Engineering Research Journal
journal homepage: https://erj.journals.ekb.eg/

Using Urban Climatology to Attain Thermal Comfort "A Comparative Analysis on Different Urban Tissues in Egypt "

Hebatallah Atef Ahmed[1, *], Mohamed Alaa Mandour[1] and Doaa Mohamed Helal[1]

[1] Architecture Department, Faculty of Engineering Mataria, Helwan University

*Corresponding Author E-mail: HebatallahAtef@m-eng.helwan.edu.eg

Abstract. Nowadays, the environmental quality of urban tissues and outdoor spaces has turned out to be one of the main issues facing urban designers. There are an ignorance of urban tissue influences on thermal comfort in urban areas. The physical characteristics of urban areas including buildings, materials, urban form, and vegetation have a great impact on the resulting microclimate conditions. Therefore, the arrangement and design of urban elements can significantly influence thermal comfort so the relation between urban climatology and urban tissue is crucial. Urban climatology has a vital role in understanding the complex interactions between cities and the atmosphere, helping to inform policies and practices that promote sustainable and livable urban environments. It investigates the impact of urbanization on various meteorological parameters, such as temperature, humidity and wind patterns. This research highlights the relation between urban climatology and urban tissue using ENVI Met considering PET (Physiologically Equivalent Temperature). Therefore, a comparative study between two different neighborhoods with various tissues (Fifth settlement and Mohandseein in Egypt) are analyzed and evaluated. The Study adopts not only the environmental variables: air temperature, wind speed, relative humidity, but also sky view factor as indicators to calculate PET during summer and winter. It also depicts the urban heat island (UHI) effect on the chosen neighborhoods. The research extracts a group of indicators that mitigate the opposing effects of climate change, attain thermal comfort, and create more sustainable and livable urban environments considering urban tissue design.

Keywords: Urban climatology, Urban tissue, Thermal Comfort, Envi-met, PET

1 Introduction

Urban climatology, the study of climate in urban areas, plays a crucial role in understanding and mitigating the impacts of urbanization on thermal comfort.[1] This field is particularly significant in regions like Egypt, where extreme temperatures are common, and the urban microclimate greatly affects the livability and sustainability of cities.[2] This research focuses on analyzing different urban tissues meaning the physical structures and layout of urban environments in Egyptian cities to identify strategies for enhancing thermal comfort.

Egypt's urban areas feature diverse architectural styles, ranging from densely packed traditional neighborhoods to modern, sprawling developments.[3] These varying urban forms create distinct microclimates, influencing temperature, humidity, wind patterns, and solar radiation [4]. By comparing different

DOI: 10.21608/erj.2024.310303.1085
Received 06 August 2024; Received in revised form 06 August 2024; Accepted 12 August 2024
Available online 01 September 2024

urban tissues, the research aims to uncover how specific design elements either contribute to thermal comfort or exacerbate heat stress.
Understanding the interplay between urban form and microclimate is essential for developing urban planning strategies that prioritize thermal comfort. This is particularly crucial in Egypt, where high temperatures can significantly impact public health, energy consumption, and overall quality of life.[5] Through a comparative case study approach, the research will examine multiple urban environments within Egypt, assessing how factors such as building density, street orientation, green spaces, and materials affect thermal conditions.
The findings are expected to provide valuable insights for urban planners, architects, and policymakers. By identifying best practices and potential interventions, the research aims to inform the development of more climate-responsive urban designs that enhance thermal comfort and resilience in Egyptian cities. Ultimately, this work contributes to the broader goal of creating sustainable urban environments capable of adapting to the challenges posed by climate change.
Urban climatology examines how urban climates affect cities and uses this information to improve urban planning and design. [6] Its unique focus integrates multiple disciplines, including meteorology, architecture, and urban design, each contributing distinct tools and techniques.[7] Cities significantly alter their environment through changes in surface cover, fabric, geometry (urban form), and anthropogenic emissions (urban function).[8] Although these alterations have been recognized for 200 years, a comprehensive understanding has developed only over the past 40 years.[9]
Research in urban climatology often centers on urban geometry, particularly the aspect ratio and street orientation, which affect the urban microclimate and thermal comfort.[10] The sky view factor (SVF) and the height-to-width ratio (H/W) are key elements in studying how urban streets impact air temperature and thermal comfort.[11] Recently, the focus has shifted towards outdoor thermal comfort in open urban spaces, driven by climate change and urban expansion. Studies highlight the importance of urban public spaces in enhancing quality of life, promoting social interactions, and improving urban vitality.[12]
Outdoor thermal comfort, a complex issue influenced by numerous factors, is essential for sustainable urban growth. It is variably defined but generally refers to a state where individuals feel neither too hot nor too cold. Thermal indices, which measure people's thermal perception, play a crucial role in evaluating thermal comfort.[13] Various indices, such as the Universal Thermal Climate Index (UTCI), Standard Effective Temperature (SET*), and Physiologically Equivalent Temperature (PET), are used to assess thermal comfort in different climatic conditions.[14]
The phenomenon of urban heat islands, where urban areas are significantly warmer than their rural counterparts, illustrates the profound impact of urban morphology on microclimate. Understanding these influences helps inform strategies to enhance outdoor thermal comfort through urban design modifications. Overall, integrating urban climatology insights into urban planning can lead to the development of more comfortable, sustainable, and livable cities.[15]
The aim of this study is to utilize urban climatology principles to enhance thermal comfort in Egyptian cities by comparing and analyzing different urban tissues. This research seeks to identify effective urban design strategies that mitigate heat stress and improve the livability and sustainability of urban environments in the context of Egypt's extreme temperatures.

