Sustainable urban development strategies to enhance outdoor thermal comfort and promote walkability in the United Arab Emirates

استراتيجيات التنمية الحضرية المستدامة لتعزيز الراحة الحرارية الخارجية
وتعزيز إمكانية المشي في دولة الإمارات العربية المتحدة

by

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Abstract

Thermal comfort has a variety of implications for how people act in their built environment, including their mobility options. In many places, particularly those prone to severe weather, trip time and distance are less significant than the outside thermal. Accordingly, Outdoor comfort is necessary when it comes to encouraging individuals to walk, bike, or take any other form of sustainable transportation.

The thesis argues that there is lack of a wider framework that evaluates numerous design iterations in terms of comfort and walkability at the same time is mostly due to a lack of adequate connectivity between the two concepts.

As such, the fundamental goal of this research is to create a link between outdoor thermal comfort and walkability by examining how various sustainable design options for increasing outdoor thermal comfort may be codified to also increase walkability.

The methodology used in this study can address both the quantitative and qualitative aspects of the problem while also allowing for the examination of several design iterations. The research used an integrated methodology that combined field survey and simulation, allowing the researcher to analyse the topic holistically and critically while studying each parameter in its own context. Field survey was employed in this research to better understand people's behaviour under various conditions, while simulation gave a complete control for the researcher to analyse the research problem parametrically.

The study assessed people's thermal perception and level of comfort through a field survey and a thermal walk experiment. The effect of urban morphology on street orientation and H/W aspect ratio is then investigated parametrically utilizing the Rhino/Grasshopper interface in conjunction with the ladybug tools plugin.

According to the findings of the field investigation, pedestrians in the UAE are most comfortable when the outdoor air temperature is between 25 and 30 degrees. While the thermal walk experiment demonstrated that going outdoors in the summer can raise the skin's temperature by up to two degrees. Moreover, individuals can walk less than 10 min in summertime before the feel very uncomfortable. while this duration significantly increases if the street is shaded. The result if simulations shows that street orientation and H/W aspect ratio can contribute to enhancement of 2 °C. In the case study NW-SE street orientation achieved the best result and the current H/W aspect ratio which is around 4.2.

ملخص

للراحة الحرارية مجموعة متنوعة من الآثار المترتبة على كيفية تصرف الأشخاص في بيئتهم المبنية، بما في ذلك خيارات التنقل الخاصة بهم. في العديد من الأماكن، لا سيما تلك المعرضة للطقس القاسي، يكون وقت الرحلة والمسافة أقل أهمية من الحرارة الخارجية. وفقًا لذلك، تعد الراحة في الهواء الطلق ضرورية عندما يتعلق الأمر بتشجيع الأفراد على المشي أو ركوب الدراجات أو اتخاذ أي شكل آخر من أشكال النقل المستدام.

تجادل الأطروحة بأن هناك نقصًا في إطار عمل شامل يقوم بتقييم العديد من التصميم من حيث الراحة وإمكانية السير في نفس الوقت ويرجع ذلك في الغالب إلى عدم وجود فهم شامل للعلاقة بين المفهومين.

وعليه، إن الهدف الأساسي من هذا البحث هو إنشاء رابط بين الراحة الحرارية الخارجية وإمكانية المشي من خلال دراسة كيفية تقنين خيارات التصميم المستدام المختلفة لزيادة الراحة الحرارية في الهواء الطلق لزيادة إمكانية المشي أيضًا.

يمكن للمنهجية المستخدمة في هذه الدراسة معالجة الجوانب الكمية والنوعية للمشكلة مع السماح أيضًا بفحص العديد من التصميم. استخدم البحث منهجية متكاملة تجمع بين المسح الميداني والمحاكاة، مما يسمح للباحث بتحليل الموضوع بشكل شامل ونقدي أثناء دراسة كل متغير في سياقه الخاص. تم استخدام المسح الميداني في هذا البحث لفهم سلوك الناس في ظل ظروف مختلفة بشكل أفضل، بينما أعطت المحاكاة تحكمًا كاملاً للباحث لتحليل مشكلة البحث بشكل حدودي.

قيمت الدراسة الإدراك الحراري للناس ومستوى الراحة من خلال مسح ميداني وتجربة المشي الحراري. يتم بعد ذلك التحقق من تأثير التشكل الحضري على اتجاه الشارع ونسبة العرض إلى الارتفاع H / W باستخدام أدوات الحوسبة.

وفقًا لنتائج التحقيق الميداني، يشعر المشاة في الإمارات العربية المتحدة براحة أكبر عندما تتراوح درجة حرارة الهواء في الهواء الطلق بين 25 و30 درجة. بينما أظهرت تجربة المشي الحراري أن الخروج في الصيف يمكن أن يرفع درجة حرارة الجلد بما يصل إلى درجتين. علاوة على ذلك، يمكن للأفراد المشي أقل من 10 دقائق في الصيف قبل الشعور بعدم الراحة، بينما تزداد هذه المدة بشكل ملحوظ إذا كان الشارع مظللًا. تظهر نتيجة عمليات المحاكاة أن اتجاه الشارع ونسبة العرض إلى الارتفاع H / W يمكن أن يساهم في تعزيز 2 درجة مئوية. في دراسة الحالة، حقق اتجاه الشارع على المحور شمال غرب – جنوب شرق NW-SE أفضل نتيجة ونسبة العرض إلى الارتفاع H / W الحالية والتي تبلغ حوالي 4.2.

To the patron of science and scientists, to the one who pushes the scientific research forward, to the one whose name is associated with science,

His Highness Sheikh Dr. Sultan bin Muhammad Al Qasimi,

May God bless him and protect him.

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To my mother, your uninterrupted prayer reaches me, and I feel it and draw my strength from it. I thank you from the bottom of my heart for always being there for me.

My father, my honour, my role model and my support, I will be grateful to you as long as you live for your constant encouragement to increase in knowledge.

To my dear wife and children.

Finally, I would like to express my gratitude to everyone who has been supportive and contributed to getting me to where I am today.

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Abbreviations

UAE	United Arab Emirates
PET	Physiological Equivalent Temperature
UTCI	Universal thermal climate index
OTC	Outdoor Thermal Comfort
SET	Standard Effective Temperature
UN	United Nations
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
ANSI	American National Standards Institute
SVF	Sky-View Factor
UHI	Urban Heat Island
Ta	air temperature
RH	Relative Humidity
ºC	degrees Celsius
ºF	degrees Fahrenheit
CFD	Computational Fluid Dynamic

3D	3-Dimentional
Tmrt	Mean Radiant Temperature
N	North
S	South
E	East
W	West
H/W	Height-To-Width
L/H	Length-To-Height
ISO	International Organization for Standardization
TSV	Thermal Sensation Votes
TCV	Thermal Comfort Vote
ASV	Actual Sensation Vote
LEED	Leadership in Energy and Environmental Design
ND	Neighborhood Developments
NEWS	Neighborhood Environment Walkability Scale
ANOVA	Analysis of variance
PMV	the Predicted Mean Vote
BMI	Body Mass Index
SOLWEIG	Solar and Long Wave Environmental Irradiance Geometry
UMI	Urban Modeling Interface
UWG	Urban Weather Generator
EUI	Energy Use Intensity
UDA	Urban Daylight Autonomy

Chapter 1. Introduction

1.1. Background information

The fact that over half the world's population in cities now, has driven urban heat to dangerous levels (Lai et al., 2019b). People adjust their discomfort by remaining in inside with air conditioning that has resulted in what is termed *"sedentary living"* (Kumar and Sharma, 2020). As a consequence, city planners and urban designers have focused their attention on the critical need to improve outdoor thermal comfort as part of achieving sustainable urban growth.

Thermal comfort has a number of effects on how individuals behave in their built environment, including their mobility choices. In many areas, particularly those where severe weather is prevalent, criteria such as trip time or distance are less important than outdoor thermal comfort when it comes to encouraging people to walk, bike, or use any other sustainable form of transportation (Cambra and Moura, 2020). Microclimate is closely linked to the satisfaction of outdoor thermal comfort, and the creation of microclimate relies on the architecture of the surroundings (Rafiemanzelat et al., 2017). The connection between these factors to assist architects and urban planners in the creation of sustainable and living cities grew more essential as the globe became mostly urbanized. With the harmful effects on the environment, such as a rise in pollution and energy consumption and a worsening of people's health due to physical inactivity, on one hand, and the steady decline in sustainable transport in the other, the dangers on people's health are particularly apparent (Mouada et al., 2019). As a result, discussions about attaining sustainable development are no longer confined to energy saving and the improvement of outside circumstances; rather, interpersonal interaction inside cities is just as essential as the previously stated objectives (Siddiqua et al., 2017).

While the issue has been identified and addressed before, finding solutions in practice remains difficult. The subjective character of "thermal comfort," as well as the inclusion of a broad variety of factors, also provide significant challenges in this endeavour. People from various cities, and even those from the same area, develop different levels of thermal comfort, which gives the term a qualitative aspect. Thermal comfort is defined as *"a state of mind"* that varies among individuals from various places, and even between individuals from the same place. The researchers investigated how "behavioural factors" influence people's physiological state because of the effects of the physical environment (Forgiarini et al., 2015). Based on climatic conditions like air temperature, wind velocity, humidity, and activity level, some researchers have created mathematical models that can measure how comfortable you are with your heat.

This "comfort index" can measure how your clothing feels, taking into account temperature, humidity, age, and other factors. Most often used models are the Physiological Equivalent Temperature (PET), Predicted Mean Vote (PMV), Universal thermal climate index (UTCI), and Standard Effective Temperature (SET) indices (Coccolo et al., 2016). Nevertheless, each has flaws. For example, PET failed to analyse several climatic zones like hot and humid (Kumar and Sharma, 2020).

The subject of outdoor thermal comfort has been explored in previous research on sustainable urban development, with particular attention paid to the effects of urban morphology and streetscape design, with people's personal aspects being overlooked (Rafiemanzelat et al., 2017). People were assumed to be sitting or standing in the majority of the studies, which focused on thermal comfort in public spaces such as parks and plazas. Furthermore, while average thermal comfort in space is important, a constant acceptable value throughout a walking path is required for any space to be considered as walkable space (Lenzholzer et al., 2018). According to Blečić et al. (2020). assessing walkability is represented as a distance function that is calculated based on the land use distribution and the connectivity of the pedestrian walkways.

It is possible to conclude that the lack of a wider framework that evaluates numerous design iterations in terms of comfort and walkability at the same time is mostly due to a lack of adequate connectivity between the two concepts. Due to the hot weather in the UAE and the Gulf area, walkability is confined to particular months (Shaaban et al., 2018). As a result, researching the relationship between outdoor thermal comfort and walkability is critical in order to offer a comparative foundation for urban planners to analyse design methods and choices in order to make an informed decision.

1.2.Global Review

The number of people living in cities has increased dramatically in the last several decades. More than half of the world's population now resides in urban regions, a historical first. This is predicted to rise to 70% by 2050, with a population increase of 50–60 million people every year, totalling 6.7 billion people. This means that the global population might grow by 2.4 billion people. City dwellers already eat up around 75% of the world's natural resources, such as primary energy and raw materials as well as fossil fuel, water, and food. By 2050, this is expected to have increased from 40 billion tons to 90 billion tons. It is an unstoppable worldwide trend, and it brings with it myriad social and economic problems, as well as unique challenges for policymakers and other practitioners. This statistic emphasizes the necessity of paradigm shifts in the way cities operate in regard to sustainability (Bibri, 2021).

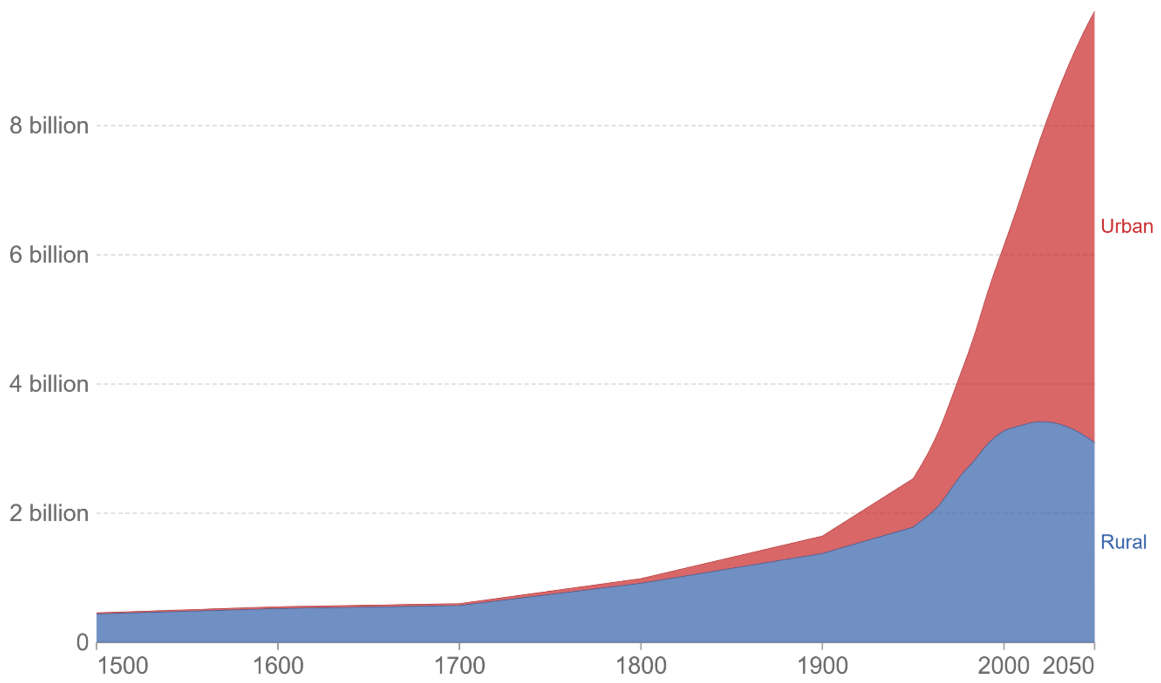


Figure 1: Population 2050 projection based on UN World Urbanization Prospects 2018 (Our World in Data, 2021).

1.3.UAE: Local review

Emirates had largest ecological impact per capita in 2006, according to WWF. The UAE's high consumption rate would necessitate more than "4.5 earths" to meet all population demands. In the years since, the UAE government has begun the process of reducing its ecological footprint in order to ensure the country's long-term viability Aside from that, putting an emphasis on sustainability has evolved into a task requiring significant resources and ongoing dedication. The most significant contributor to the UAE's ecological footprint was its high carbon footprint (Ibrahim, 2020).

Dubai 2040 Urban Master Plan and the UAE Green Agenda 2015-2030 are all aligned with the United Nations Sustainable Development Goals ("SDGs") and the Paris Agreement, and the UAE has made significant efforts in recent years to advance sustainability in the country.

The UAE government sees climate change as a major issue, and as a result, they have increased their efforts through global engagement and domestic policies, positioning themselves as regional climate action leaders during the last decade.

When the Paris Climate Agreement was ratified in 2016, the UAE was among the first countries to do so. Since its first Nationally Determined Contribution ("NDC") to the UNFCCC Secretariat in 2015, the UAE has committed to increasing clean energy to 24% of its total energy mix by 2021, among other things, while also focusing on other issues like infrastructure development, energy and water efficiency, management of water resources, food security, and public awareness. As part of its 2020 UNFCCC NDC submission, the UAE set a reduction target of 23.5% in greenhouse gas emissions by 2030 compared to business as usual. Efforts being made by the UAE to reduce emissions include a greater reliance on clean energy sources, increased energy efficiency, increased carbon capture, usage, and storage capacity, preservation of blue carbon ecosystems, and environmentally friendly waste management (RTA, 2021).

As a result of UN Sustainable Development Summit in September 2015, SDGs were officially adopted, including the 2030 Agenda for Sustainable Development with 17 SDGs, such as ending poverty and hunger, as well as taking action on climate change with access to affordable and clean energy. In 2015, the UAE signed on to the UN's Sustainable Development Goals (SDGs) (RTA, 2021).

Specifically in terms of city planning, The Dubai 2040 Urban Master Plan, unveiled in March 2021 by His Highness Sheikh Mohammed bin Rashid Al Maktoum, lays out a comprehensive vision for Dubai's future urban growth. Urban green spaces and public park areas will be doubled in size, according to the sustainable urban development plan, while nature reserves and rural natural areas will account for 60% of the emirate's total land area. Several green corridors will be built to connect the city's service areas, residential neighborhoods, and sites of employment, making it easier for people to walk, bike, and use other sustainable modes of transportation (mediaoffice.ae, 2021).

1.4. Research motivation

The study's principal inspiration comes from Sheikh Zayed bin Sultan Al-Nahyan, the UAE's founding father, who had a vision of turning the desert into a lush green oasis. Long before sustainable development became a pressing issue, his environmentalist fervour led city planners and architects to prioritize the quality of public places and the public domain. Currently, his vision is more important than ever due to the influence of climate change and global warming on people's interactions with the built environment, particularly in countries with hot, humid climate. This research is also driven by the critical role that walkability plays in achieving the sustainable development goals that the United Arab Emirates has set for itself.

1.5. Research objectives

Raising a city's quality of life requires creating a suitable outdoor place for residents to use. The subject of how the physical environment's design influences people's perceptions and walkability patterns is still largely unexplored, particularly in the gulf region. This highlights the issue that urban designers and planners face in improving the quality of city life by fostering a more suitable outdoor environment for people's daily activities and visits.

The primary objective of this research is to establish a link between outdoor thermal comfort and walkability by examining how various sustainable design solutions for improving outdoor thermal comfort can be codified to also boost walkability. The research focuses on everyday excursions to shops, schools, mosques, and public transportation in Sharjah in the United Arab Emirates. The following objectives will be used to accomplish the research objective:

1- Setting benchmarks for critical outdoor thermal comfort parameters in the UAE climate.

2- Observing the patterns of walkability in various parts of the case study and identifying the urban configuration and streetscape.

3- Evaluating people's perceptions of outdoor thermal comfort, and thermal sensation in the case study throughout the year.

4- Comparing various mitigation measures based on their applicability, cost, and impact, and then selecting the most appropriate strategies.

5- Using numerical simulation and visual analysis, determining the number of improvements.

7- Investigate the improvement in outdoor thermal comfort that would result if urban planners took this into account the proposed strategies in the early phase of design and urban planning

1.6. Dissertation contents and structure

The dissertation consists of six chapters, listed below what is covered in these chapters.

Chapter 1, introduction: provides and overview on the topic, along with global and local review to highlight the subject, and finally present the main aim and objectives of the study.

Chapter 2, literature review: This chapter contains four sections that discuss important concepts related to outdoor thermal comfort and walkability and review the latest research done in this area. The first section discusses the definition of thermal comfort. While the second section present the multiple layers of thermal perception of the individuals (physical, physiological, and psychological). The third section summarises and overview studies on mitigation strategies.

The final section of this chapter presents the knowledge gap that was concluded from the literature review.

Chapter 3, methodology, in four sections, this chapter addresses the methodology utilized to achieve the dissertation's aims; the first section describes the research approach, and the second section describes the prior approaches used to investigate this subject. The method that will be utilized in the study will then be chosen, and the choice will be justified. The methodological framework, research phases, and data analysis method are all discussed in the final part.

In addition, chapter 4, the case of Al Majaz, describes the selected case study and presents climatic analysis of Sharjah weather. This chapter also provides a summary on the field survey and thermal walks that was done in the case study documented by photos. The finals section of this chapter shows the visual code that was used for the simulation and the validation of this code.

Chapter 5, results and discussion, this chapter illustrates the results of the field survey, thermal walks, and the simulations. And discuss the results of the different scenarios propose to conclude how these strategies affect outdoor thermal comfort in the case study.

Chapter 6, conclusion, the conclusion summarizes the research and discusses the findings of the simulation results in relation to the aims and objectives outlined in the introduction. This chapter also identifies the research's contribution and research limitations. Eventually, recommendations for future research are made.

Chapter 2. Literature review

Outdoor spaces are a significant part of the anatomy of cities, it accommodates people's needs in multiple aspects of life. For instance, it is crucial for environmental, social, and economical values (Chen and Ng, 2012). Over the past 10 years, one of the most adopted topics in sustainable urban development is outdoor thermal comfort, where it was studied intensively followed by tons of research that focused on the effect of climatic factors such as relative humidity, the direction and velocity of wind, air temperature, solar radiation with considering various urban morphologies. Where these parameters were classified as physical factors.

Other researchers studied mitigation strategies that work on enhancing outdoor thermal comfort, such as providing shading devices, increasing vegetation and water bodies (Abdallah et al., 2020; Cheung and Jim, 2018; Crank et al., 2018; Kasim et al., 2018; Kim et al., 2018; Lai et al., 2019b; Li and Liu, 2020; Ouyang et al., 2020; Taleghani, 2018; Vasilikou and Nikolopoulou, 2020a; Words, 2017; Xie et al., 2019; L. Xu et al., 2019; M. Xu et al., 2019; Yang et al., 2016, 2019; Yin et al., 2012). According to Kumar & Sharma (2020) research paper, 71% of the outdoor thermal comfort studies are more oriented towards a better understanding of thermal conditions of outdoor spaces. However, 12% of studies are investigating the effects of multiple mitigation strategies.

The following chapter will introduce the concept of thermal comfort, thermal perception and outdoor thermal comfort, as well as the climatic factors that affect it. Followed with investigating the relation between outdoor thermal comfort, built environment and walkability with highlighting the latest research in this field covering the studies done on mitigation strategies and the recommended enhancements. And finally, the chapter present the knowledge gap.

2.1 Thermal comfort

ASHRAE (1992) identifies thermal comfort as a state of mind that reaches a certain level of satisfaction of the overall thermal environment. The human body is always out through various environmental factors that when combined with the body organs' needs to maintain specific levels of temperatures for them to function properly throughout the physiological processes. The conscious mind continuously combines these internal and external environmental factors until it reaches a conclusion on whether the body is sufficed with the level of comfort or not.

Generally, thermal comfort is achieved when the body is maintained in specific ranges of temperature, a low level of skin moisture, and a minimized physiological effort of regulation (ASHREA, 2020). Thermal comfort is affected by multiple elements from the exterior environment regardless of the location. For instance, wind velocity, relative humidity, air temperature, and radiant temperature. On top of that, a person's perception of the ideal thermal comfort is also affected by personal factors, such as the activity they're doing or the layers of clothing.

As mentioned above, thermal comfort is not a simple concept as the complexity lies in the various physical and psychological factors. As the human brain is not designed to quantify and grasp every single component that affects the state of comfort at any given moment. Studies on analysing the reasons behind thermal comfort perception are not well developed (Parsons, 2003). These recent studies are more oriented towards deciding what are the conditions that deliver a state of thermal comfort.

It has been established that thermal comfort affects a person's productivity, hence, studies on this topic were being conducted since before the twentieth century and up until today, in the pursuit of discovering the conditions that provide thermal comfort. Along the industrial revolution's demands, research was expanded to study how thermal comfort affects factory workers' productivity as well as the efficiency of machines and systems. Models and instruments were developed to quantify thermal comfort and predict it at any given moment. The goal of these studies is to achieve controlled comfort in indoor environments, hence allowing air conditioning systems to be better designed in an efficient way.

However, the number of research made on thermal comfort in outdoor setting had different situations. In the 1930's, research on urban thermal comfort had started with the goal of discovering the 10 health effects of extreme weather. This is due the number of complicated issues that included: diverse range of activities and clothing patterns, spatial and temporal variability of environmental conditions, and complex effects of buildings and vegetation on shading and ventilation (Feuillet et al., 2016)

2.2Thermal perception

There are multiple forms of heat transfer that happen between the skin and the thermal environment, which are convection, conduction, evaporation, and radiation. In the following segment, heat transfer forms will be discussed and explained according to three prominent books in this field: "*ANSI/ASHRAE Standard 55: Thermal Environmental Conditions for*

Human Occupancy" by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHREA), *"Human Thermal Environments*" written by KC Parsons , published in 1993 and the second edition in 2003, and lastly, "*Heat Transfer: A practical approach"* by Cengel that was published in 2003.

Conduction is the process of energy transfer by microscopic collisions from the energetic particles of a body to the less energetic ones. This process can happen in liquids, solids, and gasses (Cengel, 2003). With regards to thermal comfort, the process of conduction begins when 2 bodies are in contact with different temperatures, heat exchange occurs. For instance, sitting on a bench that has been exposed to the sun's direct heat would naturally be at a higher temperature than a human body, hence the warmth of the bench can be felt after this direct contact. Also, an example for conduction is the heat that we feel from the ambient air when we're in direct contact. Another example is when our body heat is transferred from the skin to the clothing, which is defined as part of sensible heat expelled from the skin according to (ASHREA, 2020).

