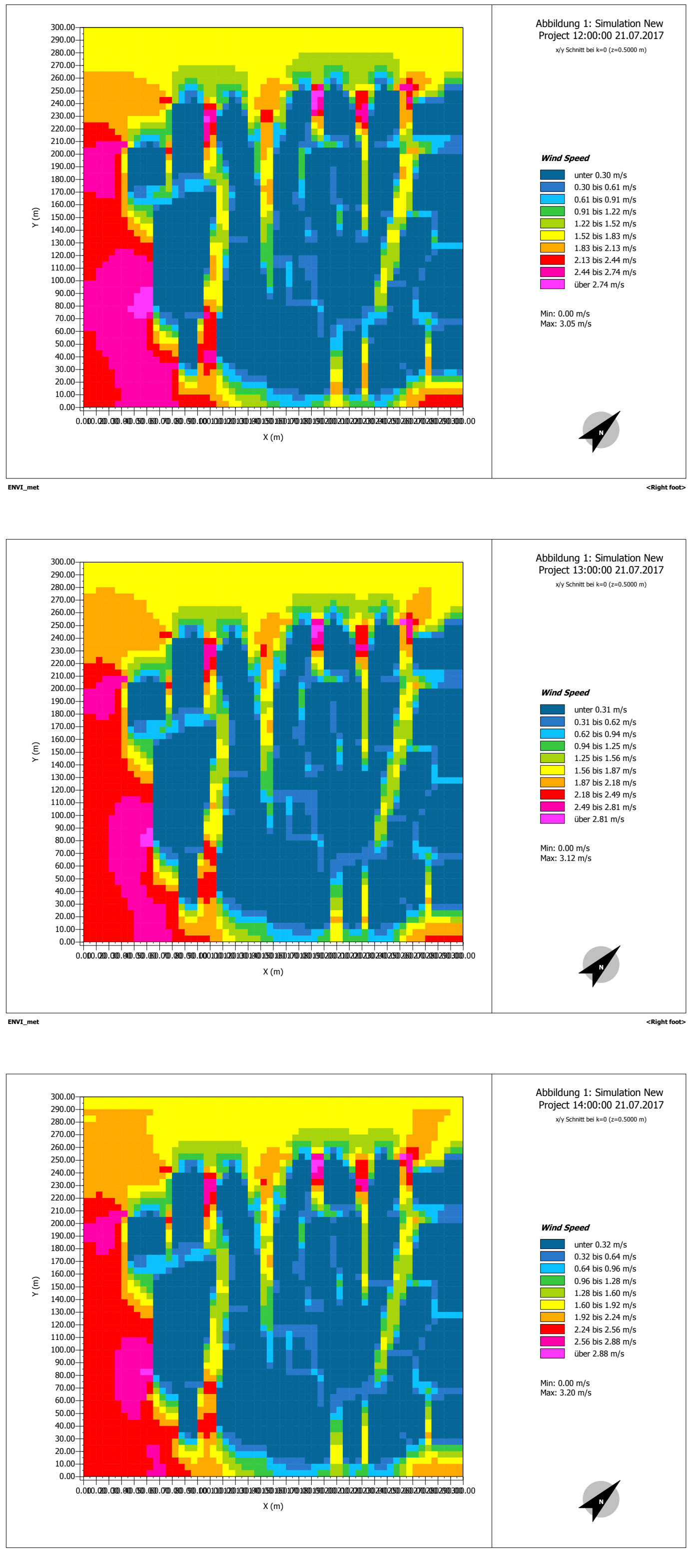


Figure C.9: Wind speed simulation for configuration 3 in phase 3.