2 Literature Review

2.1 Urban Climatology

Urban climatology is the study of urban climate, focusing on the interactions between urban areas and the atmosphere, their influence on each other, and the various spatial and temporal scales at which these processes occur.[16] Macroclimatic modeling and the complex challenges of downscaling to the urban setting have shaped our knowledge of climate change, but the models and data needed for urban climate study have received less attention.[17] The three-dimensional arrangement of structures and spaces,

human behavior inside them, and the interplay of local physical topography and regional weather all play an ecological role in determining the microclimates of human settlements.[18] Urban architecture significantly impacts parameters determining human thermal comfort, such as wind, humidity, ambient air temperature, and sun radiation. However, town planners and decision makers are less likely to consider the consequences for outdoor climate.[19]
Errell (2008) highlights six essential elements that city planning departments should consider helping cities better control their urban climate: the degree of urban density, street orientation, street aspect ratio, building and neighborhood typology, size, type, and location of city parks, and building and paving materials.[20] Lenzholzer (2015) has also created a thorough analysis of materials and methods, grouping them according to how they affect temperature, airflow, precipitation, and human perception.[21]
Cities generally have warmer temperatures than rural areas, which can lead to increased urban pollution, discomfort, and the need for air conditioning. Automated data collection and urban climatic modeling have enabled the identification of actions to improve urban climate quickly and affordably.[22] However, regulating land use zoning, design codes, infrastructure specifications, master plans, green space reservations, and policies for urban spatial structure remains a challenge. Therefore, policy and regulatory application must align with understanding urban climate to effectively manage urban areas.[23]

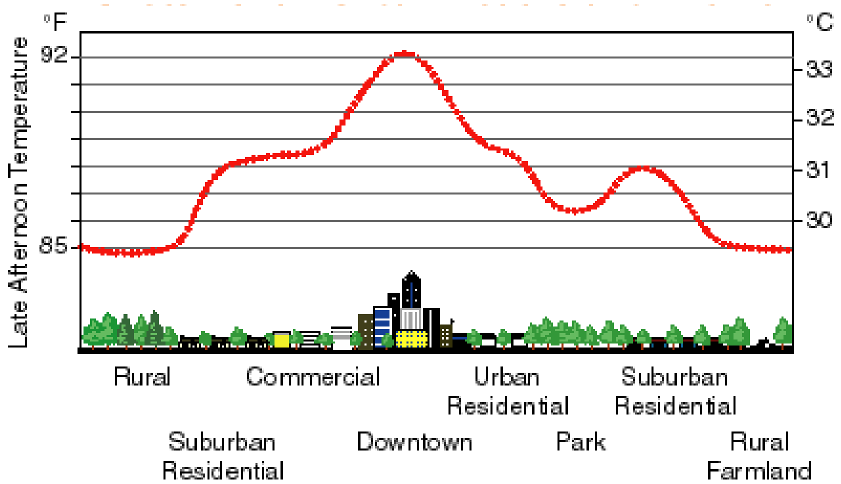


Figure 1 Sketch of the profile of temperatures typically observed in urban cities using the Urban Rural classification (Courtesy of the Lawerence-Berkeley National Laboratory)

2.2 The Influence of Urban Tissue on Thermal Comfort: Exploring the Connection Between Urban Climatology and Urban Tissue