Radiation is the process of energy emittance from a matter in electromagnetic waves, this happens due to the changes of the electromagnetic configurations of the molecules. According to (Cengel, 2003), radiation is emitting heat energy throughout empty spaces. One of the primary sources of radiation in an outdoor thermal environment is the sun. a secondary source of radiation is the emitted energy from the ground and the surrounding buildings, which already had energy stored up previously from the sun. when a human body is positioned underneath a shaded area, it can only feel the heat from the ambient air and the radiation from other surrounding objects, however the radiation is more significant when standing directly under the sun. When the human body expels heat from the skin through the clothing insulation to the outer surface, this heat is known as radiative heat. A part of sensible heat loss from the skin is quantified by (ASHREA, 2020).

Convection is the process of energy transfer that occurs between solid surfaces and the adjacent gas or liquid of which it contains particles in motion, and it includes a mix of the following combined processes: conduction and fluid motion. Convection can happen in any typical thermal environment when heat is dissipated from the skin through respiration. As mentioned previously, conduction and radiation alongside this form of heat transfer (convection), are considered as part of the total sensible heat loss from the skin according to ASHRAE (1997). It states that due to respiration the convective heat loss is much greater in amount in comparison of its occurrence in the skin, and that is because in convective heat loss during respiration, air is inhaled at room temperature conditions and exhaled at a saturated temperature that is close to the body temperature

Evaporation has a similar process of heat transfer to convection; however, it needs an initial change in the state of a substance at the skin surface from liquid to vapor and then the vapor diffuses across the boundary layer into the ambient air (Parsons, 2003). Evaporation helps in cooling down the body temperature by the effect of evaporating sweat, which leads to thermal comfort. The heat loss is dependent on the temperature difference of the water vapor pressure of the skin, the ambient environment, and the amount of moisture in the skin (ASHRAE, 1997). Another example of evaporation is the respiration process, where the ambient air is inhaled, and a more saturated air is exhaled. It is generally harder to breathe in high humidity levels, and the reason for this discomfort is due to the difficulty of expelling moist air from the body to the environment.

To better grasp the concept of human thermal comfort, it has been studied that the body is constantly exchanging heat with the thermal environment. Hence, the body has to do subconscious physiological processes and in return do conscious behavioural responses to sustain thermal comfort. In a physiological aspect, heat is produced usually in the cells of the body. Through the process of convection, heat is transferred to the skin using blood flow from the cells to the surface of the skin (Parsons, 2003). As the circulatory system goes through the human body, it passes across the brain that includes the hypothalamus. The hypothalamus is responsible for the temperature of the body and has a sensor that indicates hot or cold levels to keep it aligned with the body's core temperature (ASHRAE, 1997). Humans are homeotherms and they sustain a constant temperature of 37°C (Parsons, 2003). When the hypothalamus detects an increase of the core temperature, it sends a command for more blood flow to the outer layer of the body, so it releases the extra heat through vasodilation. In order to expel more convective and evaporative heat through the skin pores, The blood vessels near the skin expand to allow more blood circulation. In case this process isn't enough, the skin's eccrine glands will secrete sweat to help in evaporative cooling.

Conversely, When the hypothalamus detects a decrease of the core temperatures, it commands the body to make the blood vessels tighter to prevent heat from expelling out of the skin surface. This process leads to Piloerection, which is an erection of the body hair that happens due to tiny skin muscles contracting. This process helps maintain a layer of still air between the surface of the skin and the surrounding environment (Parsons, 2003). In case there was a lower temperature, the muscles start to shiver to generate the needed internal heat to maintain the core temperature.

2.2.1 Physical adaptation

In terms of physical adaption, thermal comfort is achieved through the conscious mind by ordering behavioural actions that reduces discomfort. For instance, changing activities, altering clothing, leaving certain spaces or going towards a heat source (Parsons, 2003). Changing clothes depends on the season and the climatic zones. Another example is changing body postures such as folding arms close to the chest to sustain heat. According to (Vasilikou and Nikolopoulou, 2020a), this physical adaptation that humans make to adjust themselves according to the environment they're in or alter the environment itself to suit their needs. They defined two kinds of physical adaptation: reactive and interactive. Reactive adaptation is responsible for the personal changes that a person can do, such as changing the layers of clothing, the way they are positioned, and the metabolic heat with hot or cold drinks consumption. However, interactive adaptation considers the changes that can be done to the environment to enhance their comfort conditions, for instance, opening a parasol or a window, turning on the heater, adjusting the thermostat (Tseliou et al., 2017). Apart from behavioural responses, the mind also undergoes psychological responses.

2.2.2 physiological Adaptation

In outdoor environments, researchers are focusing on finding the link between physiological factors and thermal comfort. These factors can include the temperature of the skin (Lai et al., 2019a), sweat rate and pulse (Nakayoshi et al., 2014), and heart rate (Vanos et al., 2017).

The physiological parameters vary; however, researchers are focusing on the skin temperature for it is easy to measure and it directly indicates level of thermal comfort. The mean skin temperature that indicates comfort in indoor spaces has been reported to be around 33.5° C In outdoor spaces however, according to Lai et al. (2019c), mean skin temperature that indicates comfort is Song and Jeong (2016) discovered that the mean skin temperature of subjects that are located in places with a high sky-view factor (SVF) was around 36.0° C, while it becomes lower in low-SVF places till around 33.9° C. Jeong et al. (2016) did a similar research and discovered that in an urban forest, the tested subjects' mean skin temperature is lower than those who were in a building district. Lai et al. (2019b) and Kurazumi and Sakoi (2014) did further research to find the link between mean skin temperature and outdoor thermal sensation and discovered the correlation coefficients were 0.85 and 0.66, respectively.

2.2.3 Psychological adaptation

The most important type of adaptation is the psychological adaptation. Because it greatly affects people’s perception of the surrounding environment which leads to thermal comfort (Liu et al., 2016). In this type of adaptation, all kinds of modification that the body can do whether it’s conscious or unconscious decisions to adjust environment conditions (de Dear, 1998). The research done by Nikolopoulou et al., (2001), at its initial phases is considered to be one of the primary studies alongside to the research done by DeFraites in 1985, conducted on the individuals' mental responses and psychological adaptation. According to this research, psychological adaptation has had focused attention as it turns out it can prevent discomfort in adaptation on the large scale of an environment (Nikolopoulou et al., 2001). Research was done by the local climate and the urban culture in Sweden in 2001, where they investigated how the climate was perceived, which was mainly influenced by personal beliefs and cultural knowledge, and it turned out to be perceived differently than what the standard weather forecasts (Eliasson et al., 2007).

2.3Outdoor thermal comfort and walkability

Our fundamental mode of transportation advocates for a sustainable and healthier environment, walking advances liveability, lowering obesity and rate traffic congestion (Cambra and Moura, 2020). The walkability factor in an environment does not impact the pedestrian’s choice on whether to walk or no, but whether the environmental factors fulfil their needs. Accessibility, feasibility, pleasurably, comfort and safety are the 5 pedestrian needs Alfonzo (2005) gave forth. Maslow’s (1954) hierarchy of human needs assumes that we would attend to our high order needs after attending to our basic needs, the study is used as a reference used to build theories about the pedestrian needs.

The model of thermal equilibrium anticipates thermal comfort outdoors(Vasilikou and Nikolopoulou, 2020b). The state of comfort, as commonly acknowledged, could also be impacted by qualitative measures that have not been stated in the models addressing thermal equilibrium, despite various models used for forecasting of outdoor thermal comfort created and utilized when designing urban spaces.

The influence of demographic factors has been addressed by some studies (Kruger and Drach, 2017). The survey, carried out on 985 respondents, respondents were given a questionnaire covering queries about their personal traits and their thermal perception. Anthropometric characteristics are determining factors that influence the subjects' thermal sensation, factors include age, gender, skin colour, and body mass. Age may be considered as a concerning factor climate-sensitive urban design, however, gender showed inconsequential results. Demographic importance of skin colour and weight in mitigating the impact of thermal conditions on users' thermal judgement is highlighted in the results. Meteorological data and data drawn from the multivariate regression equation show that only skin colour proved good estimator.

2.3.1 Urban heat Island

The phenomenon of having higher temperature level in cities than in neighbouring places, or as known as Urban heat island (UHI) (Piselli et al., 2018), is a serious problem that begun due to urbanization and associated climate change (Akbari and Kolokotsa, 2016). UHI happens due to changes in energy fluxes in relation to changes in land use, particularly, a growth in solar absorption, sensible heat and heat trapping, and a correlation of evapotranspiration reduction, on top of that a growth of anthropogenic heat from buildings and vehicles. The intensity of UHI is usually in the range of 0.4 °C and 11 °C, and is more noticeable during nigh time where it subjects people to an increase of thermal stress as shown in the below figure (Wong et al., 2021).

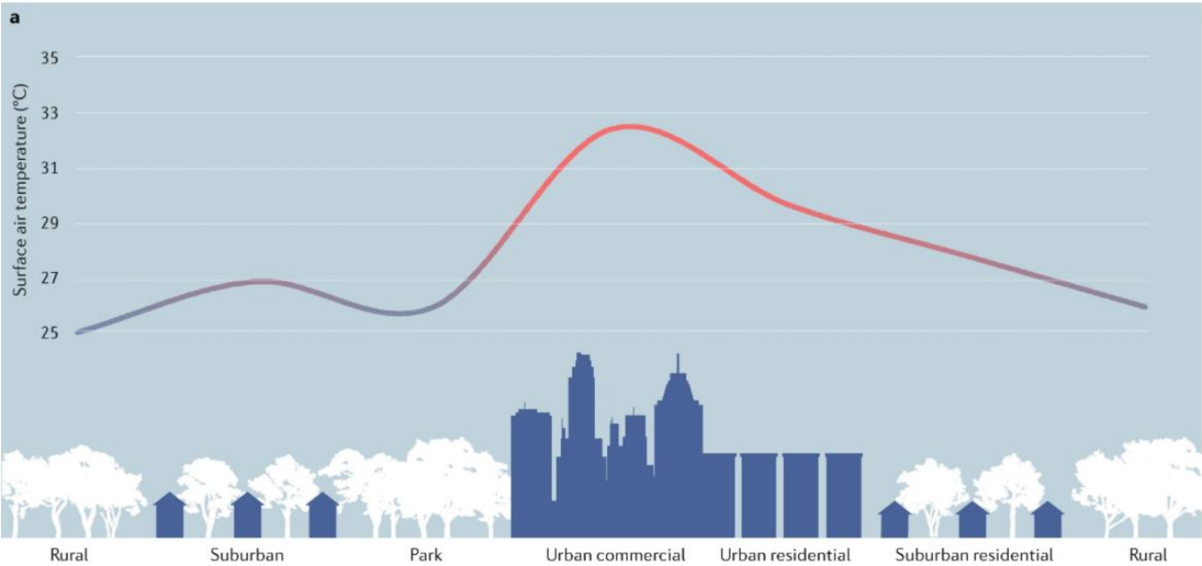


Figure 2: How a UHI profile usually looks like. (Wong et al., 2021).

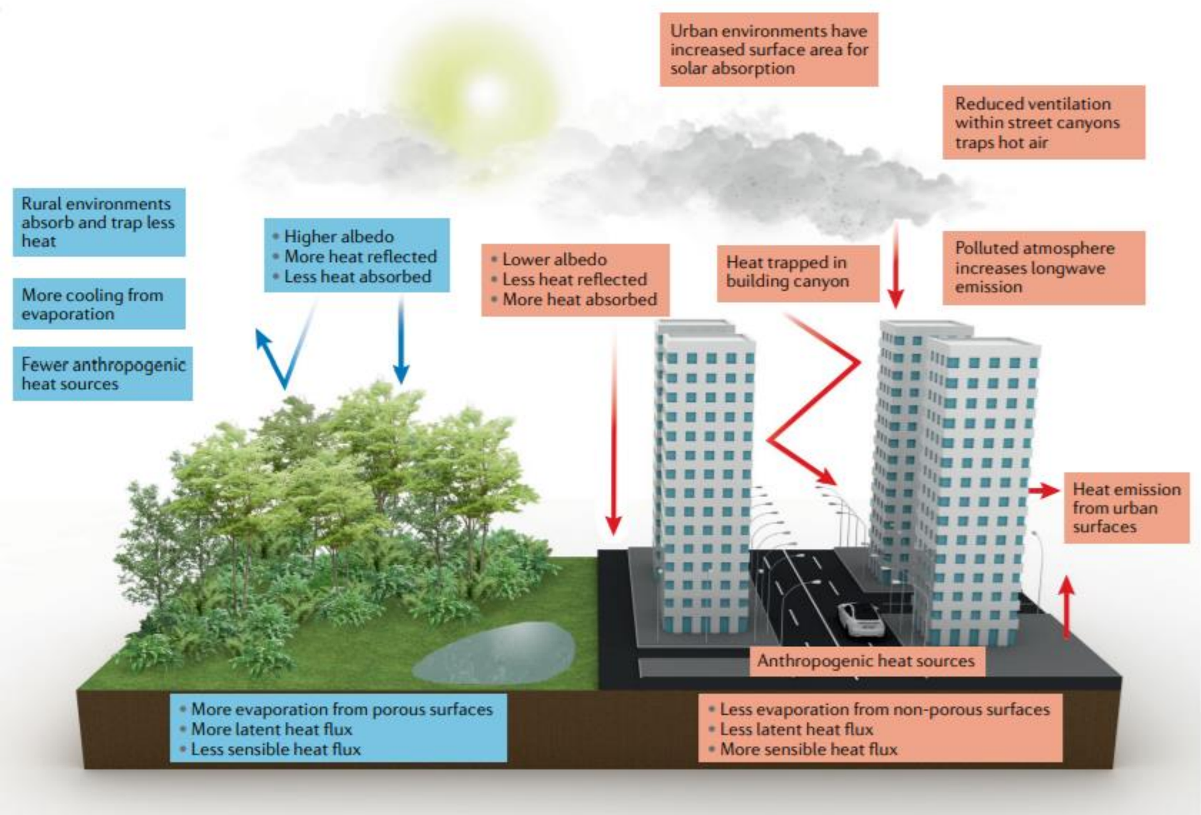


Figure 3: parameters affecting Urban Heat Island (Wong et al., 2021).

The elevated levels of temperature in urban areas lead to an increase of cooling demand, thus having high energy spending leading to an increase of pressure on the electricity grid specially throughout heat waves (Pyrgou et al., 2017). The rise of ambient temperature is also harmful on people's health (Santamouris et al., 2017). In 2003, a heat wave hit Europe and caused around 50% of the overall death cases in the west midlands. On top of that, it was also the reason behind 70,000 descendants across Europe, specifically in urban regions like Paris, France. Further investigations conducted in urban locations that include London, Shanghai, Hong Kong, Ho Chi Minh, and Athens, point to a higher rate of death cases throughout those heatwaves due to the UHI phenomenon (Wong et al., 2021).

2.3.2 Urban Climatology

Urban microclimate studies the given environment's weather, and this observation can be remarkably different from surrounding areas. It primarily involves studying the wind speed, solar radiation, air temperature, relative humidity, and other meteorological factors. Two of the most affecting meteorological parameters are wind speed and air temperature, as they influence human comfort levels and outdoor activities. Simultaneously, it is also affected by various other reasons, such as how the buildings are shaped, the amount of vegetation, plot ration, and building density (Wang, 2021).

Urban climate is a complex system—implementing any microclimate model involves a certain number of in-situ procedures and multiple physical variables, such as: air temperature, radiant temperature, humidity, and air movement that influence the human response to thermal environments. For instance, studies have found that people's activities in outdoor spaces decrease in summer with an increase in air temperature (Ta) (Lin et al., 2012).

2.3.2.1 Air Temperature

According to the zeroth law of thermodynamics, higher temperatures always flow towards lower temperature, consequently thermal equilibrium is achieved (Cengel, 2003). this also applies to the heat exchange between the human body and the environment, usually being surrounded by clothing then by air. Air temperature is the air around the human body with a heat flow between the body and the air. This was measured in a study for thermal comfort using a dry bulb temperature, using a mercury-in-glass thermometer, a thermistor, or a platinum resistance thermometer; and has the unit as degrees Celsius (ºC) or degrees Fahrenheit (ºF).

A study conducted by (Shimazaki et al., 2011) states that top two most vital parameters that affect outdoor thermal comfort are air and radiant temperature. Alongside an investigation in the university of Osaka in Japan, how tree canopies affect thermal environment. In warm seasons, radiant temperature affects thermal comfort in outdoor environment the most, following that wind speed and air temperature according to a study in in Harbin, China, (Jin et al., 2019).

2.3.2.2 Radiant Temperature

Radiant temperature is the heat radiated from any surface of any part of the body, hence, radiation exchange (McQuiston et al., 2005). Radiant Temperature is the temperature of a bare surface to the environment (ASHREA, 2020). At a given time, 15 radiant heat sources are emitted from each body that affect each other. Mean radiant temperature and plane radiant temperature are two values that are considered for measuring radiant temperature. Mean radiant temperature represents the sum of the radiant heat that comes out from around the body from different directions. It is the total average of the radiant heat between the human body and the surrounding environment, commonly used as the measure for radiant heat during studies for thermal comfort. McIntyre (1980) states this as the temperature of a black-body source as equivalent as the measured quantity of the radiation field. Meaning, it is the temperature of an enclosed environment with a black sphere with similar radiation exchange as in a real environment. (Parsons, 2003). Alternatively, Plane radiant temperature resembles the radiant heat from a single plane and provides details of the radiant heat exchange direction. The importance of this matter is to identify the specific orientation of large radiant sources to the body, such as electric fire, very cold wall, or a steel furnace. The mean radiant temperature can be derived when that value is measured from six side, such as a cube.

2.3.2.3 Relative Humidity

The ability of air to absorb moisture or water vapor is called relative humidity (Cengel, 2003). It can be defined as the proportion of the amount of water vapor present in the air to the maximum amount of water vapor that the air can embrace at a given air temperature. As the temperature of air increases, the amount of water vapor that can be maintained also increases, which in turn, decreases the amount of evaporation that the body can eject as heat through the skin. Alternatively, lower levels of humidity allow for a faster heat discharge rate from the skin to reach thermal comfort. Relative humidity should be preserved below 60% to maintain thermal comfort on the warm spectrum according to Nevins et al. (1995). 30 to 70 percent of relative humidity is the regularly requested level, according to a controlled indoor conditions study. ASHRAE Standard 55 developed the theoretical upper relative humidity limits from a limited data. However, through later studies by Vasilikou and Nikolopoulou, (2020b) the ranges for outdoor thermal comfort had higher levels.

2.3.2.4 Wind speed

The body temperature can be affected by the wind speed as it has a direct consequence to the rate of vapor or warm air is released from the body (Parsons, 2003). During high relative humidity situations, wind helps to reach thermal comfort, in some situations, pleasure, through evaporative cooling. Moist air around the body is replaced by fresh air through a moderate breeze. However, excessive air motion at higher wind speeds produces uncomplimentary cooling at certain body parts, resulting in discomfort. Mean wind speed is regularly used in thermal comfort studies since wind can come from various directions at different speeds at any specific moment, this methodology is highly convenient during measurements as the discrepancies are insignificant. The square root of the sum of squares for each wind velocity readings during the required study period calculates the average value of the immediate wind velocity (Parsons, 2003).

A study was conducted by (Ma et al., 2018) in a cold winter place located in southern China over a touristic area for investigating microclimate conditions and to propose strategies to improve outdoor comfort. Measurements were taken on-site for the relative humidity, wind velocity, and air temperature, which showed a discomfort climatic condition almost in the whole block based on assessing PET. Nonetheless, the results lead to coming up with solutions such as redesigning the entire block and adding high rise buildings, growing more plants to increase vegetation level which will provide more coverage, and changing the materials used for pavements. These suggestions will contribute about 8.7°C PET reduction which will increase the outdoor comfort.

2.3.3 Urban Morphology

The terms logy and morph make up the phrase Morphology, that translates to the logic of form recognition. These studies have been carried out in plenty of fields to tackle structure, physical character, proportions and disfigurations of objects and their subparts (Fathi et al., 2020)

Urban morphology is a science which determines the generation's thought process and inclinations that fundamentally established the form of cities. Paying attention to the tangible significance of economic, environmental, and social forces. The physics of the city display the influence of human inclination and activities. The following elements are considered imperative for the morphological analyses, gardens, streets, statues, parks, and buildings even though they are often susceptible to evolution and change over time (Fathi et al., 2020).

Various studies aim to alter urban morphology's effect on our thermal environment in the urban context, by highlighting urban morphology and addressing the substantial aspects of spatial patterns or urban forms, such as architecture bulkiness, street orientation, vegetation layout, and urban canyon condition.

By carrying out variable computational fluid dynamic (CFD) simulations, this study examined outdoor thermal comfort in 5 × 5 idealized building arrays on five uninterrupted days. Using UTCI (Universal Thermal Comfort Index) has aided in verifying the dynamic interacting effects of building layout, building distance, and building height topology on spatial distributions, spatially averaged outdoor thermal environment, and airflow patterns. The transient solar-induced temperatures on the building grounds and walls within building arrays, using CitySim Pro to render which consequently assigned as thermal boundary conditions in CFD simulations. The impact of transient wind conditions was portrayed from the outcome, on urban thermal comfort. Airflow patterns were also notable so steady or unsteady simulations of a conventional day may not produce a comprehensive overview of the wind-thermal context. Also, putting forth the outcome by spatial distribution or average UTCI may result in incompatible outcomes about the effects of urban geometry on urban thermal comfort, particularly the effect of building distance. The matching aspect ratio with spatial distributions of UTCI in 3D building arrays vary remarkably, that was not seen in the pattern of average UTCI. Upscaling the building height often reflected positive outcomes on the urban thermal comfort.

2.3.3.1 Street Orientation

The street canyon positioning can obstruct incident solar radiation at the pedestrian level and enhance airflow at the street level (Srivanit & Jareemit, 2020).

Numerous studies show that the East-West position served the minimum level of outdoor comfort for pedestrians, but North-South positioned canyons are considered the best case (Bakarman and Chang, 2015; Deng and Wong, 2020; Huang et al., 2017; Srivanit and Jareemit, 2020). In some studies, Northeast-Southwest position for street canyons was assessed as the prime arrangement in urban planning (Chatzidimitriou and Yannas, 2017; De and Mukherjee, 2018). Moreover, East-West streets are assigned to the largest figure of mean radiant temperature (Tmrt) and are exposed to supreme solar radiation (Deng and Wong, 2020). The North-South orientation of street canyons serves the maximum degree of thermal comfort for the users in outdoors; despite this, this urban arrangement creates severe energy consumption by buildings for cooling grounds (Huang et al., 2017; Pyrgou et al., 2017) and subjected to less sunlight (Srivanit and Jareemit, 2020). Streets positioned along the path of the prevailing wind flow undergo the maximum wind velocity, and this value increases when the aspect ratio of the street canyon decreases (Deng and Wong, 2020; Emmanuel et al., 2007; Kakon et al., 2009) which shows how Street orientation also plays a major role on the airflow factor zooming in on the pedestrian level (Chatzidimitriou and Yannas, 2017). Differences in the asymmetrical aspect ratios and hights of the buildings could also cause impact and turbulence and affect the air circulation surrounding high rise buildings (Emmanuel et al., 2007; Qaid and Ossen, 2015).

Nasrollahi et al. (2021) in his study, 6 urban canyons have been selected to inspect the impact of urban shading and urban geometry in enhancing the users' thermal comfort in the hot weather of Ahvaz, Iran. Micrometeorological questionnaire surveys and measurements were implemented in July 2018 to appoint the outdoor thermal comfort scope. The urban shadings and urban geometry played are studied using ENVI-met. Using RayMan to determine the outdoor thermal comfort, the Physiologically equivalent temperature (PET) is computed. Consequently, using the outcome of the field studies, the values obtained within 19.6°C to 30.9°C determine the outdoor thermal comfort scope in Ahvaz. PET Simulation outcomes concluded that by decreasing the canyon aspect the ratio PET increases, also, the nearer the canyon positioning is to the north-south direction, the mean radiant temperature (MRT) and lower the air temperature (Ta) are. Shadings had no significant impact on the air temperature. However, urban shadings reduced MRT up to 34°C and PET up to 17.6°C. PET decrease due to the shadings is less significant in broader canyons than in east-west canyons. PET and MRT in all cases are greatly associated with SVF. The examination displayed no solid relationship between relative humidity, wind speed, and Ta with SVF each one of the canyons.

(Chatzidimitriou & Yannas, 2017) : Analytical and empirical outcomes that bring forth potential developments that can be attained through urban design are the values this paper aims to provide. The paper context of study is in 18 street canyons placed in the crowded city centre of Thessaloniki in northern Greece, discussing environmental measurements taken in summer and winter periods. Values are recorded parallel to the microclimate simulation studies incorporating modelling of the 18 street canyons and some common scenarios.