Urban tissue pertains to the configuration and composition of built and natural environments in urban areas, including buildings, streets, green spaces, and other public places.[24] The impact of outdoor thermal comfort has received significant attention in recent years, particularly in the context of growing urbanization and climate change.[25] This literature review consolidates current research that analyze the impact of various elements of urban tissue on thermal comfort. It specifically emphasizes important factors like density, form, orientation, and vegetation.
The study analyzes and compares three environmental parameters, namely potential air temperature, wind speed, and relative humidity, across the chosen locales. The comfort air temperature and relative humidity are evaluated based on the comfort zone defined in Givoni's psychometric chart (see Figure 2). [26]

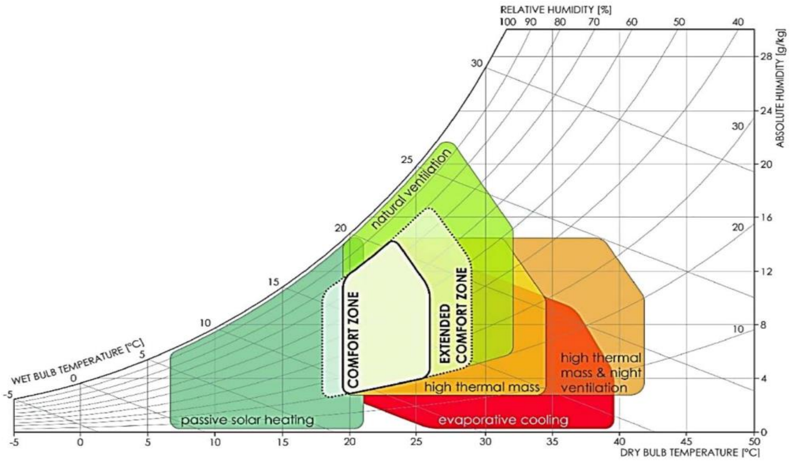


Figure 2 Givoni's psychometric chart for human comfort zone. Source [26]

- **Impact of Urban Density on Thermal Comfort**

Recent studies highlight the crucial significance of urban density in determining thermal comfort levels. An example is a research conducted by Alavi et al. (2021) [27] which showed that higher building density might result in greater heat retention and raised nighttime temperatures, hence enhancing the urban heat island effect (UHI). The authors contend that while high density might restrict the availability of green space, strategic design that incorporates plants and permeable materials can alleviate unfavorable thermal conditions. Furthermore, the research conducted by Wang et al. (2023) [28] supports these discoveries, indicating that the deliberate control of population density in urban planning is crucial for improving thermal comfort.

- **Urban Form and Microclimate Regulation**

Urban form's geometric features, such as the height and density of buildings, have significant effects on microclimate conditions. The study conducted by Ma et al. (2022) [29] investigated the impact of building layout on airflow optimization and improvement of thermal comfort. Their research suggests that arranging buildings at the ideal distance from one other may decrease the occurrence of slow airflow and enhance the movement of air, resulting in decreased temperatures in the surrounding area during hot weather periods. In addition, Xu et al. (2024) [30] emphasized that irregular urban configurations, while they may enhance visual attractiveness, may generate microclimates that have either positive or negative effects on thermal comfort. The outcome depends on elements such as the local temperature and the materials used in the urban environment.

- **Orientation and Aspect Ratio**

The orientation of buildings and streets also has a crucial impact on determining thermal comfort levels. In their study, Liu et al. (2020) performed a comparative analysis to examine the impact of building orientations on solar radiation exposure in mixed-use urban projects.[31] Their study revealed that proper alignment may decrease the amount of solar heat absorbed and provide shading, so greatly enhancing the comfort levels experienced outside. The results are consistent with the research conducted by Pochulu et al. (2023) which found that the aspect ratios of urban canyons have a significant impact on the penetration of sunlight and shade. Narrow streets get less direct sunlight, which ultimately improves comfort.[32]

- **Vegetation and Green Infrastructure**

Research has shown that incorporating green spaces into urban areas may reduce heat and enhance thermal comfort. Rivas et al. (2021) shown that augmenting the amount of tree canopy cover may lead to a significant decrease in ambient air temperatures by a few degrees, mostly due to the combined effects of evapotranspiration and shade.[33] Their models demonstrated that regions with green roofs and expansive parks had enhanced thermal comfort indices in comparison to completely urbanized areas. Zhang et al. (2022) discovered that urban parks have dual effects on the surrounding microclimates. They act as cooling oasis and enhance air circulation, hence minimizing the accumulation of heat.[34]

3 Simulation software

This study utilizes the ENVI-met model as an advanced 3D simulation tool to investigate the complex physical processes that take place among buildings, the outdoors, environment, and vegetation in urban areas. This model is very efficient at replicating meteorological conditions in specific metropolitan areas with great precision, enabling in-depth analysis of microclimate fluctuations.[34] The input data for the ENVI-met model includes a range of meteorological and geographical variables, such as longitude, latitude, beginning temperature, wind direction and speed, cloud cover, and relative humidity. In addition, a comprehensive analysis is conducted on the physical attributes of neighborhoods, with a specific emphasis on urban structure and the thermal characteristics of different land and building materials. The model's outputs encompass a wide range of climatic data, such as air temperature, relative humidity, wind speed, and Physiological Equivalent Temperature (PET). These outputs allow for a detailed comprehension of urban microclimates and their effects on thermal comfort and human well-being.[36]

4 Methodology

This research aims to analyze thermal comfort in two distinct neighborhoods in Cairo, Egypt, which share similar climatic conditions and area but differ in urban fabric, land use, and building heights. The study will employ a comparative case study approach, integrating urban climatology principles to identify strategies for enhancing thermal comfort.

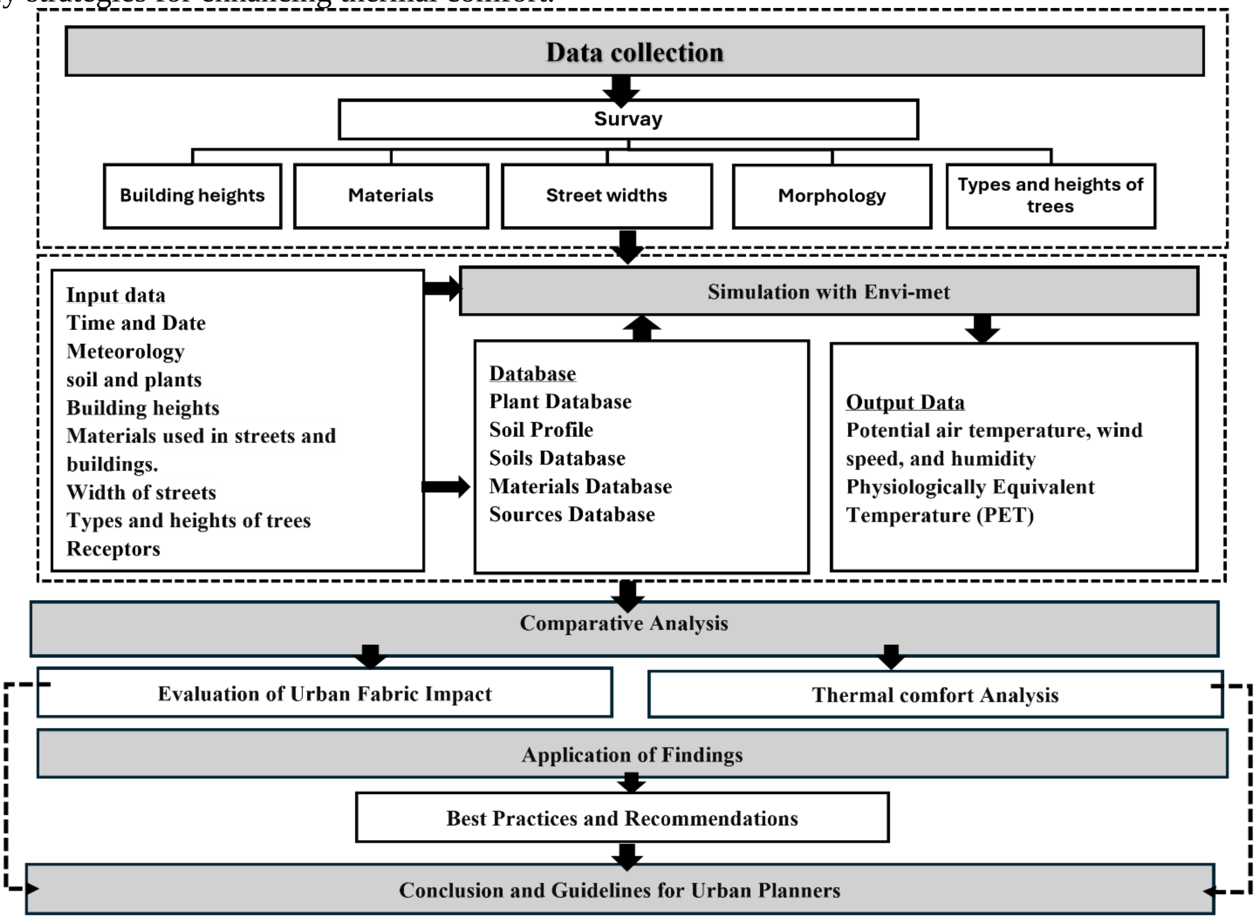


Figure 3 Methodology of the research. By researcher

5 Climate analysis

Egypt is classified as a region with a hot arid climate according to Köppen's climatic classification.

The climate in Cairo is characterized by scorching temperatures and arid conditions.[37] The mean yearly precipitation is 11mm, whereas the mean daily temperature in July is 35.7°C. It is not unusual for summer temperatures to exceed 40°C, and frequently temperatures surpass 39oC. The mean summer relative humidity is 62%. During the winter season, the temperature can drop to as low as 7 °C, while the relative humidity remains at around 50% in the month of February, [38] as depicted in the accompanying Figure.