In 18 central street canyons in the city of Thessaloniki (latitude 40.5oN) during summer and winter seasons, measurements have been taken. The study group encompassed streets that were transversal to the normal grid of the city (N-S and E-W). The analysis also involved a criterion of a few with a primary axis alongside the coast and another criterion of a few with their axis orthogonal to prevailing winter winds and to the coast (NW-SE and NE-SW). Varying figures of the ratio of building height to street width ranged from 0.6 to 3.3. The data was captured in 7 canyons running NW-SE with aspect ratios ranging from very wide to very deep (0.6–3.0), 7 NE-SW canyons with aspect ratios from medium wide to very deep (1.0–3.3), 2 deep N-S canyons with aspect ratio 1.7 and 3.0 and 2 deep E-W canyons with aspect ratio 1.7 and 3.2. The previous data have been split into 4 sets: very wide (0.6–0.7), medium wide (1.0–1.1), medium deep (1.7) and very deep (2.8–3.3).

The NE-SW orientation is preferred during winter for medium wide and medium deep canyons (aspect ratio between 1.0 and 1.7) and NW-SE axis positioning is preferred during summer. The largest contrast amidst distinctly positioned canyons in summer midday was almost 22 K between the NW side of a NE-SW canyon and the SW side of a NW-SE canyon, however, in winter respective variances does not go above 4 K. The most convenient positioning seems to be NW-SE in winter and E-W in summer and N-S for deeper canyons.

(Yang et al., 2016) This paper studies the urban street of the central business district in Singapore touching on an investigation of the impact of street layout on outdoor thermal comfort, zooming in on the design criteria of the height-to-width ratio (H/W), vegetation, and street orientation. To collect data for microclimate parameters, an all-inclusive field measurement with various points and were performed that were used to confirm a commonly used computer software holistic microclimate modelling system. The importance of this study is that valid field data from various measurement points on microclimate parameters are developed and the influence of street design guidelines on outdoor thermal comfort is scaled. The paper shows that when addressing thermal comfort in Singapore, that a H/W of 3 can be accounted as a limit with regards to outdoor thermal comfort and the NW-SE positioned street is more exhausting than the NE-SW street in the afternoon. The outcomes presented can serve as guidelines for urban designers and planners to obtain enhanced outdoor human thermal comfort as stated in the conclusion of the paper.

2.3.3.2 Aspect ratio (H/W)

The ratio connecting the width of the street with a building's height is referred to as aspect ratio. Aspect ratio is among one of the notably integral design criteria in thermal comfort-based urban planning (Srivanit & Jareemit, 2020).

The ratio "*building height-to-width outdoor space*" (H/W) and ratio "envelope surface-to-volume" (S/V) are two elementary indexes of the spatial composition of the urban spread, both factors directly influence the microclimate. The degree of coherence of the building volume is indicated by the S/V factor. Conversely, H/W portrays the degree of "openness", meaning, the dynamic of the peripheral outdoor spaces with the building measurements, this can be represented using the sky view factor (SVF). SVF is a scale measuring the solid angle of the perspective of the sky viewed from an urban area. This is directly linked to the study of urban heat island (UHI) and temperature deflections affecting diverse urban contexts. This factor amounts to one, meaning that there is a maximal sight showing the sky. Therefore, temperatures seem to meet the forecasted meteorological figures, but if the figure is zero then the sky view is obstructed, and the temperatures are influenced by the urban context (Kouklis & Yiannakou, 2021).

The H/W ratio plays a direct role influencing the urban microclimate as it shows an effect on the infusion of solar radiation through the wind flows, urban canyon, and the abduction of radiation given off by materials. Moreover, the building volumes, shading and the design of the apertures of the buildings have an impact on the makeup of the microclimate. Distinct H/W ratios show distinctive influence on distinguished environmental measures. For clarification, a large H/W ratio can indicate little to average winter solar gains, average or large subjection to the summer sun, high blockage of air circulation, large capturing of sunlight with reflections and the little to average acquirable zones for tree planting. Having said that, a little signifies large solar gains, little subjection to the summer sun, little to average capturing of sunlight with reflections, little to average blockage of air circulation, and large acquirable zones for tree planting. Hence, it is not a simple task to procure an ideal H/W rate that coincides all the case-by-case domains (Kouklis & Yiannakou, 2021).

Muniz-Gäal et al. (2020) conducted a study that aims to determine if whether geometric parameters set for the urban street canyons play a role on their pedestrian thermal comfort and microclimates. It is essential for accomplishing sustainability, to grasp the impact which these parameters play on the microclimate affecting the urban street canyons in both urban habitation and thermal comfort. This study was carried out in the city of Campinas, São Paulo, Brazil, which is characterised by a Cwa climate. The computational modelling tool ENVI-met 4.0 preview is used to conduct this study. As a result of 36 scenarios, both carried out considering gaps and neglecting gaps within buildings have been simulated for summer and winter. The 36 scenarios varied in their aspect ratio (H/W) (avenue (H/W < 0.5), regular (H/W $= 1.0$), and deep (H/W > 2.0) canyons) and length-to-height (L/H) ratio (short (L/H < 3.0), medium (L/H $= 5.0$), and long (L/H > 7.0) canyons). By examining the difference in the physiological equivalent temperature (PET), wind speed, and air temperature, the Canyon operation was evaluated. The outcome displayed that canyon with a larger H/W aspect ratio optimize the shading by buildings and wind speed, thus uplifting the thermal comfort zooming at the pedestrian level, particularly during summer. On the opposite hand, no considerable impact on the thermal comfort perception at the pedestrian level was caused by the rise in the L/H ratio had, which was comparable to the scenario that neglected the space midst the buildings.

2.3.3.3 Vegetation

Lately, various research investigated bioclimatic techniques that could amplify outdoor thermal comfort user experience. Cardinal models frequently demonstrate that additional tree coverage or vegetation offer a cooling sensation and enhance the human thermal comfort, but what differs is the cooling range for a specified quantity of vegetation. Those alteration take place because of the climatic environment at diverse geographic areas, the kind of vegetation or the volume, and wind corridor design or building layout (Chen et al., 2021; Yang et al., 2016). Even though trees were broadly approved to be beneficial in enhancing human thermal perception in concentrated urban streets and mitigating heat (Gachkar et al., 2021; Priya and Senthil, 2021; Sayad et al., 2021; Srivanit and Jareemit, 2020), research has hardly investigated how residential tree spacing, arrangements and locations affect the human thermal comfort and outdoor microclimates. A majority of the current literature mimics human thermal comfort and outdoor microclimates by haphazardly finding trees assumed form the real-world landscaping design or to a secure percent of the (Bachir et al., 2021; Chen et al., 2021; Eliasson et al., 2007; Labdaoui et al., 2021; Lin et al., 2012; Meili et al., 2021).

No.	Authors	Year	Climate/ Geographic locations	Type of vegetation	Results	Reference
1	Chen T., Pan H., Lu M., Hang J., Lam C.K.C., Yuan C., Pearlmutter D.	2021	Guangzhou/ China	Not been identified, however, 2 sizes of tree crown were modelled	PET is decreased by 4 degree Celsius under big crown trees while Small crown trees has warming effect.	(T. Chen et al., 2021)
2	Gachkar D., Taghvaei S.H., Norouzian-Maleki S.	2021	Urmia, Iran	Pine and Cypress as evergreens and Platanus, Populus and Fraxinus	Platanus and Pine are the most effective plants in enhancing OTC by decreasing the temperature in summer, while Cypress trees has successfully enhance OTC in winter from cold *to cool*	(Gachkar et al., 2021)
3	Sayad B., Alkama D., Ahmad H., Baili J., Aljahdaly N.H., Menni Y.	2021	Guelma/ north-eastern Algeria	Palm trees, Fraxinus and Populus trees	increase the percentage of vegetation in site lower the temperature 0.8 degree Celsius and increased the humidity	(Sayad et al., 2021)
4	Priya U.K., Senthil R.	2021	tropical areas	N/A	the use of vegetation can reduce air temperature from 4-degree Celsius to 12 degree Celsius according to the type of vegetation	(Priya & Senthil, 2021)
5	Labdaoui K., Mazouz S., Reiter S., Teller J.	2021	Annaba/ Algeria	N/A	the result of survey of 1230 interviewees in 4 locations has shown that participants expressed a better thermal satisfaction than the other areas	(Labdaoui et al., 2021)
6	Bachir N., Bounoua L., Aiche M., Maliki M., Nigro J., El Ghazouani L.	2021	Mostaganem/ Algeria	Cylindric, Populus nigra, Platanus, and Acer pseudoplatanus	Vegetation effects on air temperature 1.5-degree Celsius reduction in average and the best arrangement scenario is street alignment	(Bachir et al., 2021)
7	Meili N., Acero J.A., Peleg N., Manoli G., Burlando P., Fatichi S.	2021	Singapore	Theoritical trees proporities	Vegetation effects on air temperature 3-degree Celsius reduction in average	(Meili et al., 2021)
8	Yilmaz S., Mutlu B.E., Aksu A., Mutlu E., Qaid A.	2021	Erzurum, Turkey	Deciduous trees	in the summer season, the air temperature is reduced about 1.0 °C in the case of the street with vegetation and increased about 2.0 °C in winter season.	(Yildirim & Yavuz, 2012)

Mouada et al. (2019) has carried out research to examine the interrelationship between urban morphology, walkability, and outdoor thermal comfort, by conducting an analysis between the three different types of neighbourhoods in Algeria: the old, the modern and the extension. Various parameters were taken into consideration during this study, such as: human scale, building density, vegetation, H/W ratio, walkability speed and land-use diversity. The product this study signified is that the old one showed the most promising results for a thermally comfortable neighbourhood, and this is caused by the high building density which served more dense vegetation and shade that aided the maintenance of air temperature in the confines of 24°C - 32°C. Another research in Arizona done by Zuniga-Teran et al. (2017) analysed four distinct kinds of neighbourhoods in terms of traditional, suburban, cluster housing and gated community to study the impact of the design of the neighbourhood on the physical activity. In terms of walkability, the results showed that the traditional neighbourhood was the dominant, and cluster housing showed most promising results when tested for physical activity.

Research conducted by Lenzholzer et al. (2018) was carried out to evaluate outdoor comfort on the thermal notion of members, where it analysed the effect of the kinetic state (stationary or in motion) of members taking part in the study. The results signified that there is a prominent variation between both states, but the minority aimed on members in motion, but the majority of the studies aimed stationary mode. The analysis established that if the evaluation of thermal comfort where users are in stationary mode on plazas, parks, and urban squares, could be accepted, contrary to that, the outcome would show false results when the analysis focuses to analyse a bigger urban sequence where it bears in mind the user's daily routes. This had been confirmed by Peng et al., (2019) where he investigated direct and indirect parameters which played a role in comfort levels in outdoor settings where it comprises human physical conditions and behavioural factors tested in an industrial area in Netherlands all through field interviews. The microclimatic factors and air temperature affect people's apprehension of thermal comfort as stated in the conclusion of the study; however, people's proneness to partake in outdoor activities is compelled majorly by relative humidity. This study declared that relative to sitting, biking, and standing, less thermal comfort is caused by people walking.

2.4Knowledge Gap

Numerous knowledge gaps have been identified by a review of prior studies. To begin:

1- There is a lack of studies that combine outdoor thermal comfort and walkability in holistic approach, which take into consideration the thermal perception of the individual in certain areas along with the physical parameters.
2- Studies that focus on hot, humid, or dry climates studies are most of the time apply the simulation on theatrical model. Studies that take case study tends to take very small area, for example street scale which limit the validity of the results for Urban district.
3- Similarly, studies that study the affect of number of parameters togethers tend to work on theoretical site as it is easier to parametrize, however, it is not the case on the reality.
4- There is a shortage of study on the effect of microclimate on persons walking, as the majority of studies assume people are standing or sitting.
5- Finally, outdoor thermal comfort studies in UAE focus on Abu Dhabi and Dubai, while there is absence of research taking Sharjah as case study even though, Sharjah has a very unique urban fabric and known as the most family-friendly city in uae. Which make it an interesting case study.

Chapter 3. Methodology

3.1 Research Approaches

Due to the large variety of factors and parameters involved, many methodologies were employed to study outdoor thermal comfort and walkability. Each approach has distinct advantages and disadvantages that may be determined according to the study objective. The investigated approaches demonstrate a proclivity towards data collection via field measurement. Recent study has identified the most often utilized approach as a combination of field measurements and questionnaires. To obtain more control over the parameters, several researchers have used numerical simulation. Additionally, a field experiment dubbed the "thermal walk" is gaining popularity. Finally, because the corpus of research on the subject has grown significantly over the last two decades, several review papers have been published.

3.2 Methods used to investigate this topic area

3.2.1 Field survey

Field survey methodology may include objective measurements made with specialized equipment, questionnaire surveys, or a combination of the two. This methodology has been extensively used in this subject. This is primarily due to the availability of international standards that evaluate data collection procedures (e.g., ISO 11079), survey preparation procedures (e.g., ASHRAE Standard 55), and thermal characteristic estimation procedures (e.g., ISO 9920). Additionally, by integrating field and questionnaire measurements, researchers can examine both the quantitative and qualitative components of the problem (Kumar and Sharma, 2020).

Field measurements capture data in the "actual world" (Lai et al., 2019b), whereas the questionnaire elicits information about people's perception and temperature experience. For example, to investigate how direct and indirect factors affect thermal comfort in a dynamic outdoor environment, Peng et al., (2019) monitored meteorological variables over a 10-day period in a Netherlands industrial area using monitoring sensors and a data logger in accordance with the ISO7726 standard. The monitoring sensors recorded the temperature of the air, the global temperature, the wind velocity, and the relative humidity. Simultaneously, 1000 questionnaire-based interviews were conducted, with the duration of each interview and the respondents' physical condition documented. The researchers utilized a statistical approach called "path analysis" to examine the relationship between endogenous and exogenous variables. The same standard (ISO7726) was utilized for field measurements in Mouada et al., (2019) study on outdoor thermal comfort and its relationship to walkability and urban morphology, while ASHRAE Standard 55 was employed in a questionnaire to evaluate 180 participants' thermal sensation votes (TSV).

Numerous questionnaires have been utilized in the prior literature. For instance, in an attitude survey, participants rate their agreement or disagreement with a sentence on a five-, six-, or seven-point scale known as a Likert scale. On the other hand, personal interviews or semi-structured interviews can elicit more valid responses by allowing participants to respond freely. The second type, on the other hand, necessitates preparation and recording. The type of questionnaire to use is determined by the size of the case study and the criteria. Zuniga-Teran et al., (2017) developed a questionnaire based on LEED-ND and other validated questionnaires to assess the walkability and wellbeing of various community designs. The questionnaire is divided into nine components, the first of which is used to determine the type of neighborhood in which each participant resides using an aerial photo and supporting questions about urban characteristics. The section on walkability was created using the Neighborhood Environment Walkability Scale (NEWS), the walk score, and other valid tools. Additionally, walking was categorised according to the reason for walking, which included recreation and transportation. The questionnaire was distributed via a webpage, but it did not achieve a balanced amount of participants across neighbourhoods; for example, the number of participants who live in traditional development filled out the questionnaire is 189, but the number of participants who live in cluster housing is only 3. As a result, a paper copy was distributed at a park, and emails were sent to inhabitants of enclosed and cluster areas. 380 surveys were completed in total (online, paper-based, emails). Analysis of variance (ANOVA) was used to assess the data acquired via the questionnaire. ANOVA is a statistical model that describes the variation of outcomes according to the size of relationships.

3.2.2 Literature review

While perusing papers in the fields of outdoor thermal comfort from a behavioural perspective and the influence of the urban environment on walkability, it is found that various research published in the previous two years have employed a literature review methodology to investigate the issue. This could be a result of the increasing interest in this subject. Typically, the approach for conducting a literature review begins with data collection via academic databases and the use of certain key words selected by the researchers. This approach provides several advantages. To begin, it enables researchers to construct an assessment framework based on the findings of prior investigations. Second, it serves as a standard for previous work in the topic, assisting researchers in finding any knowledge gaps, conflicting results, or opportunities for development. Finally, it is an effective tool for highlighting the shortcomings of the various approaches employed to research the topic.

Kumar & Sharma (2020) undertook a comprehensive review of the literature on outdoor thermal comfort, focusing on research completed via field surveys and questionnaires between 2001 and 2019. The study's search process identified five keywords, including outdoor thermal comfort and thermal perception. Additionally, the researchers organized the literature according to the following themes: climatic zones defined by the Köppen climate classification system, OTC indices classified according to their frequency of use, the indices' validity and suitability for each climatic zone, data collection method and standard used for measurements, and finally, the key findings of each study. The study was successful in identifying various knowledge gaps as well as areas of future research interest.

In contrast to the previous section, a literature review methodology was utilized to classify optimization solutions for outdoor thermal comfort in a specific region, taking human activities into account (Li and Liu, 2020; Shooshtarian, 2019). Li & Liu (2020) conducted a review of 123 papers that examined outdoor thermal comfort ranges and thermal perception in China. These papers were chosen from a total of 378 articles on China's outdoor thermal comfort that were compiled using four academic databases (ScienceDirect, SAGE journals, Scopus, and Web of Science). In addition to the data-driven analytical strategy, the researchers scanned the bibliographic data to categorise the results using scientific mapping. Additionally, the Citespace scientometric tool was employed to do the analysis. The study classified the papers into the following categories: thermal indices (just the four most frequently used- PET, PMV, UTCI, and SET), study region, urban elements (including buildings, vegetation, pavement, weather, and vehicles), and noteworthy findings. At the conclusion of the study, specific solutions for optimizing outdoor thermal comfort were developed for the Chinese thermal perception. Similarly, Shooshtarian et al. (2020) concentrated on the Australia region with the objective of laying the foundation for an Australian standard for outdoor thermal comfort.

Antonini et al. (2020) conducted a comprehensive review of outdoor thermal comfort in terms of wellbeing. As with past studies, the work begins with a data gathering phase that utilizes multiple keywords to search academic resources. A total of 855 research papers were identified; the researcher filtered them by excluding those that did not include at least three keywords in order to identify the most pertinent ones; 236 papers were selected and analysed under three main sections to investigate mathematical models and indexes used to quantify human energy balance, human thermal perception (physical, physiological, and psychological). The study's findings indicate that a transdisciplinary approach is necessary for comprehending the behavioural implications.

3.2.3 Field experiment "Thermal walks"

The thermal walk is a qualitative approach used to measure people's perceptions of outdoor thermal conditions while they are moving. This methodology was first developed by Vasilikou (2014) as a tool for evaluating the point-to-point performance of a group of participants during an organized walk. The methodology's origins can be traced back to the sense-walking idea proposed by Southworth (1969). The experiment begins with the researchers selecting a walking path or many walking paths, depending on the area's scale. A number of people will be requested to walk the walkway during various times of the day and occasionally seasons and rate their thermal comfort in defined positions using a 5-point Likert scale. The scale is intended to record the level of thermal comfort and the change in this level caused by spatial changes during the walk. This experiment is frequently conducted in conjunction with field measurements of weather conditions (Lenzholzer et al., 2018).

Sabbagh et al. (2016) used thermal walk methods to determine people's tolerance for walking outdoors across the seasons in Dubai. Three guys and three ladies aged 32-35 years and with a BMI of 26-29 participated in the experiment. The participants walked for 15 minutes along the path six days a week during the months of January, May, and November. Each day, the experiment took place at the same time. To determine the influence of wind and shading on precepts, a shaded region with a fan generating wind at a speed of 3.2 m/s was placed at the path's conclusion. Participants walked for approximately four minutes in the shade before returning to the sun for an additional minute. Thermal sensation and the influence of spatial transitions were evaluated using two different criteria: the Thermal Sensation Vote (TSV) and the Thermal Comfort Vote (TCV). Throughout the experiment, air temperature, wind speed, and relative humidity were recorded using a handheld device (testo 410-2). Skin temperature was determined using a different equipment (Fluke 563 infrared thermometer). The ASHRAE 7-point scale and the ASHREA 6-point comfort scale were used to measure the level of comfort.

On a bigger scale of urban sequence, Vasilikou & Nikolopoulou (2020b) investigated the thermal perception of persons walking 500-meter-long paths that have the same sky view factor in the central business districts of two European cities (Rome and London) using thermal walks. Six places were established along each trip for participants to provide comments on heat experience via questionnaire. Summer and winter, people walk daily at 2 p.m. and 12 p.m. 314 questionnaires were completed throughout a three-year period. Microclimatic monitoring was carried out during the experiment using a stationary weather station equipped with a datalogger and sensors that adhere to the ISO 7726 standard and recorded air temperature, global temperature, relative humidity, wind velocity, and illuminance. Additional measurements of the surface temperature of walls and pavement were taken using an infrared thermometer pistol. Actual Sensation Vote (ASV) and differential thermal sensation were used to examine the data (dASV).

3.2.4 Simulation

Nowadays, numerical simulation is a widely used methodology for simulating real-world phenomena by utilizing sets of pre-coded mathematical equations (numerical models). It enables the investigation of variables in a variety of suggested satiations in a cost-effective and straightforward manner. Simulation techniques address the limits of conventional methodologies in terms of scale, duration, expense, and level of control. Numerous simulation software packages are currently available for simulating urban microclimates, including RayMan, SOLWEIG, UMI/UWG, and DIVA for assessing radiation, FlowDesign and Fluent for assessing wind speed and air temperature, and ENVI-met and CityComfort+ for assessing all of them simultaneously (Crank et al., 2018; Elwy et al., 2018; Fröhlich et al., 2019; Gál and Kántor, 2020; Liu et al., 2020; Roth and Lim, 2017; Sharmin et al., 2017).The comparison in Table 1 is between simulation software used to calculate thermal comfort indices.

ENVI-met is the most often used simulation tool in this field of inquiry (outdoor thermal comfort). Ma et al. (2019) conducted a detailed assessment of numerous urban characteristics impacting tourist outdoor comfort in Tai Zhou's historic downtown area. According to the researchers, the area was divided into six blocks based on its urban physical characteristics. On July 30th and 31st, from 9:00 a.m. to 5:00 p.m., microclimate measurements for wind speed, air temperature, and relative humidity were taken in each block for model validation purposes. The site was modelled in ENVI-met using Google Maps and field data; additionally, the grid cell size was set to 333 meters. Simulating the existing state took around 48 hours. The researcher evaluated four redesign scenarios: increasing building height, increasing vegetation coverage, modifying the material of pavements, and combining all of them based on the PET value at six points in each model. At the conclusion of the study, researchers addressed a fundamental shortcoming of the software, namely that it treats buildings as a single wall and disregards wind velocity, wind direction, and sky cover conditions.

Another study conducted by Aydin & Jakubiec (2018) used a parametric simulation interface called Grasshopper for Rhino to assess the effect of several urban design parameters on outdoor thermal comfort. These parameters included building geometries and their relationship to the street, orientation, construction material, pavement, and greenery. Researchers were able to calculate four critical environmental indicators using the ladybug tools plugin, including the Urban Heat Island (UHI) using Dragonfly simulation tools, the Universal Thermal Climate Index (UTCI) using Honeybee simulation tools, the Urban Energy Use Intensity (EUI) using Butterfly OPENFOAM, and the Urban Daylight Autonomy (UDA) using Urban daylight simulation tools. A potential parametric urban model with a plant border and a surface separated into sidewalks and pavements was created. The heights of the buildings were determined by their intended function, with a 3 m floor height and shading elements ranging in depth from 0.1 m to 1.5 m. The results were analysed using sensitivity analysis.

Table 1: Outdoor thermal comfort- simulation tools comparison (researcher)

Simulation Tool	**Microclimate Parameters**			**Strength**	**Weakness**
	Radiation	Wind Speed	Temp. Air		
CityComfort+	Yes	Yes	Yes	Identify and evaluate several radiation-related measurements, such as long-wave radiation emitted by the atmosphere and by urban surfaces (direct/ diffuse/ reflected).	The software is not yet commercially available as it is still in the development stage
ENVI-met	Yes	Yes	Yes	Simulate the mean radiant temperature (T_{mrt}) Simulate a while surface.	Geometries transformed into pixels/ doesn't process vectors Time consuming (6h for one simulation) Validation of the software showed a weak match with long-wave radiation
ANSYS Fluent	No	Yes	Yes	One of the best CFD software Consume less simulation time comparing to other CFD software Reliable accuracy Perform optimization Allow customization of input	High computational cost Only perform CFD

FlowDesing	No	Yes	Yes	Very quick and easy Interactive: the effects of changes on the model is simulated immediately Free for students	High computational cost No recent publication used flow-design Only perform CFD Doesn't allow customization
Diva	Yes	No	No	Specialized in advance lighting simulation and radiations a NURBS modeling	Expensive Assess only radiation
SOLWEIG	Yes	No	No	Easy to use Fast Compatible with GID system	Use very simplified formulas to simulate solar radiation. Demonstrates errors
RayMan	Yes	No	No	Simulate the mean radiant temperature (T_{mrt}) Easy to use	Gives results for one point on each run Errors accrue with low solar angles Do not include reflected short-wave radiation

3.3Research method and justification

This research acknowledged the need of making recommendations to urban planners and designers on how to simultaneously improve outdoor thermal comfort and walkability in the UAE. As such, this research seeks to establish a relationship between outdoor thermal comfort and walkability by examining how various sustainable design techniques for improving outdoor thermal comfort may be codified to also improve walkability. The technique used in this study should be capable of addressing both the quantitative and qualitative aspects of the problem while also allowing for the investigation of numerous design iterations. Table 1 compares the examined techniques in light of the study's primary objective. The comparison indicates that the research will employ an integrated technique that blends field survey and simulation. The technique enables the researcher to explore the subject holistically and critically, while also studying each parameter in its own context. Field surveys are a good way to understand people's behavior under certain conditions, whereas simulations give a complete control that allows the researcher to analyze the research topic parametrically.

Table 2: Comparison between the methodologies (researcher).

Methodology	Comparison criteria		Additional comments
	Strength points	**Weakness points**	
Field survey	▪ Provide real-world data. ▪ Capture social context, individual's subjectivity and behavioral aspects. ▪ High accuracy level ▪ Availability of international standards.	▪ Require resources: measuring equipment, manpower (to collect data and questionnaires) ▪ Many parameters cannot be controlled. ▪ Time-consuming; in case of evaluating scenarios in various session.	Since this research is customized to UAE weather and culture, field motoring is required to record the meteorological data.
Literature review	▪ Develop a thorough foundation for the preceding work ▪ Emphasize inconsistencies in the outcomes. ▪ Determine the knowledge gap. ▪ Contribute to the development of recommendations and future enhancements	▪ Restricted to readily accessible sources ▪ Restriction of researcher intervention.	It is a required auxiliary approach that assists researchers in selecting study parameters, analytic methodologies, and standards.
Field experiment	▪ Allow for involvement by researchers in real-world scenarios. ▪ Capture the social context, the subjectivity, and behavioral characteristics of an individual.	▪ Resources and volunteers are required. ▪ Numerous factors are uncontrollable. ▪ Time-consuming; especially when assessing scenarios across several sessions. ▪ The precision of the results is dependent on the number of participants and repetitions. ▪ Expensive.	Thermal walks as field experiments are still considered novel, though.
Simulation	▪ Give the model total control. ▪ Can be conducted at a variety of urban sizes. ▪ Affordable. ▪ Can be used to account for all climates. ▪ Researchers have access to this tool. ▪ Reduce the amount of equipment required. ▪ There is no requirement for more room. ▪ Can be used to conduct an optimization study.	▪ Validation against field measurements is required. ▪ Accuracy is proportional to the amount of detail in the model and the duration of the simulation.	Among all of the techniques available, simulation is the most convenient for testing proposed scenarios.

3.4Methodological framework

As indicated previously, this project will employ an integrated technique that will incorporate field survey and simulation. The next sections will discuss the phases of study, the instruments and tools that will be necessary, and the estimated time frame.

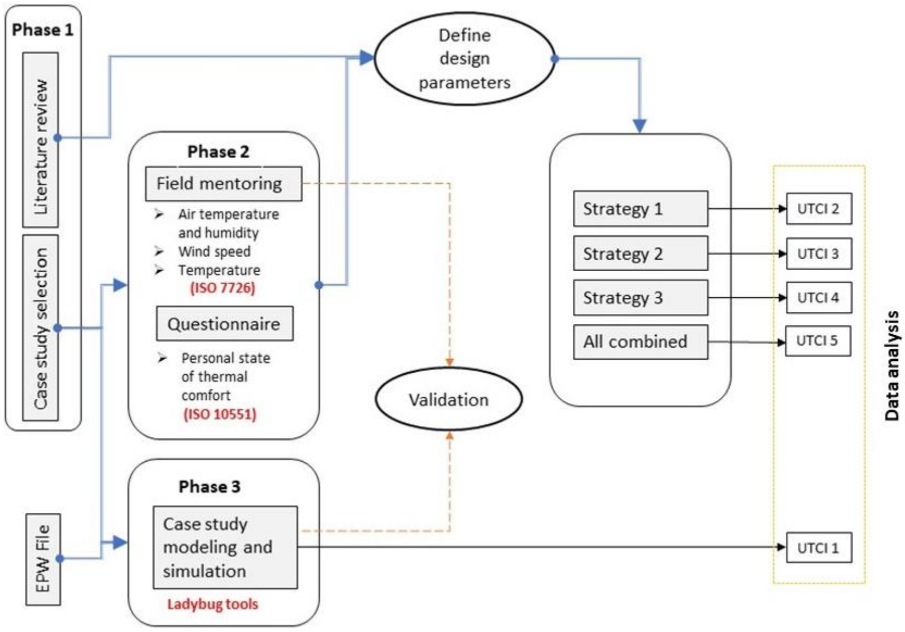


Figure 4: Methodological framework (researcher).

3.5 Research phases

Phase 1: Literature review and Case study selection

The research will begin with a review of publications, books, conference papers, and reports on sustainable urban design development, outdoor thermal comfort, and walkability. Numerous academic databases and search engines, including ScienceDirect, Research Gate, and JSTORE, will be utilised. The following should be accomplished by the conclusion of this stage:

- Identify factors impacting people's outdoor thermal comfort while walking.
- Classified the parameters according to their natural or constructed surroundings and individual motivations.
- Determine the method of evaluation to be utilized, as well as the criteria and thermal comfort indices to be employed.
- Determine the most promising strategies at the urban development level.

Additionally, a mixed-use neighbourhood in Sharjah will be chosen as a case study to reflect Sharjah's urban areas. The case studies will be chosen based on their "walk score," which is a grading indicator for how pedestrian-friendly a region is when activities within walking distance are considered. The project will employ a neighbourhood as a case study to enable comparisons between the various journey's individuals take, with a particular emphasis on pedestrian routes that connect to significant landmarks and services in the town.

Phase 2: Field survey

The research focuses on Sharjah's unique climate and includes a case study with its own urban structure and features, necessitating a field survey. The field study will be divided into two primary objectives: characterizing the built and natural environments and observing people's travel behaviour. To accomplish the first objective, field monitoring will be conducted in chosen case studies to assess the influence of each space type and morphological feature on the microclimate at a number of locations inside each urban canyon. Urban climatology is the primary factor that defines the level of comfort in an outdoor environment, and field measurements may be used to analyse a hypothesis or connection. Accuracy and method for field measurements are dependent on the equipment employed. A set of measuring stations will be established to record Tair, sun radiation, relative humidity, and wind speed, in accordance with the ISO 7726 standard, which recommends taking measurements at a fixed height (0.6 to 1.1 m) and shielding the equipment.

On the other hand, a questionnaire will be randomly given to pedestrians along the routes at various times of the day in order to assess people's happiness and resolve subjective issues. A pilot survey will be issued first to see whether the questionnaire is clear and easy for participants to complete. Participants' information will be collected, including their gender, age, attire, and reason for walking (recreational or daily journey). The ASHRAE 55 scale will be used to assess subjective ratings of thermal comfort (TCV) and thermal sensation (TSV).

Phase 3: Simulation

At this level, micro-urban performance simulations for the case studies will be undertaken. The simulation will be carried out utilizing Ladybug tools within the Rhino 3D visual coding interface Grasshopper. The primary reason for using Grasshopper is that it enables the straightforward inclusion of a large number of parameters, as well as the availability of optimization tools within the same plugin and the ability to evaluate several heat balancing indices such as UTCI and PET. This phase will consist of the following steps:

1. Creating a model for the Base scenario, importing data from the EnergPlus weather file (EPW), and running an initial simulation to determine the UTCI.

- Validation of the results by comparison to field monitoring data: UTCI is computed using the following microclimate factors: air temperature, mean radiant temperature, relative humidity, and wind speed. Instruments for monitoring the aforementioned microclimate parameters are required. There will be two sorts of instruments used: stationery and handhold. Instruments with a handle are required. two evaluate microclimate variance throughout the trail in order to discover benefits resulting from physical factors like as shade and vegetation. The following table details the instruments that will be utilized.

Table 3: Instruments used in field monitoring (researcher).

Parameter	Temperature, humidity,	Air velocity and wind-chill	Mean radiant
Instrument (Available at BUID)			
	Data logger model 42280	Mini Thermo-Anemometer Model: 45158	Heat Stress WBGT Meter Model HT30

2. Developing a parametric model to connect the key parameters that enhance thermal comfort and promote walkability as identified through field surveys and questionnaires. For example, many studies identified H/W as a key parameter; H/W is affected by building height, making increasing building height a strategy that could be parametrically linked to increase the value of the outdoor thermal comfort metric (UTCI).
3. Use UTCI simulation to determine the influence of altering urban morphologies (Street orientation and H/W) on outdoor thermal comfort in a case study. The optimization process will be conducted in four stages: the first stage will involve modifying the vegetation location and density while maintaining a 1.5 m clear path for walking; the second stage will involve modifying the building height while maintaining a 1.5 m clear path for walking; the third stage will involve optimizing the street ground floor design while allowing shading devices to be extruded to 1.5 m depth; and finally, all proposed modifications will be combined. While the suggested adjustments are based on the

literature study, additional modifications should be made based on the results of the field survey.

3.6 Data analysis method

The simulation and optimization results will be analyzed and compared in terms of the percent increase in outdoor thermal comfort that each approach can accomplish and the greatest decrease in UTCI that can be achieved. Additionally, a qualitative study will be done to compare the practicality of each approach to the state of the pedestrian path. A critical assessment factor is if the path achieves a high degree of consistency in terms of comfort level.

Chapter 4. The case of Al Majaz in Sharjah

4.1. Introduction

The first section of this chapter introduces Al Majaz in Sharjah as the selected urban district for the field investigation and simulation in addition to, an overlook on the area nature, location, typology, facilities, street design, land use, and climate. Followed by field observation and survey, and finally provide an overview on the simulation code and the scenarios.

4.2. The context

The city of Sharjah is one of the largest emirates in UAE and the third-most populous one after Dubai and Abu Dhabi. It sits in the southern part of the Arabian Gulf and shares its border with Dubai, Ajman, Al Fujairah, and Ras Al Khaimah. Conveniently located at the heart of Sharjah, Al Majaz is a mixed-use waterfront community lunched by Sharjah Investment and Development Authority on the curve of Khalid lagoon. Spreading over 231000 Sq.ft, Al Majaz known as one of the most coveted residential areas in Sharjah that accommodate low-, mid- and high-rise residential buildings along with several outdoor spaces and attractions.

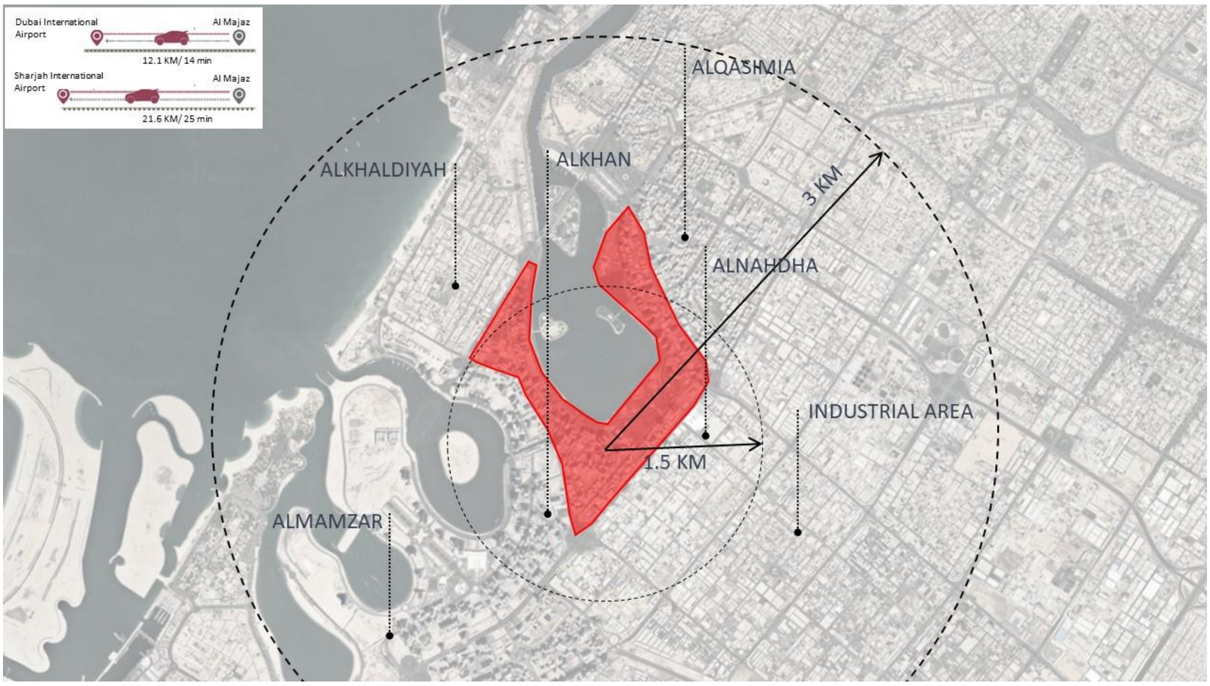


Figure 5: Location of the case study and surrounded area (researcher).

A mixed-use area in Al Majaz is selected for the investigation as shown in the Figure 6. Figure 7, is a key map of pictures locations that was taken during site visits. As shown in the picture, the site is characterized as dense, and it accommodates number of facilities, for example, retails, mosques and medical centres.

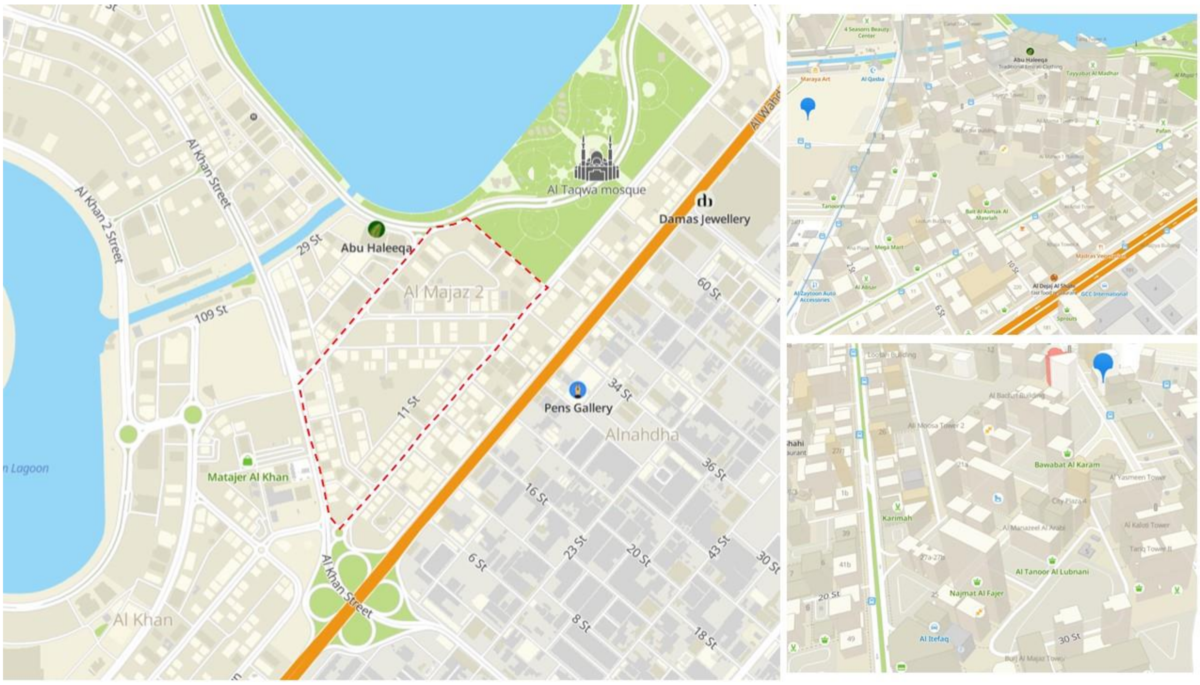


Figure 6: The selected site in Al Majaz (2gis.ae, 2021)

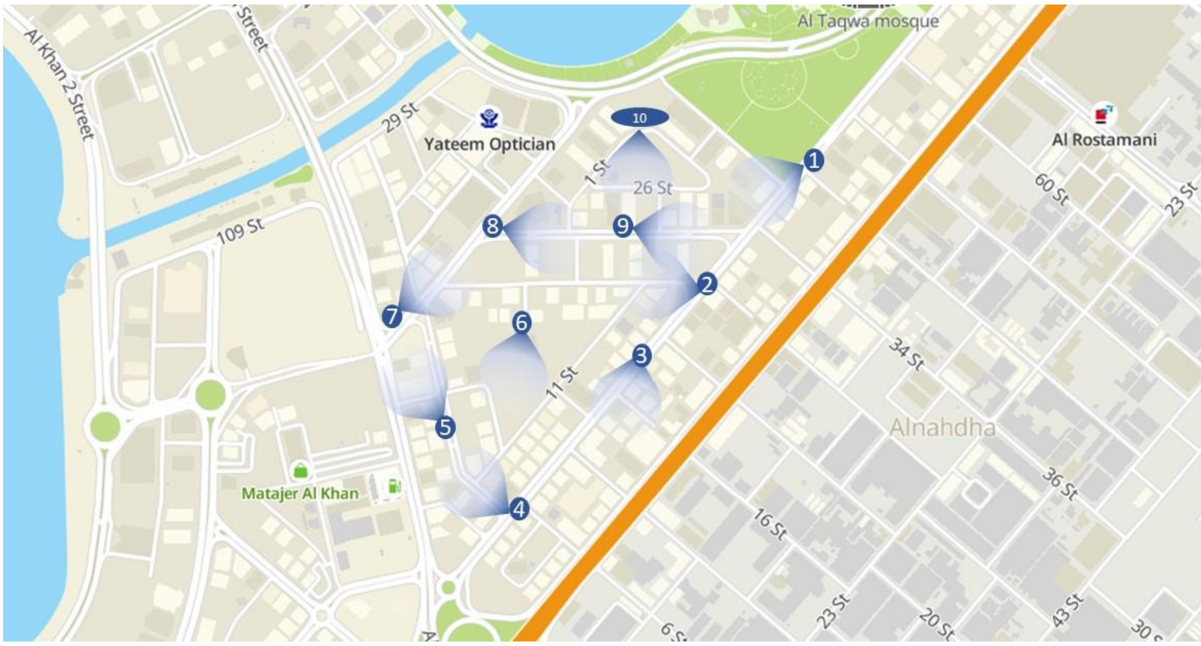


Figure 7: Key map for the site pictures (2gis.ae, 2021 edited).

Figure 8: Photos of the selected area- site visits (researcher).

Two primary roads with width of 36.6 m crossing the selected site along with another primary road with width of 24.4 m. Most of the secondary roads have a width of 18.3 as shown in Figure 9.

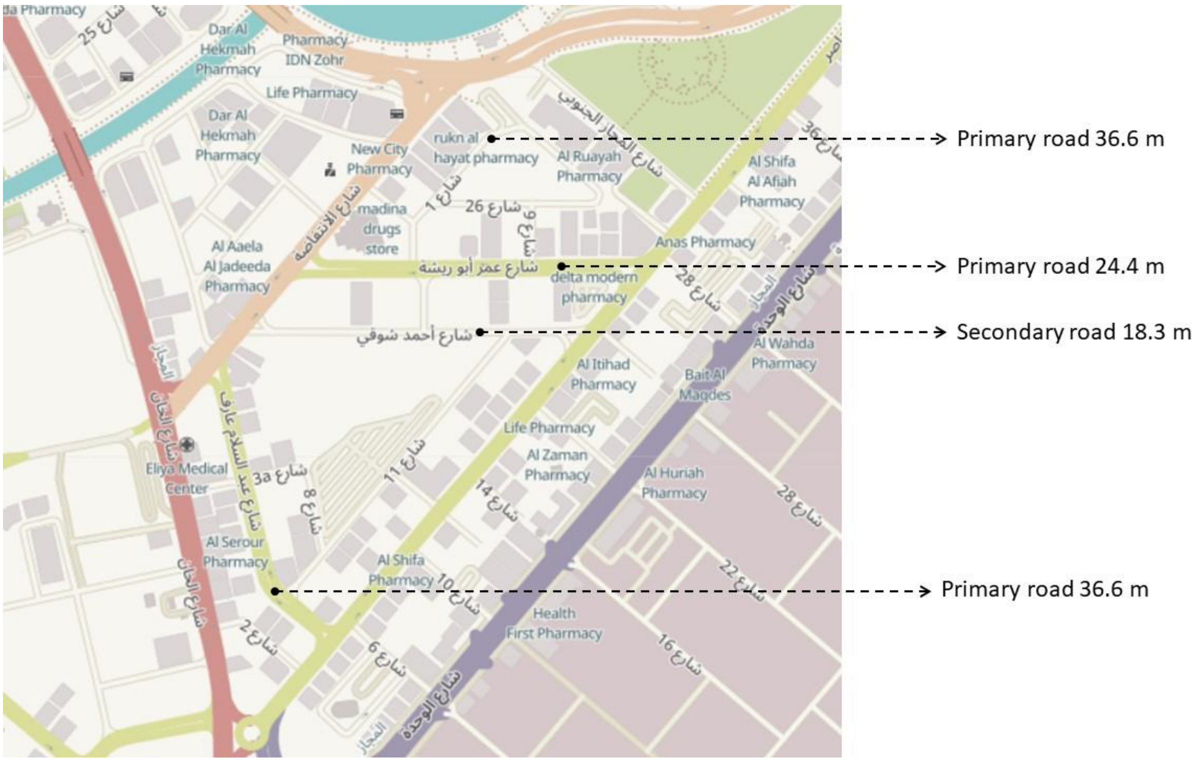


Figure 9: The hierarchy of roads within the site (OpenStreetMap, 2021 edited).

4.2.1 Climatic Analysis

In the UAE, summers are hot and humid; little rain falls in the UAE during the year, and winters are mild. However, rainfall has increased recently, albeit in small amounts, as a result of current climate change. For the simulation process, the climatic data provided in this section will be used as climatic data such as temperature, rainfall, humidity, and wind speed. The presented information was taken from The National Center of Meteorology, Meteorological department, Sharjah international airport weather station. The climatic data is recorded for the year 2020. 7

4.2.1.1 Temperature in Sharjah

Sharjah's temperature can reach 47.5°C and typically hovers between 28 and 34°C. As illustrated in Figure 10, Sharjah's average temperature in 2020 is 21.3°C in the winter and sometimes it reached 9.2°C at night. July, but at the other hand, is the warmest month, while february is the coldest. The average minimum and highest dry bulb temperatures in Sharjah throughout the year are depicted in Figure 10. Average sun duration per month is in Figure 11.

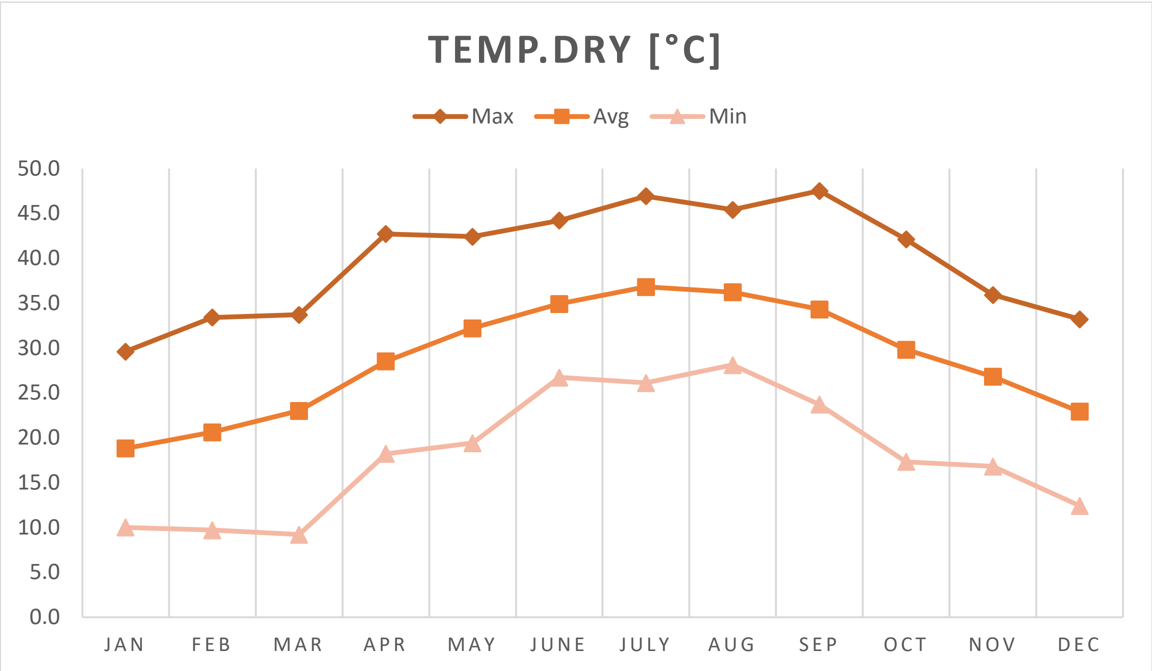


Figure 10: Average, minimum and maximum of dry bulb temperature in Sharjah over the year of 2020, (The National Center of Meteorology 2021).