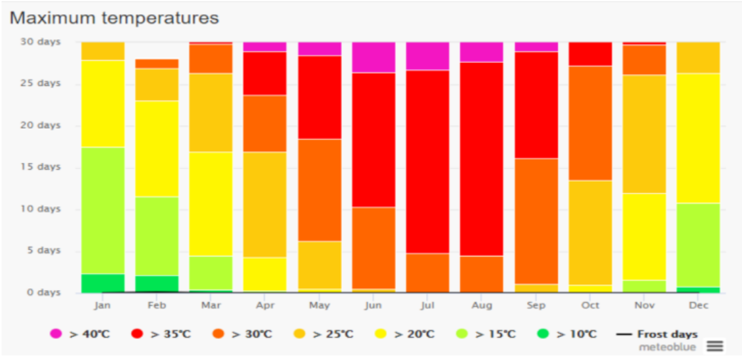


Figure 4 All year climate and weather averages in Cairo Source: Climate & Weather Averages in Cairo, Egypt, url: https://www.tim**eanddate.com/weather/egypt/cairo/climate.** **Accessed ,17 January 2024**

6 Case study selection and description

The selection of study areas was based on their pertinence to the research aims and the availability of pertinent data sources. Both areas in Cairo, Egypt have a hot arid climate and are around 1 km² in size. However, they differ in terms of building height and land use. This makes them perfect settings to study thermal comfort in different urban tissues.

***Case study 1**: Fifth Settlement (Retaj Compound)*

The study area is situated in the Greater Cairo region, notably within the Fifth Settlement, renowned for its grid urban tissue. This residential neighborhood covers an expanse of 1 square kilometer and consists of buildings that have an average height of four stories. and is distinguished by the incorporation of green spaces that are distributed across this area.

- **Category** Residential
- **Building Heights**: The buildings in the development are all the same height, specifically four floors high.
- **Urban Fabric**: The overall design of the urban area is characterized by a consistent and low-rise layout, with plenty of green areas interwoven throughout the development.
- **Pattern of tissue:** (Retaj compound plan) with rectangular street pattern (grid type)

***Case study 2:* Mohandessin is bounded by Gamaet El-Dewal El-Arabeya Street and El-Mohandes Mohamed Hassan Helmy**

The study area is situated in the Greater Cairo region, Giza government notably within El-Mohandseen city, bordered by Gamaet El Dewal El Arabeya Street and El-Mohandes Mohamed Hassan Helmy Street, renowned for its radial urban tissue. This residential neighborhood covers roughly an expanse of 1 square kilometer and consists of buildings that have a different height from 1 up to 20 stories. and is distinguished by the incorporation of little green spaces that are distributed across this area.