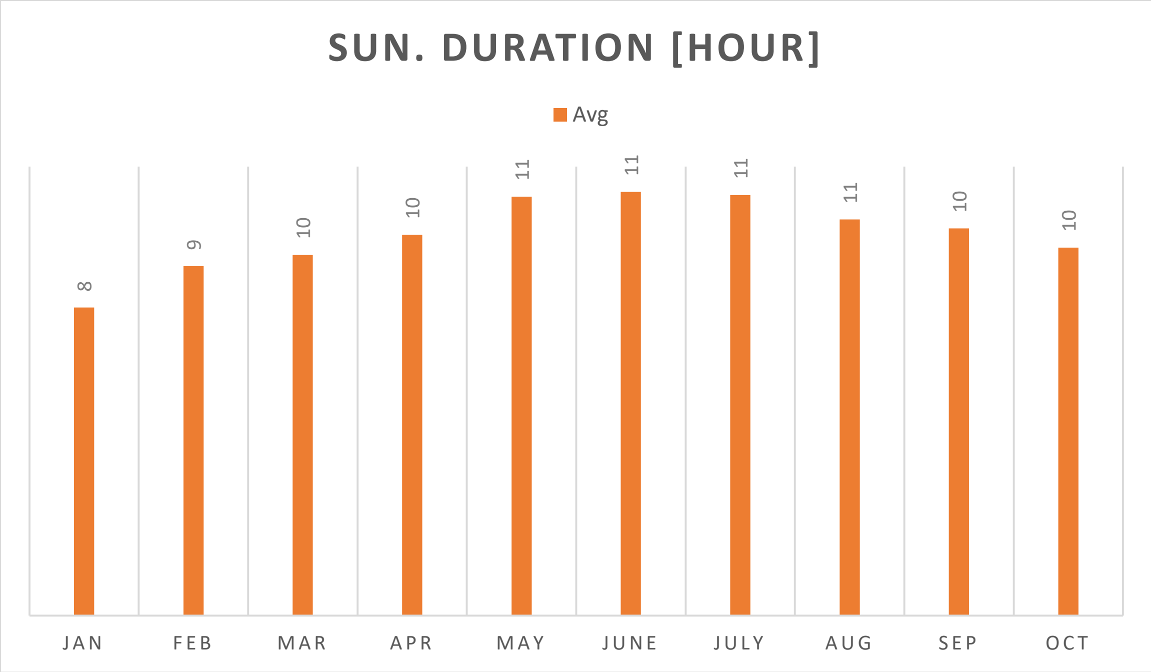


Figure 11: Average hours of sun duration each month in year (The National Center of Meteorology 2021).

4.2.1.2 Rainfall in Sharjah

The UAE has a dry climate. The National Center of Meteorology noted that thunderstorms are common in December and January. January in 2020 was the wettest month, on the other hand, February normally is considered the wettest month, while August is considered the driest. depicts the average annual precipitation in Dubai.

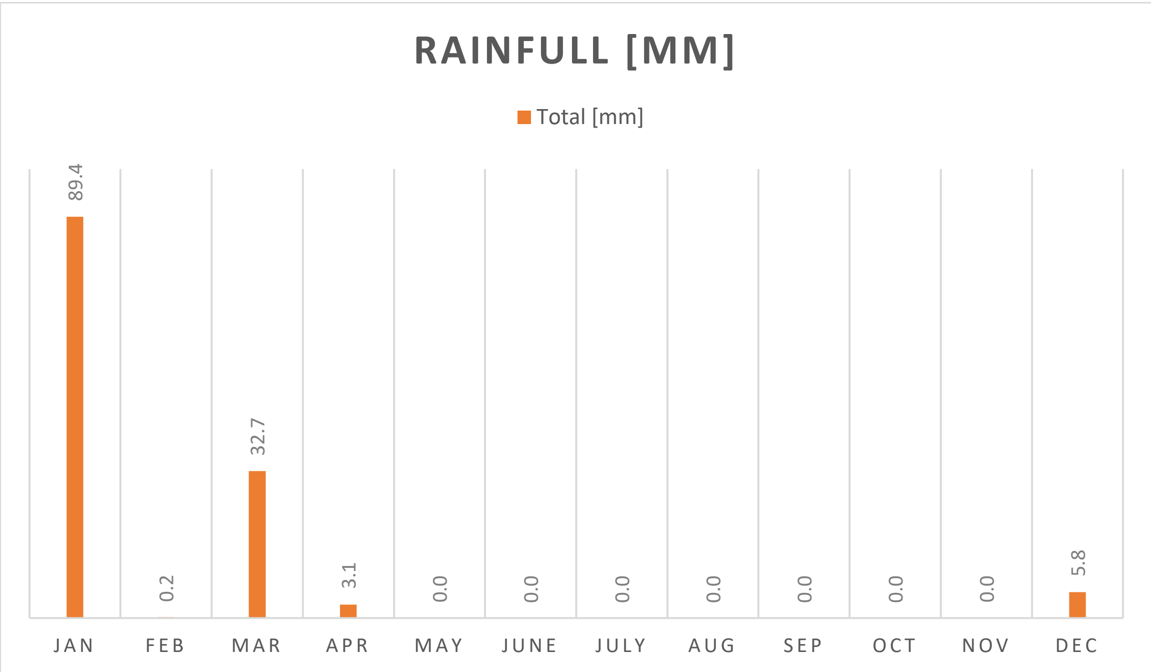


Figure 12: precipitation in Sharjah over the year 2020 (The National Center of Meteorology 2021).

4.2.1.3 Humidity in Sharjah

The average relative humidity in Sharjah Rangers between 50% in summer and 59% in winter. However maximum humidity in 2020 recorder 99%. And the lowest humidity was recorded in the year of 2020 is 2% in october.

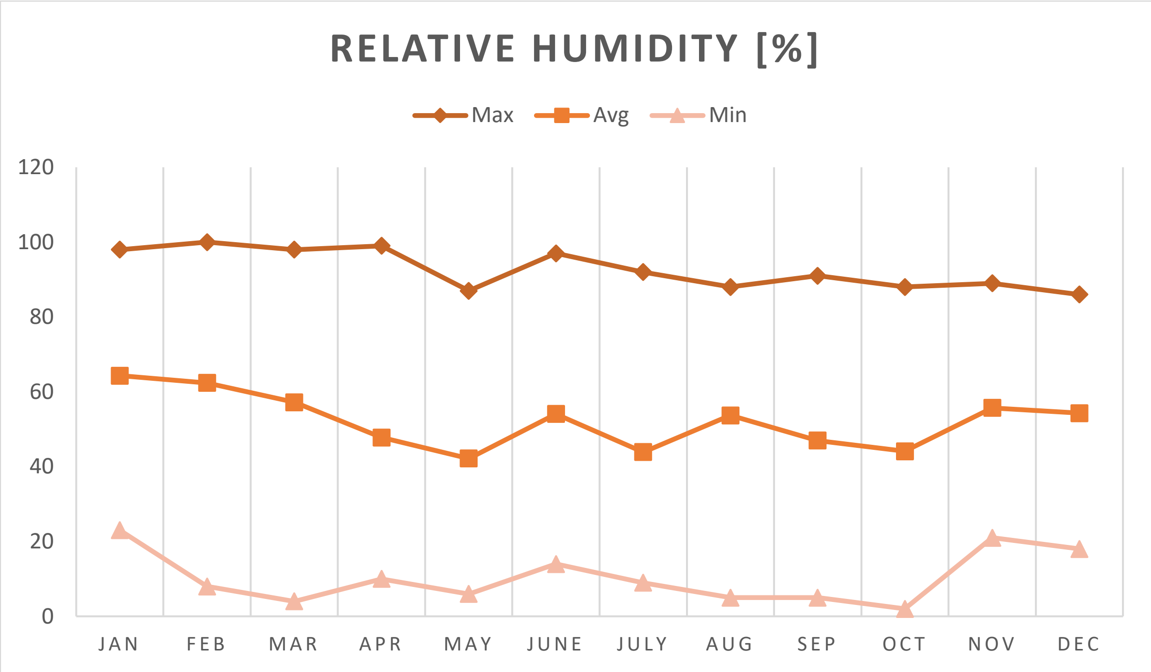


Figure 13: Average, minimum and maximum of relative humidity in Sharjah over the year 2020 (The National Center of Meteorology 2021).

4.2.1.4 Wind in Sharjah

In Sharjah, the stronger winds blows from the northern-west direction mostly in May and July.

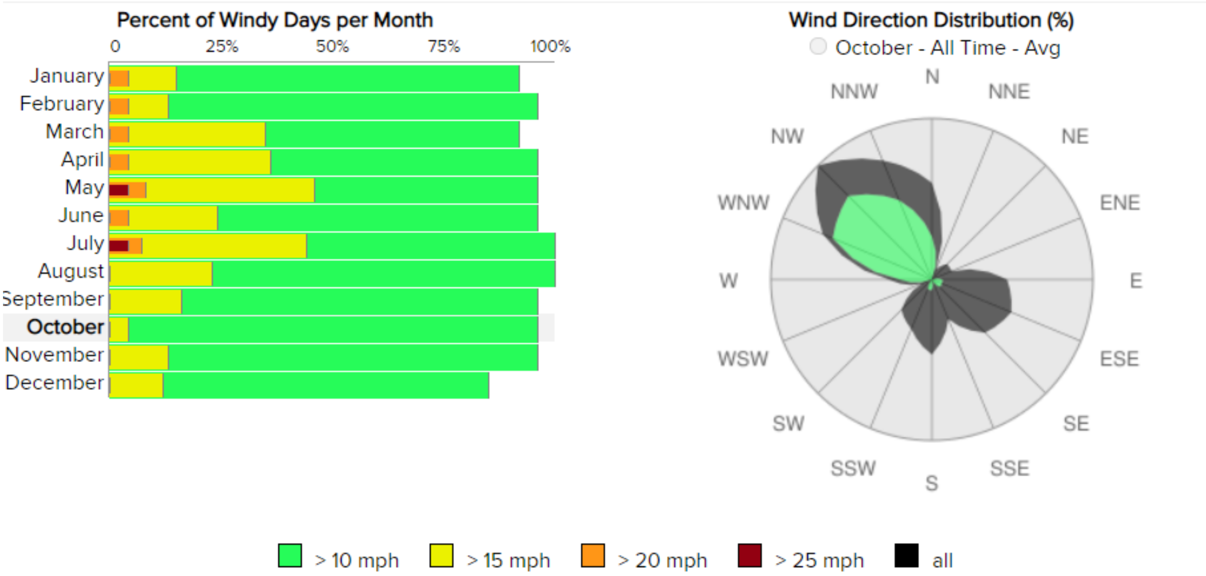


Figure 14: Windrose and the percent of windy days per month in sharjah (from 2007 to 2021) (https://windalert.com/ 2021).

The average wind speed in Sharjah ranges from 9 Km/h to 13 Km/h and can reaches up to 48 Km/h in January and April as show in the data recorded for the year 2020 as shown in Table 4.

Table 4: Average, and maximum of wind speed in Sharjah over the year 2020 (The National Center of Meteorology 2021).

Wind Speed [Km/h]		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Max	48	43	46	48	52	33	44	30	30	26	31	28
	Avg.	12	11	13	11	12	12	13	12	10	9	10	9

4.3. Field survey and monitoring

Field observations and interviews along with field measurements for Air temperature, humidity and wind speed and direction was done for three days, 15th of February, 15th of July and 15th of September between 9:00-10:00, 12:00-1:00 and 16:00-17:00. The main aim of the interviews was to understand thermal sensation of people walking in the selected area and identify their comfort levels. While the measurements in necessary to link the comfortability level of individuals with the climatic conditions. The investigator approach people while they are walking in the site. It was observed that during July many individuals refused to do interview or didn't complete it because they don't want to stand outside. Several field observations were recorded from site visits and field measurements as shown in the below group of photos.

Figure 15: Photos of the field interviews and field measurements (researcher).

Before each interview, date, time air temperature, wind speed and humidity wet bulb temperature are recorded. Then the interview starts with general information about the individuals such as, gender, age, and clothing. Then individuals were asked to describe their feeling if they are feeling cold, cool, slightly cool, neutral, slightly warm, warm, or hot which is thermal sensation measure according to ASHRAE (TSV) and rate their overall comfort from 1 (very comfortable to 5 very uncomfortable using ASHRAE (TCV).

The interview also includes questions on the individual's perception on the microclimate conditions and their walking routes and routine, if they have a car or not and other information.

4.4.Thermal walk

An 11 min-walk path was selected for the thermal walks as shown in the Figure 16. The main reasons of selecting this path are first, it is straight path and second it has no obstacles which minimize the chance of facing issues during the thermal walk.

The aim of the experiment is to investigate how individual perception is affected by the level of activity and identify the duration of short walks that they can attempt with maintaining their comfort under the site microclimatic conditions.

Five participants accepted to do the experiment in 9th of September. Each participant did three walks, one in the morning between 9:00am to 10:00 am, one afternoon at 12:00pm to 13:00 pm and the last one between 16:00 pm to 17:00 pm. All participants are males, with BMI ranges between 24.7 to 27. Moreover, participants are from different nationalities: Emirati, Indian, Filipino, Jordanian, and Egyptian. The investigator approached several females asking them to participate in the thermal walk, but none accepted.

All participants spent 15 min in air-conditioned area before starting the thermal walk. They were asked to describe their thermal sensation and comfort level through TSV and TCV method at the beginning and the end of the walk. Moreover, their temperature was recorded each minute while walking using Digital Infrared Forehead Thermometer.

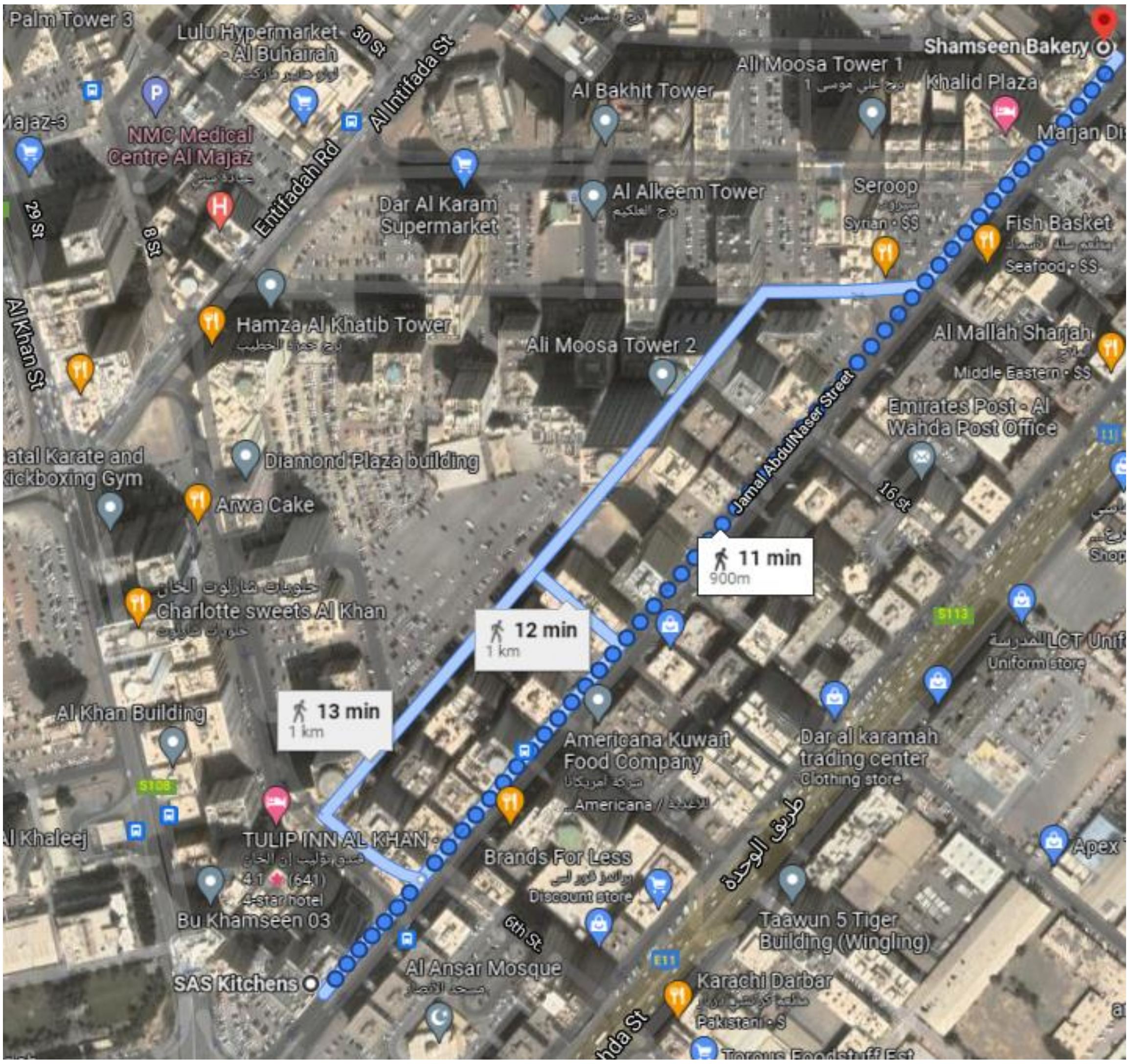


Figure 16: Path of the experiment of thermal walks (Google Maps 2021).

Table 5: summary of thermal walk participants (researcher).

No.	Nationality	Age	Number of years in UAE	BMI
1	Emirati	31	31	26.8
2	Indian	27	2.5	26.9
3	Filipino	29	3	24.1
4	Jordanian	26	6	25.8
5	Egyptian	29	29	26.4

4.5.Parametric model and UTCI code in grasshopper

The current condition of the site was coded using grasshopper parametrically to allow changing the building height throughout the simulation of the scenarios and linked to UTCI simulation tools which are part of ladybug plugin in Grasshopper. UTCI code sample is provided on ladybug website, however, the code was edited to serve research goal by customizing the period of analysis. This was an important step that allowed the simulation to be conducted on urban district scale which was not possible in the original code. Figure 17 illustrates the code used to do the simulation in grasshopper.

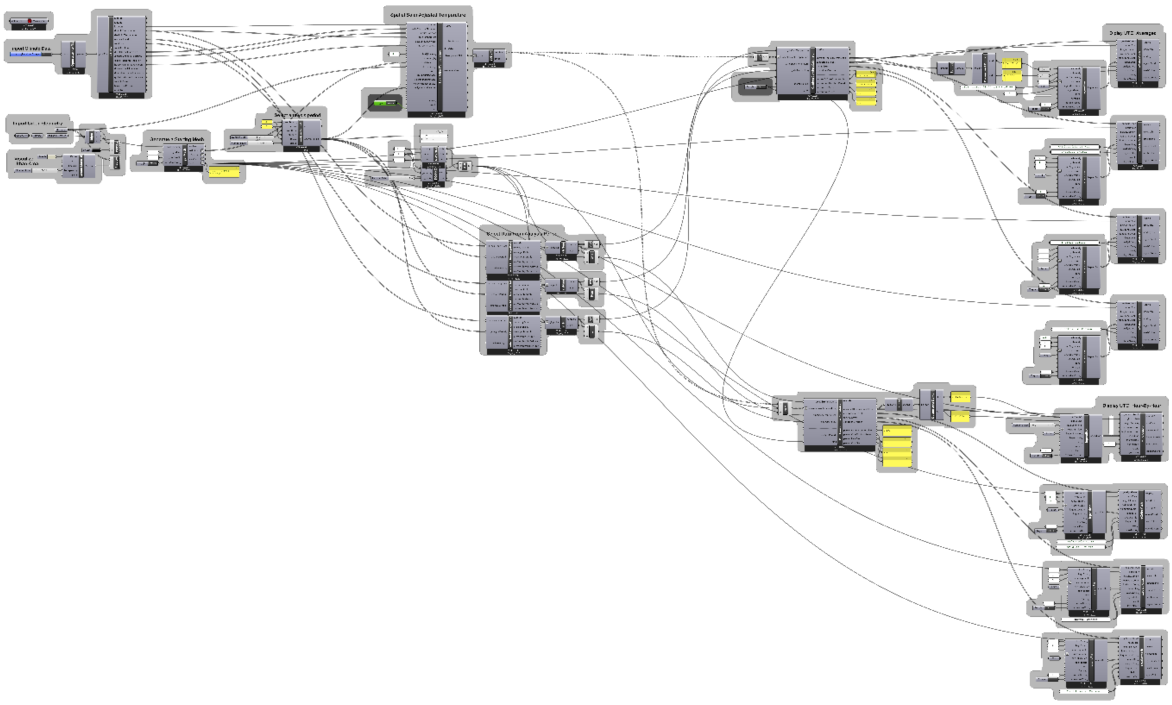


Figure 17: UTCI visual code in developed in grasshopper (researcher).

The first part of code is to activate ladybug tools and to import the weather file in (epw) of Sharjah as shown in Figure 18.

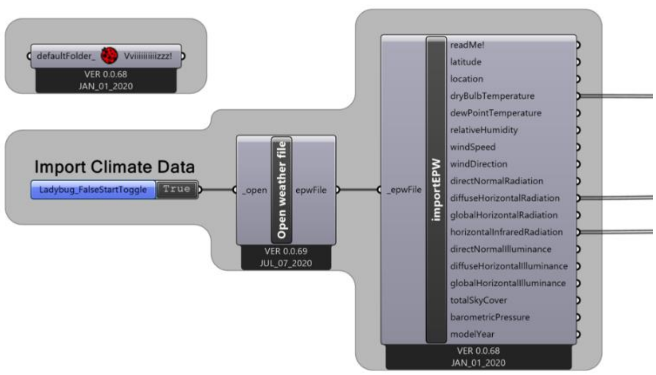


Figure 18: UTCI visual code part 1 (researcher).

The second part of the code is used to inseart the geometry of the buidling and the boundry of the site for the simulation and generate a mesh for visulizing the results of the UTCI simulation as illustrated in Figure 19.

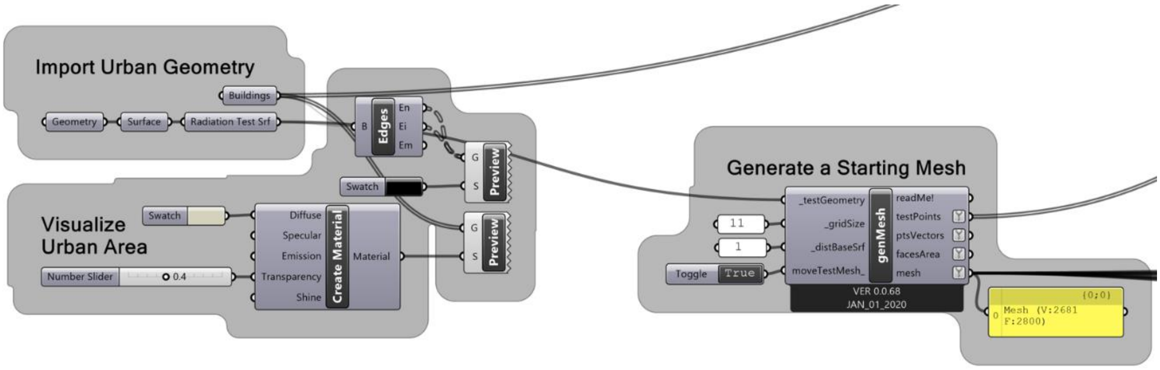


Figure 19: UTCI visual code part 2 (researcher).

The third part of the code is to limit the simulation to define duration of the year. This lowers the number of processes the computer will do to get the results. Which make the simulation process faster and more efficient.

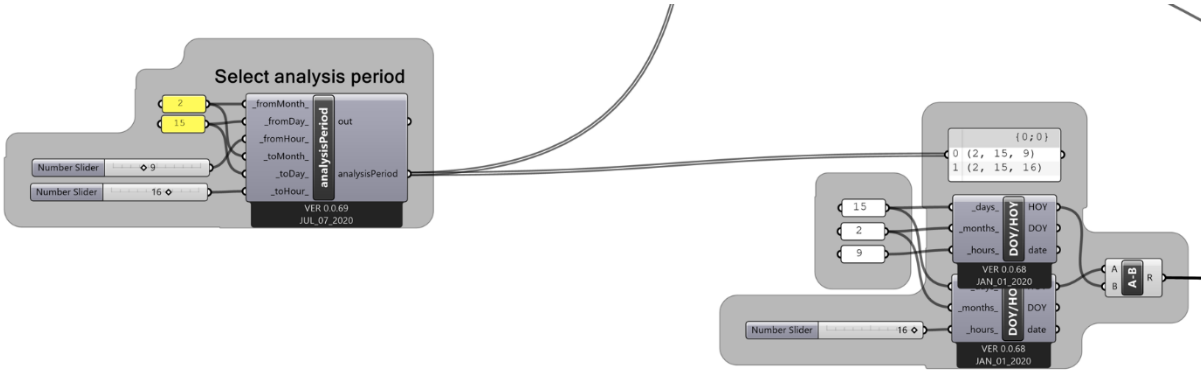


Figure 20: UTCI visual code part 3 (researcher).

The fourth part is solar adjusted temperature. This component fed by the information of the weather data that was imported in part 1 of the code along with the mesh generated from part 3 and the analysis duration identified in part 3 of the code. The component compensates for shortwave solar radiation in an existing Mean Radiant Temperature. After adjustment, the corrected mean radiant temperature can be employed in the comfort studies.

This component calculates the amount of direct and diffuse sun radiation falling on a comfort mannequin using Radiance functions. The portion of radiation reflected off the ground and onto the comfort mannequin is calculated using these direct and diffuse radiation values.

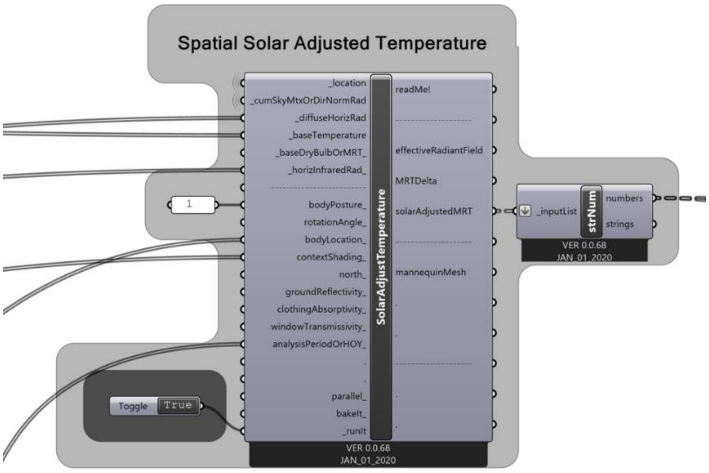


Figure 21: UTCI visual code part 4 (researcher).

The final part is the outdoor thermal comfort calculator which results in temperature of how the weather feels like taking into consideration the weather condition inputted to the component with the human energy balance model.

The results express as “no thermal stress” or “comfortable” for UTCI ranges between 9°C to 26°C and slight heat stress to 28°C, moderate heat stress to 32 °C, strong heat stress to 38 °C and extreme above 38 °C.

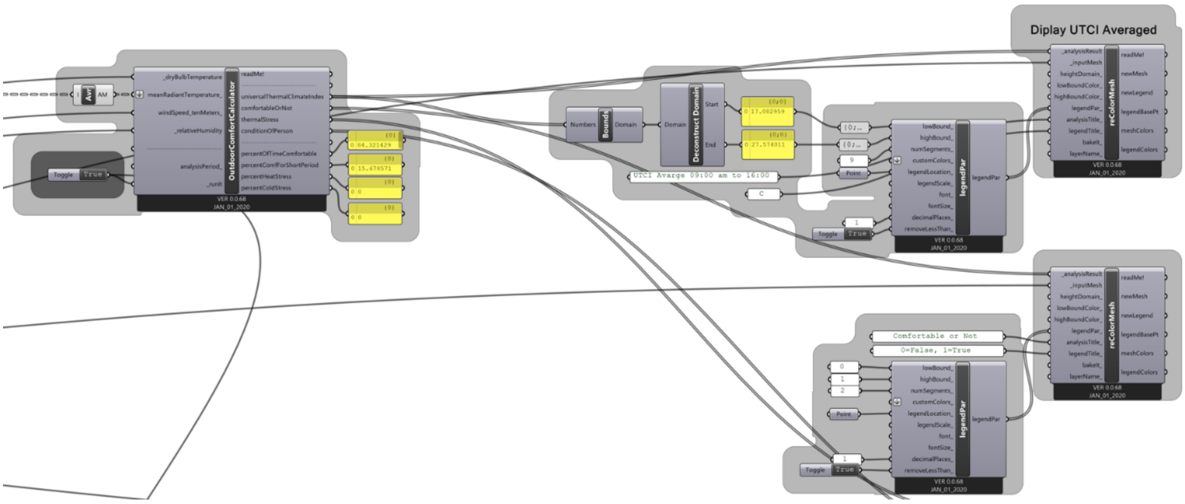


Figure 22: UTCI visual code part 5 (researcher).

Part 6 of the code is an addition that allow visualizing the results per hour which give more information for the analysis. This component is used to extract the UTCI in the same hours of field measurements and thermal walks to compare.

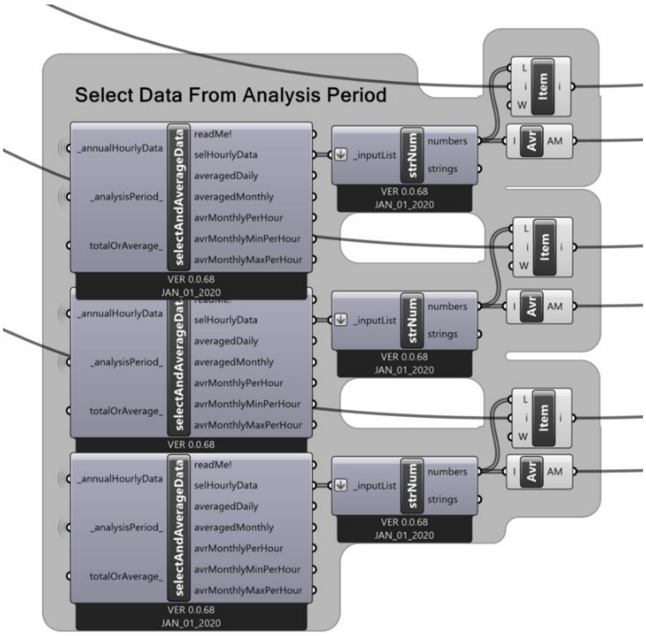


Figure 23: UTCI visual code part 6 (researcher).

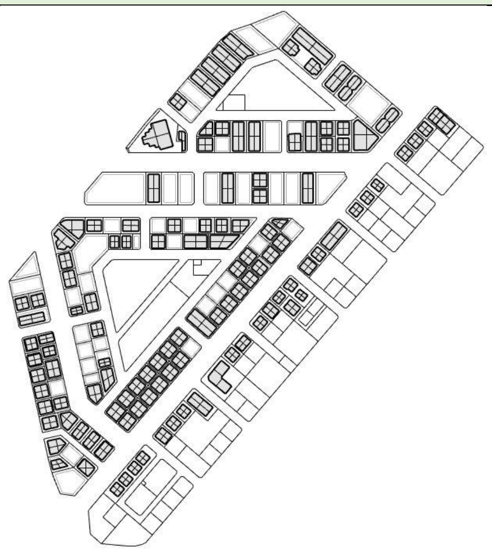
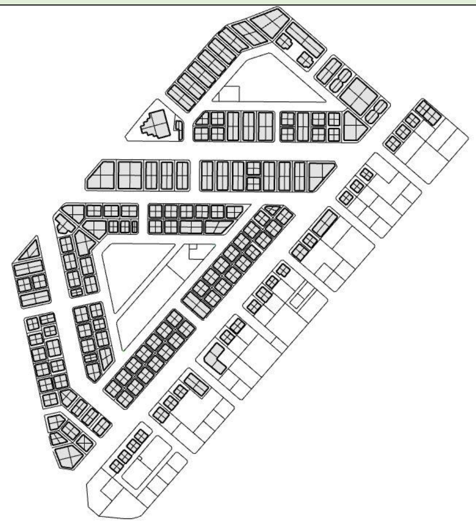
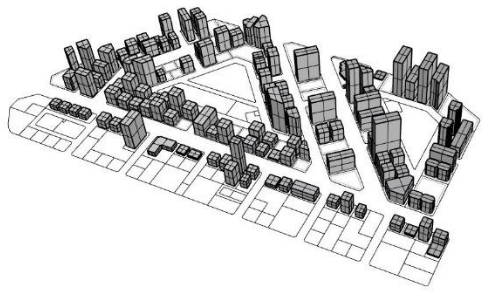
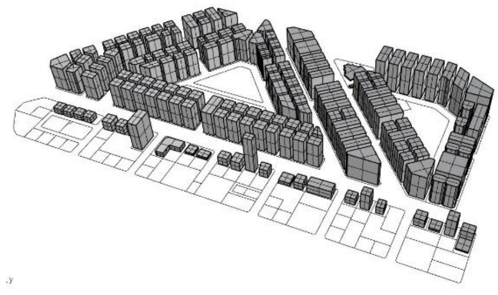
4.5.1 Model setup and scenarios

3D model of current condition of the site was done using rhino interface with parametrizing the height of the buildings using grasshopper. Heights of buildings in base case model are matching the exciting heights and was taking from 2gis.ae website building by building. The compassion between the current condition of the site and the master plan from Sharjah Planning Department, shows that the site still not fully occupied as planed (some plots still empty) while buildings heights are within the regulation as it not exceeding the maximum height.

The model of the current condition is labelled as "Base case" and the model of the site according to master plan setbacks and height is labelled here as "basecase_Rev".

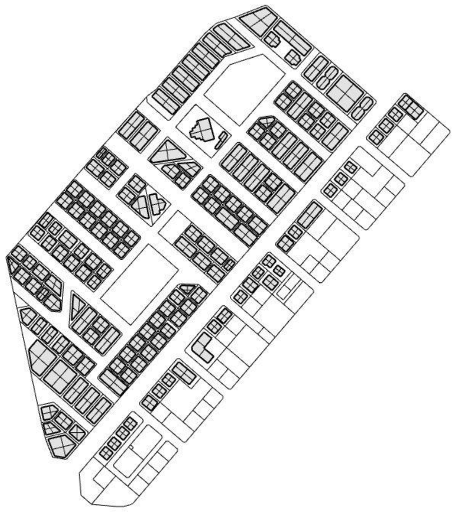
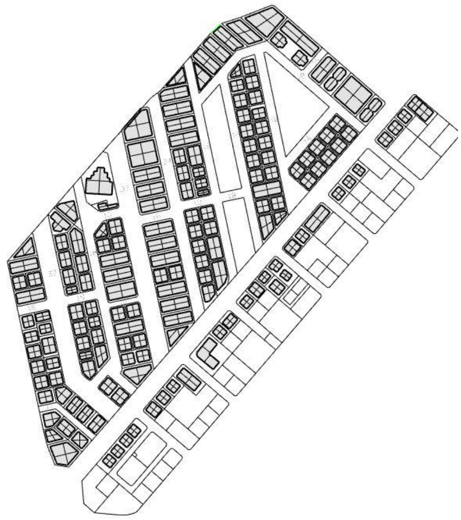
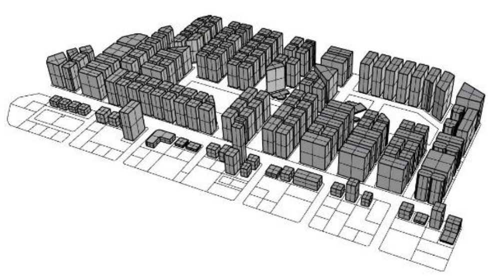
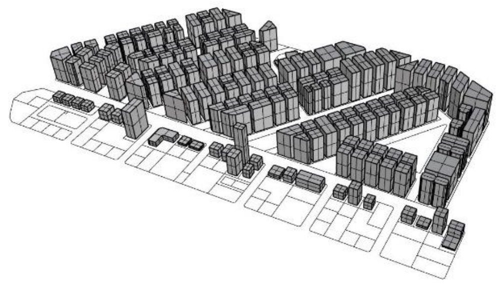
The proposed scenarios will be according to the plot sizes, setbacks and buildings regulated heights to standardize the scenarios, which make more sense to compare it with "basecase_Rev". Table below shows the different between models of the current situation and the one as per master plan.

Table 6: Base case current condition vs base case as per the master plan (plan & perspective of building heights)

	Base case- current condition	**Base case- as per the master plan**
Plan		
Perspective		

First investigation is conducted for the street orientation. The current street has different orientations. According to the literature review, NW-SE orientation is preferred during summer (Chatzidimitriou and Yannas, 2017; Yang et al., 2016), and N-S orientation in most of the studies achieved the biggest improvement in terms of thermal comfort (Bakarman and Chang, 2015; Deng and Wong 2020; Huang and Li, 2017; Srivanit and Jareemit, 2020). As discussed in the literature review, studies achieved this result by simulating a theoretical grid-design sites or by comparing existing neighbourhoods' orientation. Accordingly, in the first round of simulation we will investigate if these recommendations are valid for our case which is unique as the scenarios will be matching in the existing plot's sizes and shapes, and number, footprint, and height of the buildings in irregular urban district boundary. Figures illustrate scenario 1 with NW-SE orientated streets and scenario 2 with N-S oriented streets of strategy 1 (change street orientation.

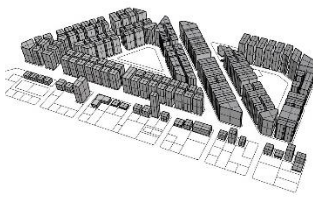
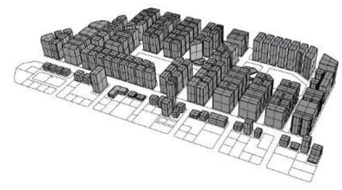
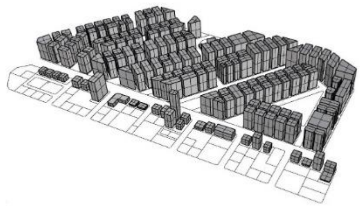
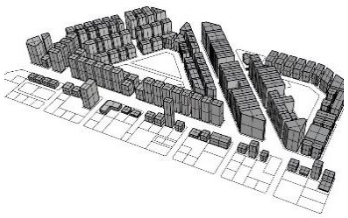
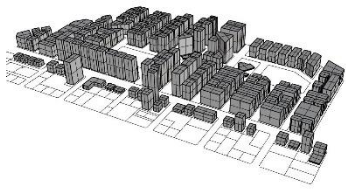
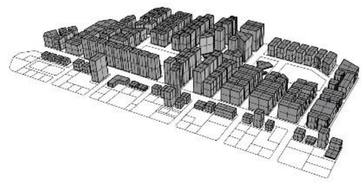
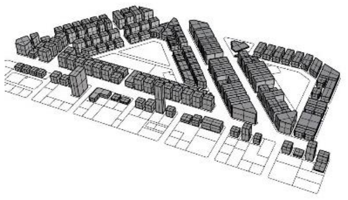
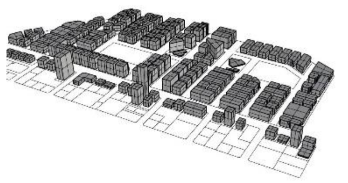
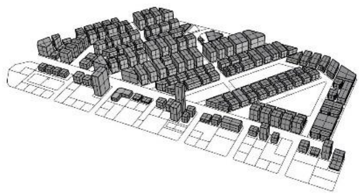
Table 7: Proposed scenarios of strategy 1- change the street orientation (plan & perspective of building heights).

	Scenario 1: NW-SE street orientation	**Scenario 2: N-S street orientation**
Plan		
Perspective		

Second round of simulation investigates height to width aspect ratio. Back to the literature review, it was concluded that larger H/W aspect ratio optimizes the shading by buildings and wind speed. Where building heights as regulated in the master plan achieve a large H/W aspect ratio that ranges between 4.2 to 1.7, the simulation investigate the effect of lower ratios H/W equal 2 and H/W equal 1.

For each scenario, UTCI simulation is conducted for daytime (9:00 am to 16:00 pm) for 15^{th} of February, 15^{th} of July and 15^{th} of September. And for each day the simulation is conducted for 3 hours: at 9:00 am, 12:00 pm and 16:00 pm.

Table 8: Proposed scenarios of strategy 21- change H/W aspect ratio (perspective of building heights).

New Base case		Scenario 1: NW-SE street orientation	Scenario 2: N-S street orientation
			
	Basecase_Rev	Scenario_1	Scenario_2
H/W=2			
	Basecase_Rev_A	Scenario_1_A	Scenario_2_A
H/W=2			
	Basecase_Rev_B	Scenario_1_B	Scenario_2_B

Chapter 5. Results and discussion

This chapter illustrates the results of the field survey, thermal walks, and the simulations. Moreover, it discusses the results of the different scenarios propose to conclude how these strategies affect outdoor thermal comfort in the case study.

5.1. Field survey and measurements.

A total of 90 interviews was conducted during 15th of February, 15th of July and 15th of September. In each month, 10 interviews were conducted in the morning between 9:00 to 10:30, and 10 interviews in afternoon between 12:00 to 1:30 and the last 10 in the evening between 16:00 pm to 15:30.

Before starting the interview, dry bulb temperature, wet bulb temperature, relative humidity and wind speed and direction was recorded as shown in Table 9.

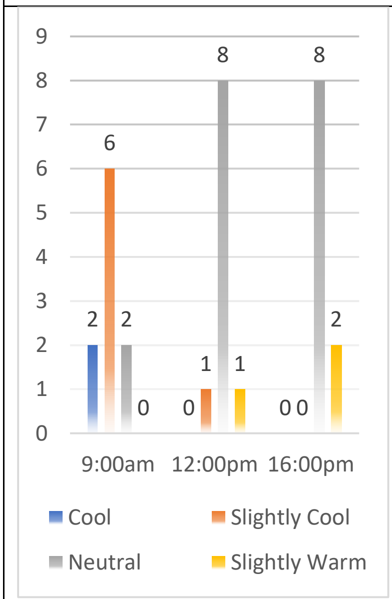
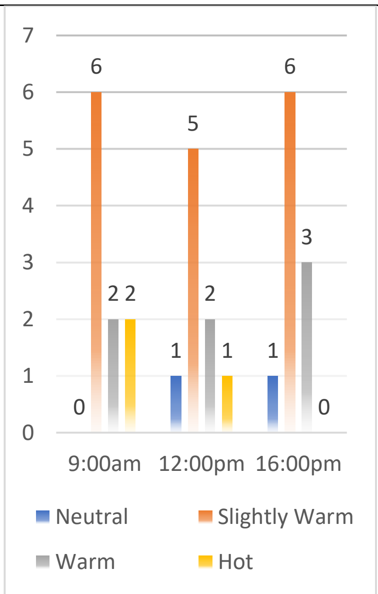
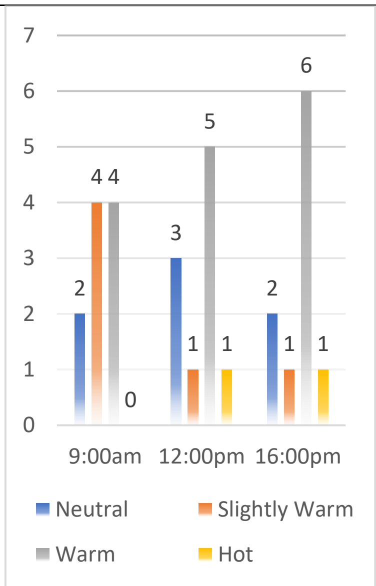
Table 9: Field measurements for 15th of Feb, 15th of July and 15th of September (researcher).

Year	Month	Day	Hour	Temp.Dry	Temp.Wet	Relative Humidity	Wind.Dir	Wind Speed
			Local Time	[°C]	[°C]	[%]	[°]	[Km/h]
2021	2	15	8	14.3	14.2	99	160	7
2021	2	15	9	15.4	15.3	99	100	6
2021	2	15	10	19.1	17.6	86	50	6
2021	2	15	11	21.9	18.4	70	170	2
2021	2	15	12	25.2	17.2	41	10	6
2021	2	15	13	27.3	16.5	28	10	7
2021	2	15	14	26.1	18.9	48	320	17
2021	2	15	15	26.0	17.3	38	300	19
2021	2	15	16	25.4	17.5	42	310	19
2021	2	15	17	24.8	18.2	50	310	19
2021	7	15	8	35.6	26.5	47	120	19
2021	7	15	9	36.4	27.4	48	120	37
2021	7	15	10	37.4	27.6	45	120	41
2021	7	15	11	37.7	27.3	43	120	35
2021	7	15	12	38.3	27.3	41	120	33
2021	7	15	13	40.2	26.7	33	120	28
2021	7	15	14	41.2	26.8	30	100	15
2021	7	15	15	42.3	26.3	26	80	13
2021	7	15	16	41.6	27.5	32	10	22
2021	7	15	17	40.6	26.3	30	20	20
2021	9	15	8	29.2	28.5	95	180	20
2021	9	15	9	33.2	28.0	66	180	11
2021	9	15	10	38.2	24.7	30	180	11
2021	9	15	11	40.0	23.2	20	200	17
2021	9	15	12	41.3	23.1	17	230	6

2021	9	15	13	41.8	27.6	32	210	7
2021	9	15	14	40.6	28.4	39	330	15
2021	9	15	15	39.1	28.3	43	320	19
2021	9	15	16	38.7	28.1	43	310	19
2021	9	15	17	37.6	28.0	47	330	19

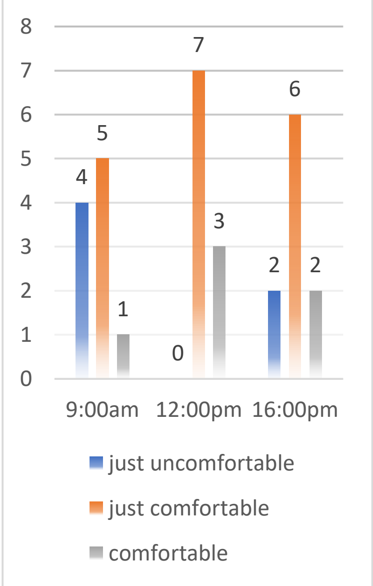
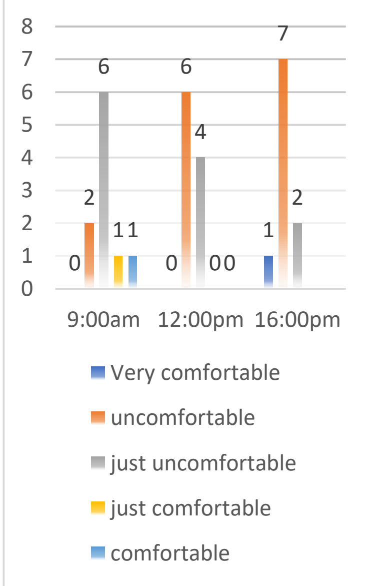
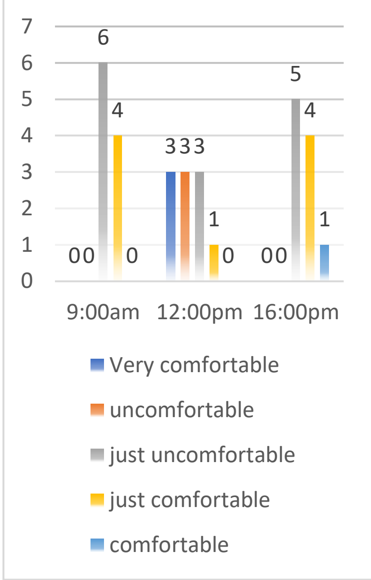
Interview results in February morning reveals that most of the pedestrian felt slightly cool in the morning (temperature between 15.4 to 19.2) except two females expressed their thermal condition as cool, and two other interviewees answered they felt neutral about the weather. At 12:00 pm, most of the interviewees expressed neutral regarding their thermal sensation and similarly in at 16:00. Table 10 presents the answers to question “How do you feel now?” for all interviews conducted in the three months (February, July, and September). As shown in the table, in July, several interviewees felt slightly warm during the day. While interviewees in September mostly felt warm.

Table 10: interview answers - "How do you feel now?"

February	July	September
		

In other hand to evaluate TCV, interviewees were asked to evaluate their comfort level. Interestingly, most of interviewees that felt slightly warm in the previous question, answered that they feel “comfortable” or “just comfortable”. Table 10 presents the answers to question *“How would you describe your overall comfort level?”* for all interviews conducted in the three months (February, July, and September).

Table 11: interview answers - " How would you describe your overall comfort level?"

February	July	September
		

As shown in Figure 24, in February, the thing that bothers most of the interviewees is humidity. While in July, interviewees said that both of air temperature and sun radiation are the most bothering things. Similarly, in September, interviewees got bother from air temperature and sun radiation. Figure 24 presents the answers to question "The thing that bothers you most about the weather is?" for all interviews conducted in the three months (February, July, and September).

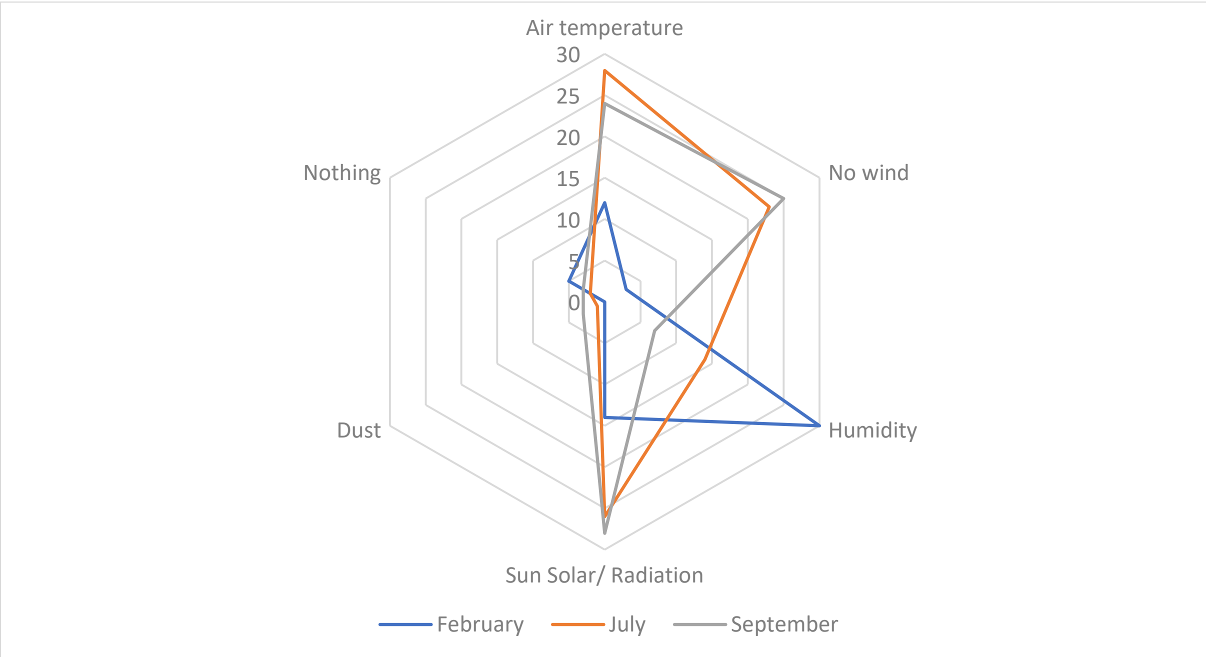


Figure 24: interview answers - "The thing that bothers you most about the weather is?"

From the interviews, several points are concluded:

1- There are two main destinations people used to walk to in the selected case study: the cantered parking land and the mosque. Trip from surrounding building to these to destination take in average 8-9 min.
2- All interviewees would prefer to have more wind and more shade.
3- In average, interviewees can walk only from 6-10 min comfortably during typical summer mid-day hours, while they can walk up to 30 min or more comfortably during typical winter mid-day hours.
4- Most interviewees prefer outdoor air temperature to be between 25-30 °C.

5.2. Thermal walk

A total of 15 short walks (11 min walk) were done on 9th of September 2021 in 3 timing during the day (9:00, 12:00 and 16:00). Observations and analysis of the experiment can be concluded as the following:

1- Participants expressed their thermal sensation as slightly warm before the first walk in the morning and just uncomfortable in term of their level of comfort. While they expressed feeling warm before the second and third walk (at 12:00 and 16:00) and uncomfortable as their level of comfort.
2- Three participants change their thermal sensation to warm after the first walk in the morning and their comfort level to uncomfortable while two participants (nationality: Indian and Egyptian) expressed that their thermal sensation still slightly warm and just uncomfortable in term of their level of comfort. While they expressed feeling hot after the second walk (at 12:00) and uncomfortable as their level of comfort except one participant that change his level of comfort to very uncomfortable just after the 7th min of walking (nationality: Filipino).
3- All participants maintain their thermal sensation after the third walk (16:00) as warm and uncomfortable as their level of comfort. This can be related to the path being shaded by building shadow at this time of the day.
4- Difference in the skin temperature was noticed in the second walk at 12:00 as shown in the Figure 25. Figures illustrate pictures during the experiment.

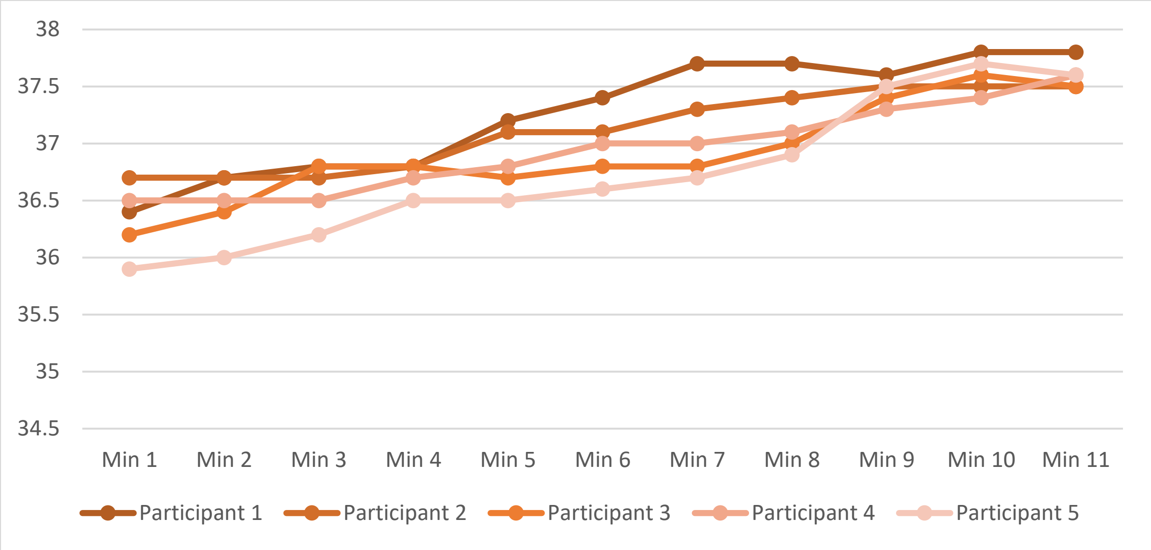


Figure 25: Skin temperature of the participants during the thermal walk, recorded each minute (researcher).

Figure 26: Pictures during the thermal walk experiment (researcher).

5.3.UTCI Simulation

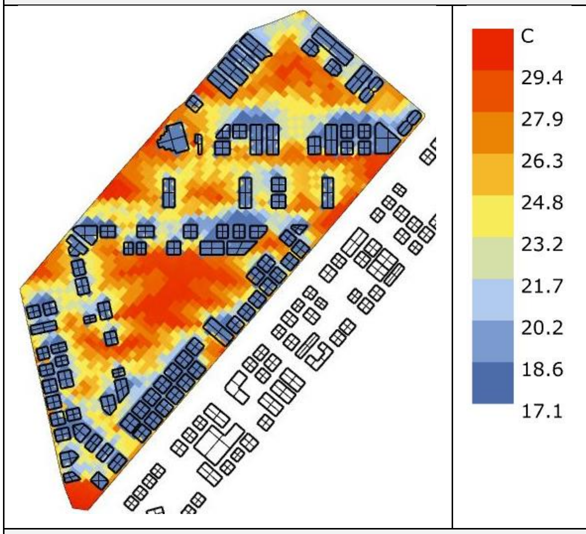
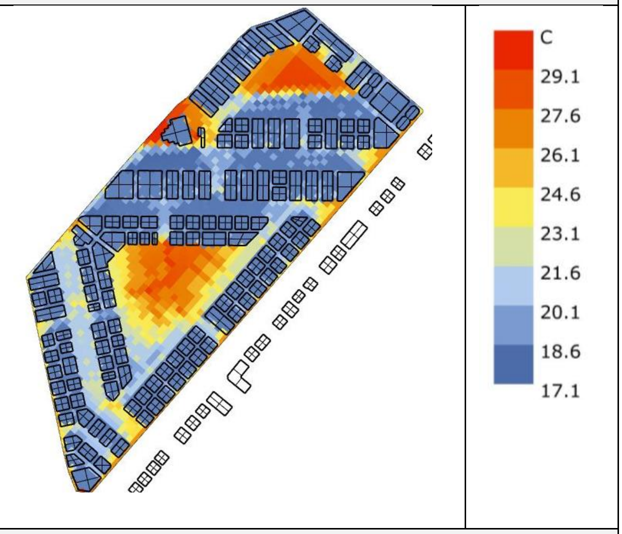
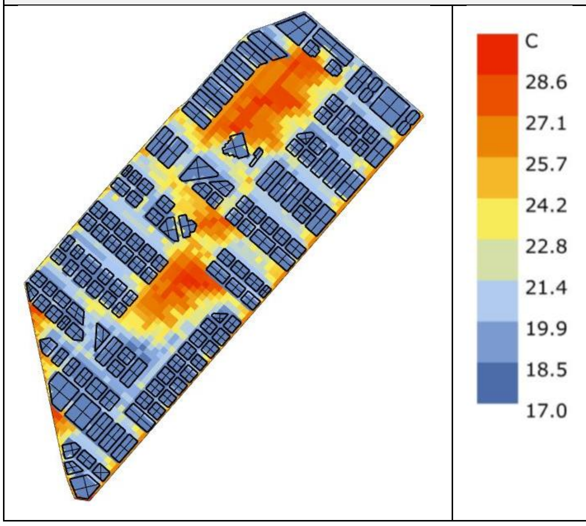
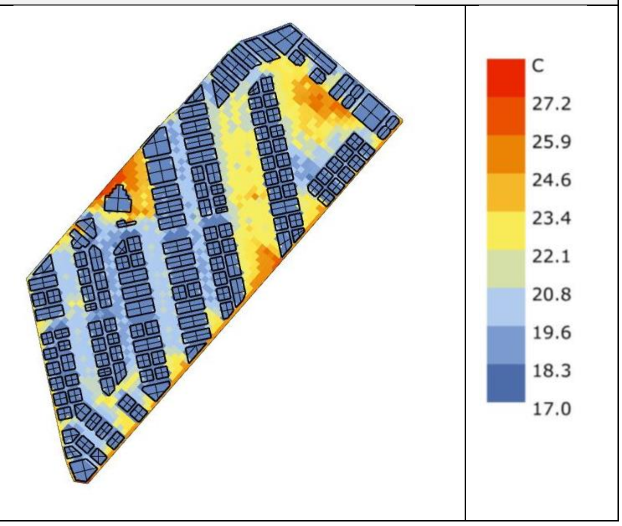
The first part of the analysis presents and discusses the results of implementing change on streets orientation to two proposals recommended by previous studies. While the second part will discuss changing the H/W aspect ratio. The results will be presented in format of average UTCI per daytime (average UTCI for the hours from 9:00 to 16:00) for each of February, July, and September. Further discussion will be made on the percent of time comfortable, percent comfort for short period, percent of experiencing heat stress or cold stress. The discussion will highlight enhancement in UTCI per hour to investigate if some scenarios work better in a certain hour of the day.

5.3.1 Street orientation

- **Daily values for 15th of February, July, and September.**

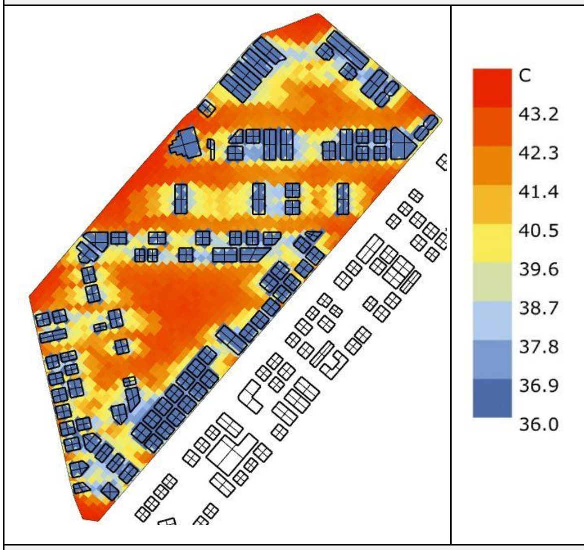
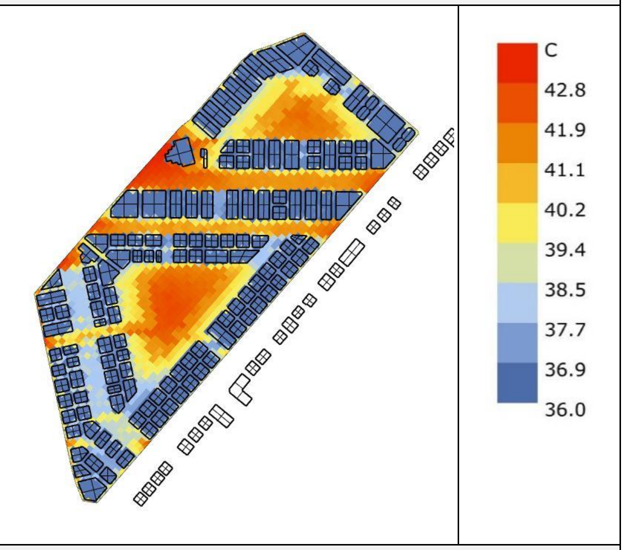
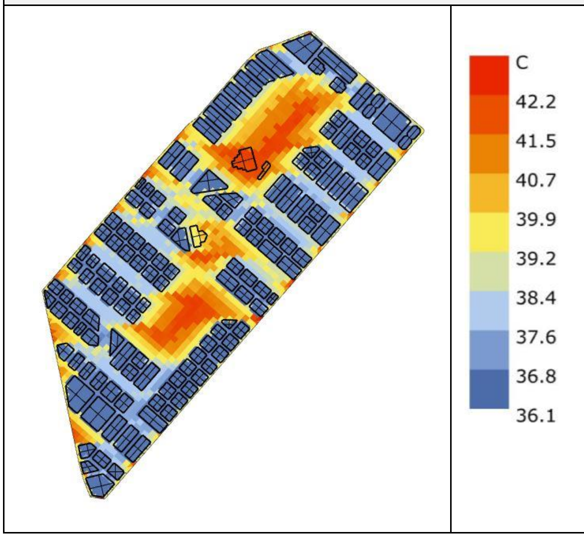
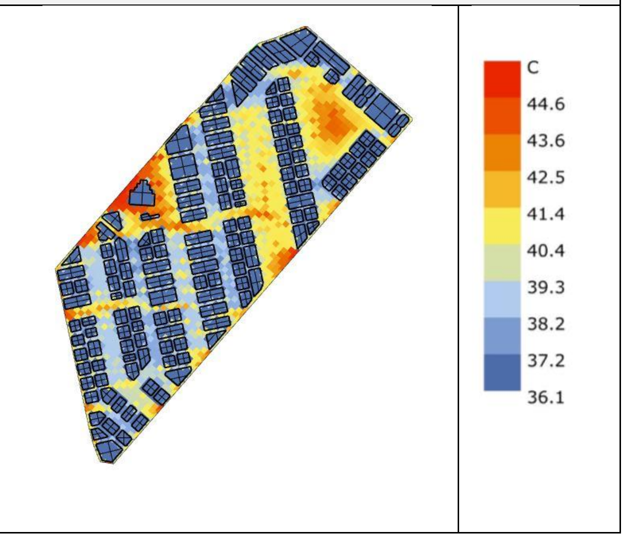
Table 12: street orientation strategy- Average UTCI (9:00 -16:00) – February (researcher)Table 12, presents average UTCI during the day. Comparing the graph of basecase basecase_rev, the UTCI temperature of the street areas in the basecase_rev is lower which is preferable in hot humid climate. Comparing the scale of the basecase_rev with scenario_1, the maximum UTCI temperature dropped around 0.5 °C. Comparing all cases we can conclude that in February scenario_2 with N-S street orientation achieves the best outdoor thermal comfort as temperature in the streets feels like 19 °C to 24 °C and the maximum temperature dropped 2 °C compared with the basecase.

Table 12: street orientation strategy- Average UTCI (9:00 -16:00) – February (researcher)

<table>
<tr><th colspan="2">Average UTCI (9:00 -16:00) – February</th></tr>
<tr><th>Basecase</th><th>Basecase_Rev</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Scenario_1</th><th>Scenario_2</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Comparing the basecase with the basecase_rev, we can find that there is no major enhancement in UTCI in most of the main streets. In the other hand comparing the scale of scenario_1 with basecase scale, we find the maximum temperature is reduced by 1°C. Moreover, UTCI in scenario_1, mostly ranges between 36 °C to 38 °C compared with 40°C to 42 °C in basecase_rev and 41°C to 43 °C in the basecase. While scenario_2 39 °C to 41°C according to the map, however the maximum UTCI temperature has 1.4 °C compared with basecase. Comparing all cases, we can conclude that in July scenario_1 with NW-SE street orientation achieves the best outdoor thermal comfort.

Table 13: Sreet orientation strategy- Average UTCI (9:00 -16:00) – July (researcher)

Average UTCI (9:00 -16:00) – July	
Basecase	**Basecase_Rev**
	
Scenario_1	**Scenario_2**
	

Comparing the basecase with the basecase_rev, we can find that sidewalks UTCI is reduced around 2°C (from 41°C to 38 °C) while there is no significant enhancement maximum and minimum value of UTCI. In the other hand comparing the scale of scenario_1 with basecase scale, we find the maximum temperature is reduced by 0.8°C. Moreover, UTCI in scenario_1, mostly ranges between 37 °C to 38 °C (same as scenario_2) compared with 42°C to 43 °C in basecase_rev and 38°C to 42 °C in the baecase. Comparing all cases, we can conclude that in September scenario_1 and scenario_2 achieve the best outdoor thermal comfort.

Table 14: street orientation strategy- Average UTCI (9:00 -16:00) – September (researcher)

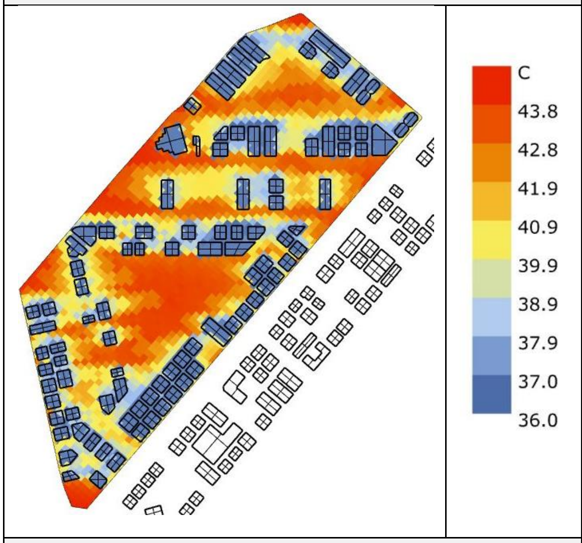
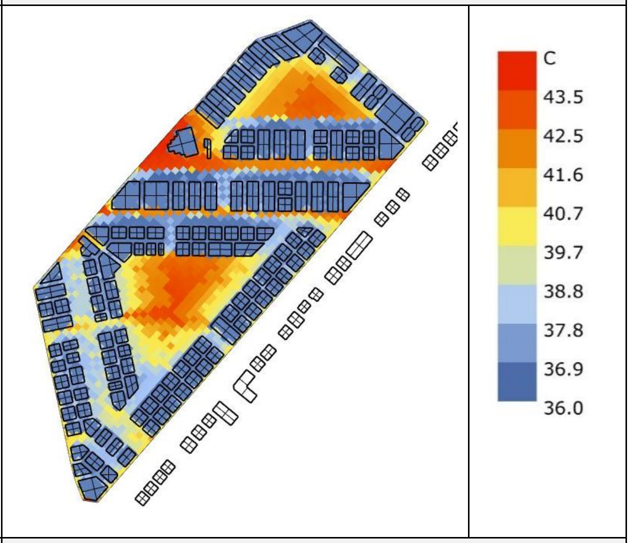
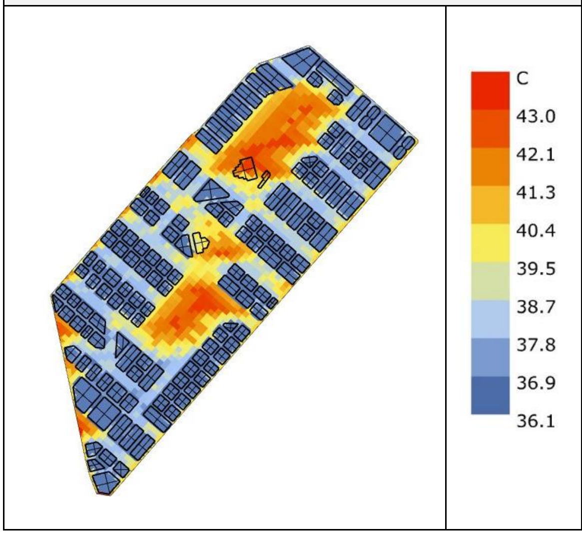
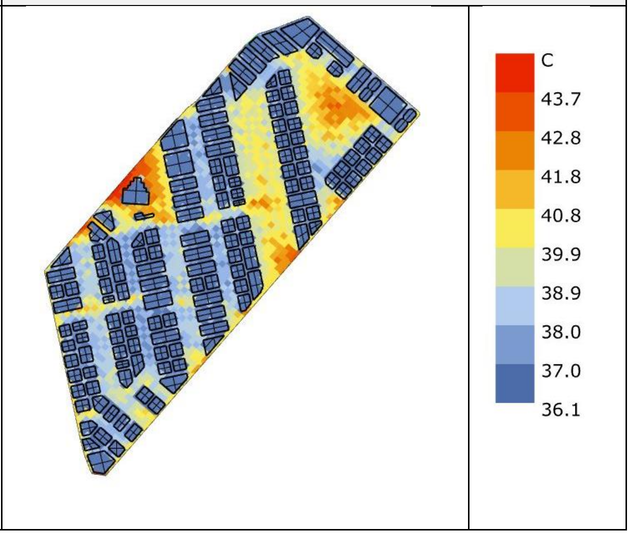
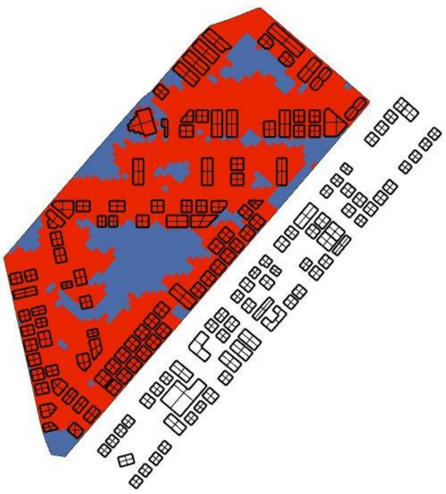
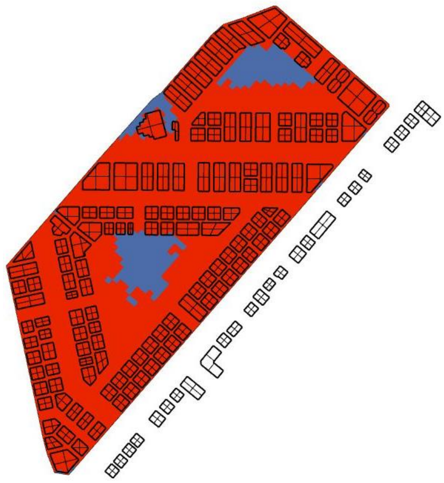
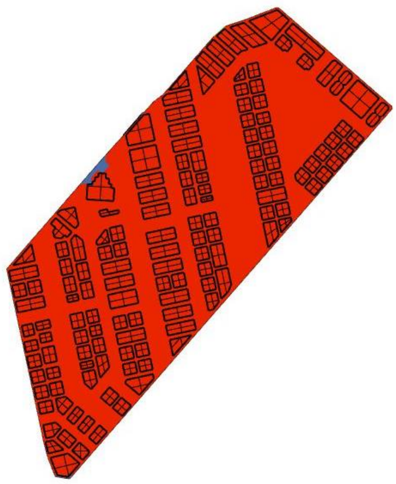
Average UTCI (9:00 -16:00) – September	
Basecase	**Basecase_Rev**
	
Scenario_1	**Scenario_2**
	

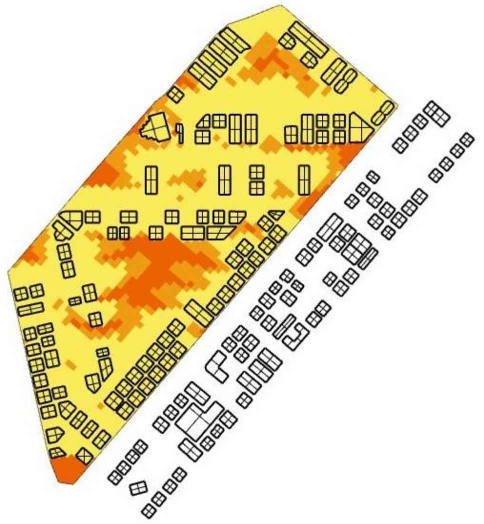
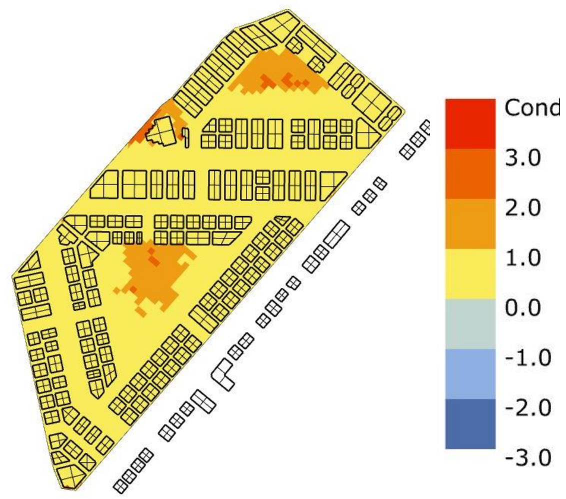
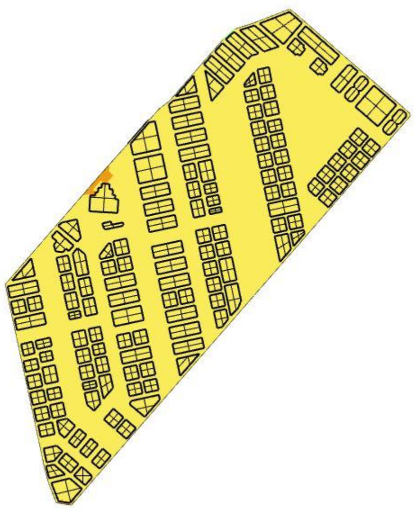
Table 12: street orientation strategy- Average UTCI (9:00 -16:00) – February (researcher)Table 15 presents percentage of time comfortable from 9:00 to 16:00 where the red indicates comfortable, and the blue indicate uncomfortable. In base case 76.3% of the time the space is comfortable while 91% of the time the space in basecase_rev. this means that comfort level of the area can be less 30% due to variations in the actual build environment. Scenario_1 manage to achieve 93% and the best scenario is scenario_2 that 99% percent of time the space is comfortable in February. Percent of time comfortable for both July and September are not presented as the percent of time comfortable in all scenarios is 0% (fully blue maps).

Table 15: street orientation strategy- Percent of time comfortable (9:00 -16:00) – February (researcher)

Percentage of time comfortable (9:00 -16:00) – February **Red= comfortable, Blue= uncomfortable**	
Basecase = 76.3 %	**Basecase_Rev = 91%**
	
Scenario_1 = 93%	**Scenario_2 = 99%**
	

Another way to identify comfort level is the condition of the person, which express the expected thermal perception of individuals according to potential cold or heat stress.

Table 16: street orientation strategy- Condition of person (9:00 -16:00) – February (researcher)

Condition of person (9:00 -16:00) – February -3 - Strong Cold Stress/ -2 - Moderate Cold Stress/ -1 - Slight Cold/ 0 - No Thermal Stress/ +1 - Slight Heat Stress/ +2 - Moderate Heat Stress/ +3 - Strong Heat Stress	
Basecase = 9.8% heat stress	**Basecase_Rev = 6.8% heat stress**
	
Scenario_1 = 6.4% heat stress	**Scenario_2 = 0% heat stress**
	

- **Hourly values at 9:00, 12:00 and 16:00.**

Table 17, Table 18 and Table 19 shows the hourly UTCI at 9:00, 12:00 and 16:00.

Table 17: street orientation strategy- UTCI at 9:00 February (researcher)

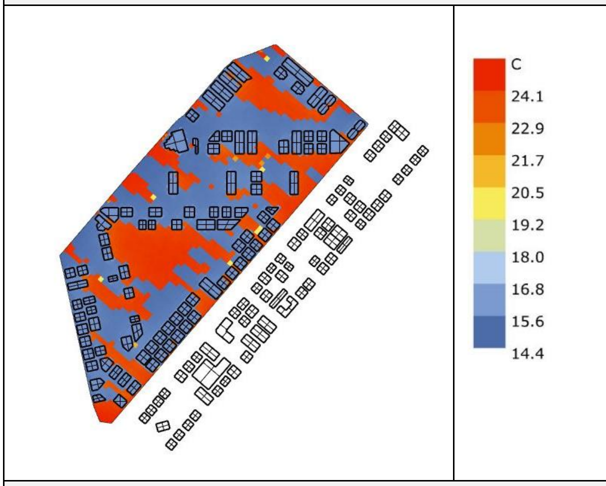
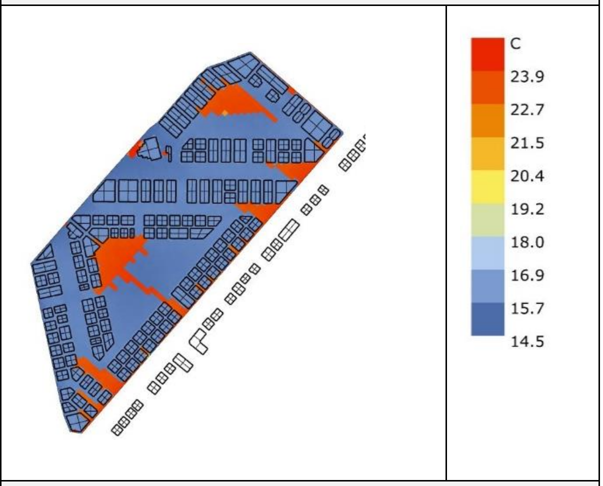
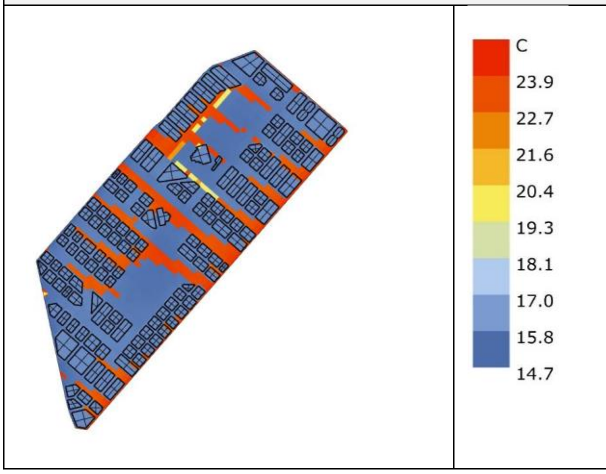
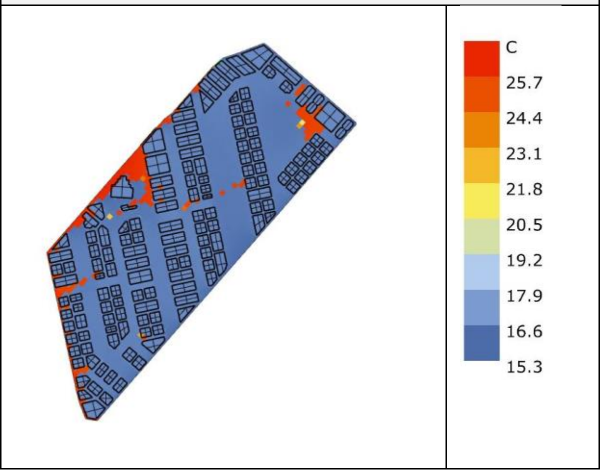
<table>
<tr><th colspan="2">UTCI 9:00/ February</th></tr>
<tr><th>Basecase</th><th>Basecase_Rev</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Scenario_1</th><th>Scenario_2</th></tr>
<tr><td>
</td><td>
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Table 18: street orientation strategy- UTCI at 12:00 February (researcher)

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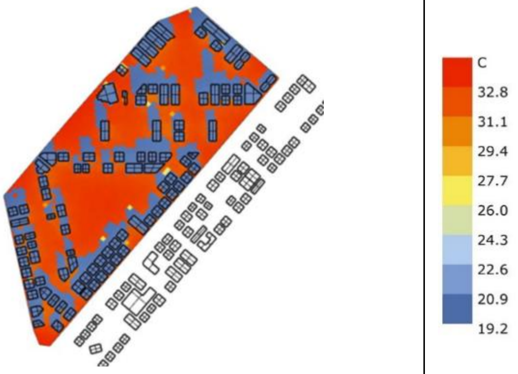
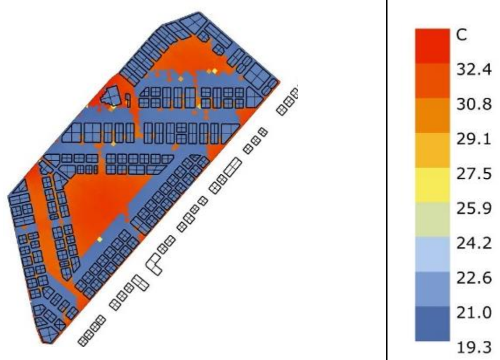
<tr><td>
</td><td>
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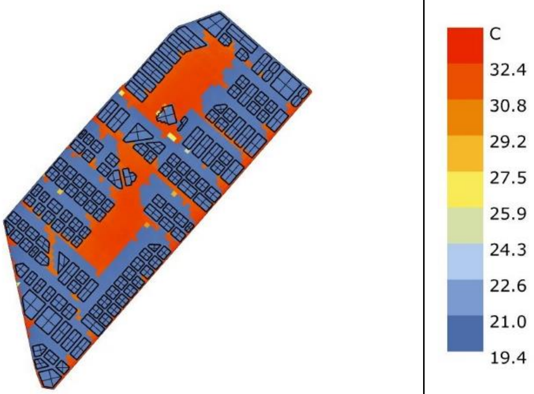
<tr><th>Scenario_1</th><th>Scenario_2</th></tr>
<tr><td>
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</td></tr>
</table>

Table 19: street orientation strategy- UTCI at 16:00 February (researcher)

<table>
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<tr><th colspan="2">Basecase</th><th colspan="2">Basecase_Rev</th></tr>
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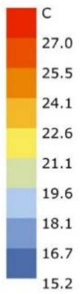
<td>
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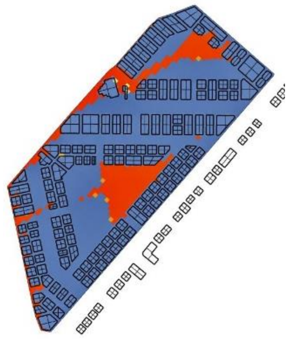
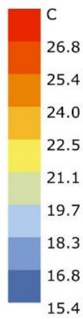
<td></td>
<td>
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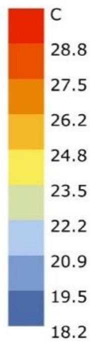
</tr>
<tr><th colspan="2">Scenario_1</th><th colspan="2">Scenario_2</th></tr>
<tr>
<td></td>
<td>
</td>
<td></td>
<td>
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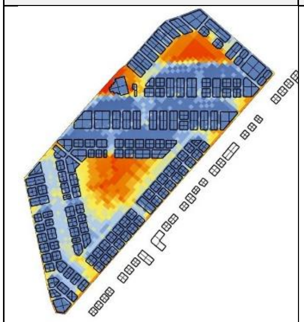
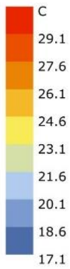
</table>

5.3.2 H/W aspic ratio

Table 20 presents H/W aspect ratio of all the scenarios in February. Analysing the maps along with the scale we can conclude that Scenario_1_a which has aspect ratio 2 is the best scenario in terms of outdoor thermal comfort.

Table 20: H/W aspect ratio- Average UTCI (9:00 -16:00) – February (researcher).

<table>
<tr><th colspan="6">H/W aspect ratio- Average UTCI (9:00 -16:00) – February</th></tr>
<tr><td>Basecase_Rev</td><td></td><td>Basecase_Rev_A</td><td></td><td>Basecase_Rev_B</td><td></td></tr>
<tr>
<td></td>
<td>
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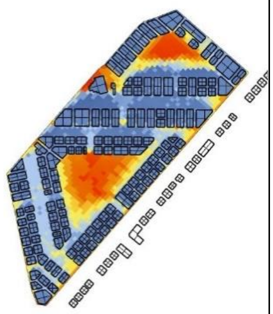
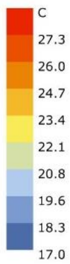
<td></td>
<td>
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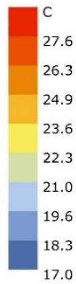
<td>
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</tr>
<tr><td>Scnario_1</td><td></td><td>Scnario_1_a</td><td></td><td>Scnario_1_b</td><td></td></tr>
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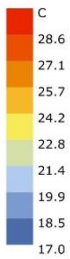
<td>
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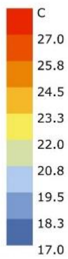
<td>
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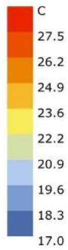
<td>
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</tr>
<tr><td>Scnario_2</td><td></td><td>Scnario_2_a</td><td></td><td>Scnario_2_b</td><td></td></tr>
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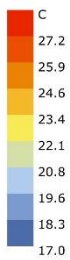
<td>
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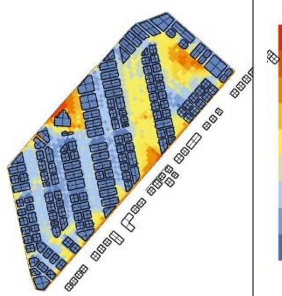
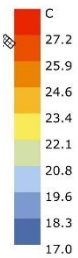
<td></td>
<td>
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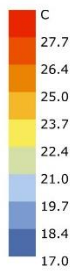
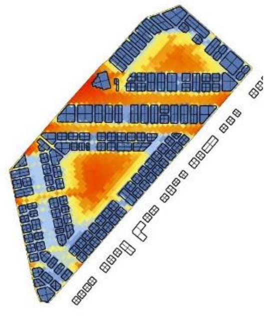
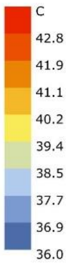
<td>
</td>
</tr>
</table>

Table 21 presents H/W aspect ratio of all the scenarios in July. Analysing the maps along with the scale we can conclude that Scenario_1 which has aspect ratio around 4.2 is the best scenario in terms of outdoor thermal comfort.

Table 21: H/W aspect ratio- Average UTCI (9:00 -16:00) – July (researcher).

<table>
<tr><th colspan="6">H/W aspect ratio- Average UTCI (9:00 -16:00) – July</th></tr>
<tr><td>Basecase_Rev</td><td></td><td>Basecase_Rev_A</td><td></td><td>Basecase_Rev_B</td><td></td></tr>
<tr>
<td></td>
<td>
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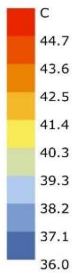
<td>
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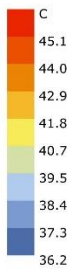
<td>
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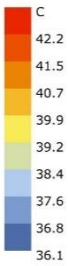
</tr>
<tr><td>Scnario_1</td><td></td><td>Scnario_1_a</td><td></td><td>Scnario_1_b</td><td></td></tr>
<tr>
<td></td>
<td>
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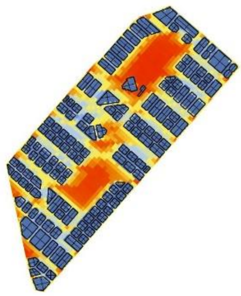
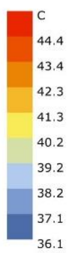
<td></td>
<td>
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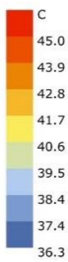
<td>
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<tr><td>Scnario_2</td><td></td><td>Scnario_2_a</td><td></td><td>Scnario_2_b</td><td></td></tr>
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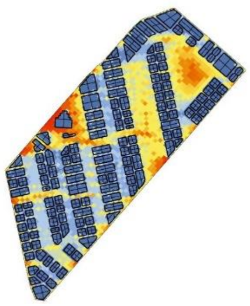
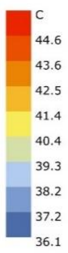
<td></td>
<td>
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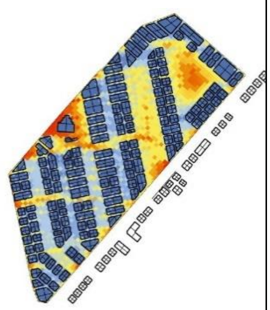
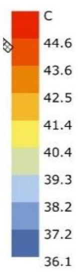
<td></td>
<td>
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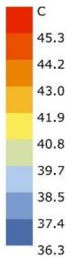
<td>
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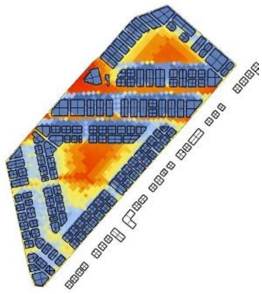
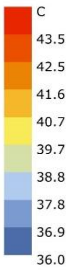
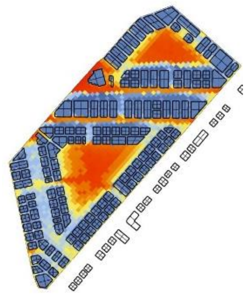
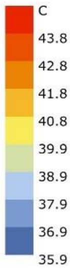
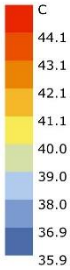
</tr>
</table>

Table 22 presents H/W aspect ratio of all the scenarios in September. Analysing the maps along with the scale we can conclude that Scenario_1 which has aspect ratio around 4.2 is the best scenario in terms of outdoor thermal comfort.

Table 22: H/W aspect ratio- Average UTCI (9:00 -16:00) – September (researcher).

<table>
<tr><th colspan="6">H/W aspect ratio- Average UTCI (9:00 -16:00) – September</th></tr>
<tr><td>Basecase_Rev</td><td></td><td>Basecase_Rev_A</td><td></td><td>Basecase_Rev_B</td><td></td></tr>
<tr><td></td><td>
</td><td></td><td>
</td><td></td><td>
</td></tr>
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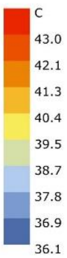
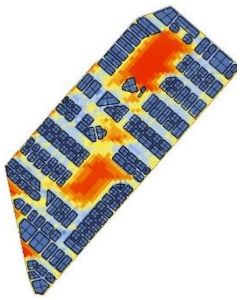
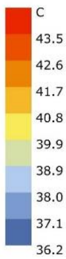
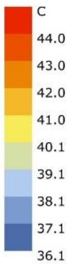
<tr><td></td><td>
</td><td></td><td>
</td><td></td><td>
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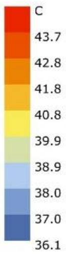
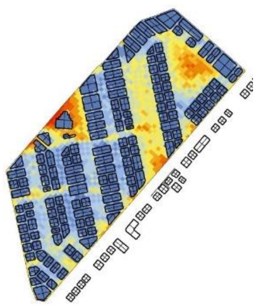
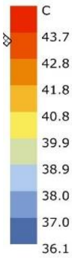
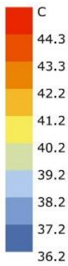
<tr><td></td><td>
</td><td></td><td>
</td><td></td><td>
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Chapter 6. Conclusion

The conclusion summarizes the findings in light of the dissertation's goals, including the impact of urban morphology on outdoor thermal comfort as well as individual thermal sensation and perception. This dissertation fills the knowledge gap that was identified at the end of the literature review chapter- the absence of research that study enhancement of outdoor thermal comfort with combining the two sides of the issue, in one hand urban microclimate resulted from the urban morphology and in the other hand individual's sensation and perception. Moreover, this dissertation is unique by taking district in Sharjah as case study.

The primary objective of this research was:

"To establish a link between outdoor thermal comfort and walkability by examining how various sustainable design solutions for improving outdoor thermal comfort can be codified to also boost walkability".

In chapter 4, the conclusion of field interview, observations, and measurements along with the thermal walk experiment results have made the base for the morphological changes proposed in the scenarios as well as for analysing the simulation outputs. This link has been established by combining several qualitative and quantitative methods. Moreover, this link has been studied and developed by taking challenging site that has no symmetries in streets directions and sizes, buildings in the site has different shapes and heights and the shape of the site itself is irregular.

Other objectives of the dissertation are:

"Setting benchmarks for critical outdoor thermal comfort parameters in the UAE climate"

In chapter 2, (literature review), outdoor thermal comfort was discussed and analysed in detail including the concept of thermal comfort, thermal perception and the link between outdoor thermal comfort and walkability, the phenomena of Urban Heat Island, and the effect of urban climatology and morphology on thermal comfort. The literature review covered all the aspects and concepts related to the topic with focus on the latest studies (done within the last 5 years).

"Observing the patterns of walkability in various parts of the case study and identifying the urban configuration and streetscape" *and* ***"Evaluating people's perceptions of outdoor thermal comfort, and thermal sensation in the case study throughout the year"***

These objectives were achieved by field interviews, observations and measurements that was explained and documented in chapter 4.

"Comparing various mitigation measures based on their applicability, and impact, and then selecting the most appropriate strategies"

Chapter 2 presents the various mitigation strategies and measures and compare between them according to the previous research conducted in the field.

"Using numerical simulation and visual analysis, determining the number of improvements" *and* **"*Investigate the improvement in outdoor thermal comfort that would result if urban planners took this into account the proposed strategies in the early phase of design and urban planning*"**

Chapter 4, section 5 presents the visual code that was developed on rhino/ grasshopper interface. While chapter 5 illustrates the result of the simulation using the environmental analysis tool ladybug plugin. The results showed that considering these strategies from the initial phases of urban planning can contributes to improving the outdoor thermal comfort.

7.1.Summary of the research

This dissertation recognizes that raising a city's quality of life requires creating a suitable outdoor place for residents to use. While the subject of how the physical environment's design influences people's perceptions and walkability patterns is still largely unexplored, particularly in the gulf region, this dissertation sets out to investigate it the issue. The main focus of the study is to quantify the enhancement that can be achieve if urban planner incorporates mitigation strategies analysis and studies as part of the urban design process in a comprehensive approach that takes into consideration the level of thermal adaptation of the users of the space. This includes the study of thermal sensation and perception.

The dissertation started by providing an overview on the subject, followed by global and local review on the latest efforts done in the topic of enhancing outdoor thermal comfort to encourage walkability. In the second chapter, literature review was conducted, which create the solid base for selecting the suitable strategies for the investigation. At the end of the chapter, a knowledge gap was identified to validate the need for this study. The third chapter, methodology presents a comprehensive review of the methods and standards applied in studying this subject area and compares between them. By this review, it was decided that both a qualitative and quantitative methods is needed for this research. The chapter ends by explaining the selected methodology and justify this selection.

Chapter 4 provides more in-depth explanation on the case study, and the climatic conditions. Then the chapter presents technical detail on the process of conducting the interview, taking the measurements in the site and implementing the thermal walk experiment. The chapter ends by show the visual code that was developed and implemented for the simulation part.

Chapter 5 illustrates the results of the field survey, thermal walks, and the simulations. And discuss the results of the different scenarios propose to conclude how these strategies affect outdoor thermal comfort in the case study.

7.2. Summary of the results

The results of thermal walks have showed that 10 min walking outside can increase the skin temperature up to 2°C. By going back to the literature, similar results achieved by Sabbagh et al. (2016) that used thermal walk methods to determine people's tolerance for walking outdoors across the seasons in Dubai. In the other hand, according to the results of UTCI simulation presented in Table 12, Table 13, and Table 14, N-S street orientation was performing better than the current streets orientations which confirms Huang et al., (2017) and Pyrgou et al., (2017) results. Also, the results indicate that streets with N-S orientation performed better than NW-SE orientation which contradict with Chatzidimitriou & Yannas, (2017) results that was discussed in the literature. Table 15 illustrated that N-S orientation can enhance the percentage of time comfortable from 76.3% in the case study to 99%. While Table 16, illustrate that in February the best scenario managed to achieve 0% of persons with a condition of experiencing a heat stress. However, changing the aspect ratio H/W from the current condition (around 4.2) to 2 in scenarios: Basecase_Rev_a, Scnario_1_a and Scnario_2_a, and to 1 in scenarios: Basecase_Rev_b, Scnario_1_b and Scnario_2_b has resulted in reducing the thermal comfort. These results aligning with Muniz-Gäal et al. (2020) study outcome that canyon with a larger H/W aspect ratio optimize the shading by buildings and wind speed, thus uplifting the thermal comfort zooming at the pedestrian level, particularly during summer.

7.3. Research Limitations

Several limitations were identified in the time duration of the study. First, it was plan to conduct the experiments of thermal walk in number of months; however, no volunteers accepted to committed for the experiment as it requires the involvement of the participant in specific day each month, in different timing during the day which was inconvenient for them.

Second main limitation is that UTCI simulation consider to be heavy on the computers (the simulation tends to crash in most of the cases).this is because it involves a huge number of information processing, which limits the investigator in the size of the urban space that can be simulated, however, the code was edited to restrict the simulation in small duration and gave the opportunity to perform for the district.

7.4.Future research

The future research should investigate more the thermal walk experiment with a larger number of participants and within several urban districts for a whole year. This can benchmark the level of thermal adaptation according to individuals' differences and can redefine the outdoor thermal concept in specific urban configuration.

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