- **Category**: Mixed-use district
- **Building Heights**: Diverse, with mixed-use buildings ranging in height
- **Urban Fabric**: Characterized by high-rise buildings closely situated, with a variety of building materials and limited green areas

- **Pattern of tissue:** (Mohandessin plan) with radial-ring street pattern

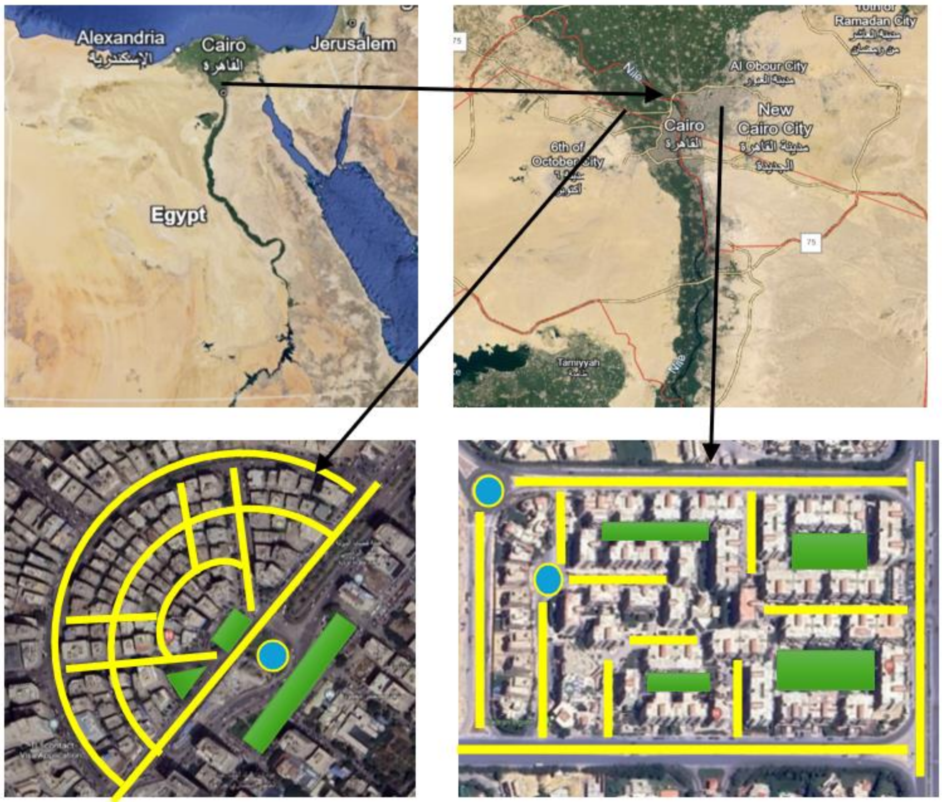


Figure 5 shows both of case studies site location, the right is case study 1 and left represented case study 2. Adapted by the researcher from google earth.

6.1 Morphology

Fifth Settlement area is characterized by a **grid urban fabric** by a systematic orthogonal pattern of streets and buildings, creating a grid of square or rectangular blocks. This layout improves accessibility, connectivity and land use efficiency, making navigation clear and easy. While El-Mohandseein District has a **radial urban fabric**, including streets that extend outward from a central point. This design promotes improved connection, navigation, and land use efficiency.

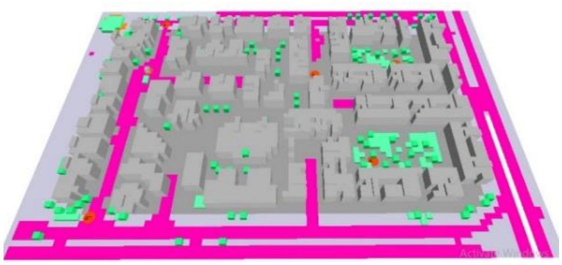


Figure 6 Layout shot for case study 1. Source researcher from Envi-met program

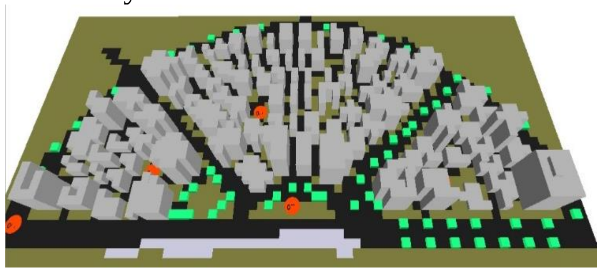


Figure 7 Laypout shot for case study 2. Source researcher from Envi-met program

6.2 Building heights

Case study 1 showcases a harmonious blend of urban functionality and residential tranquility, with buildings averaging four stories, resulting in a balanced skyline and consistent architectural aesthetic. While the case study 2, situated in the central area of Cairo, Egypt, is a vibrant urban hub known for its distinctive urban layout and diverse range of building heights from one up to 20 floors. This dynamic neighborhood has a wide array of architectural styles, including contemporary skyscrapers and classic residential structures. As shown in figure (8&9).

Figure 8 Buildings height of case study 1 and Images form site. Source researcher

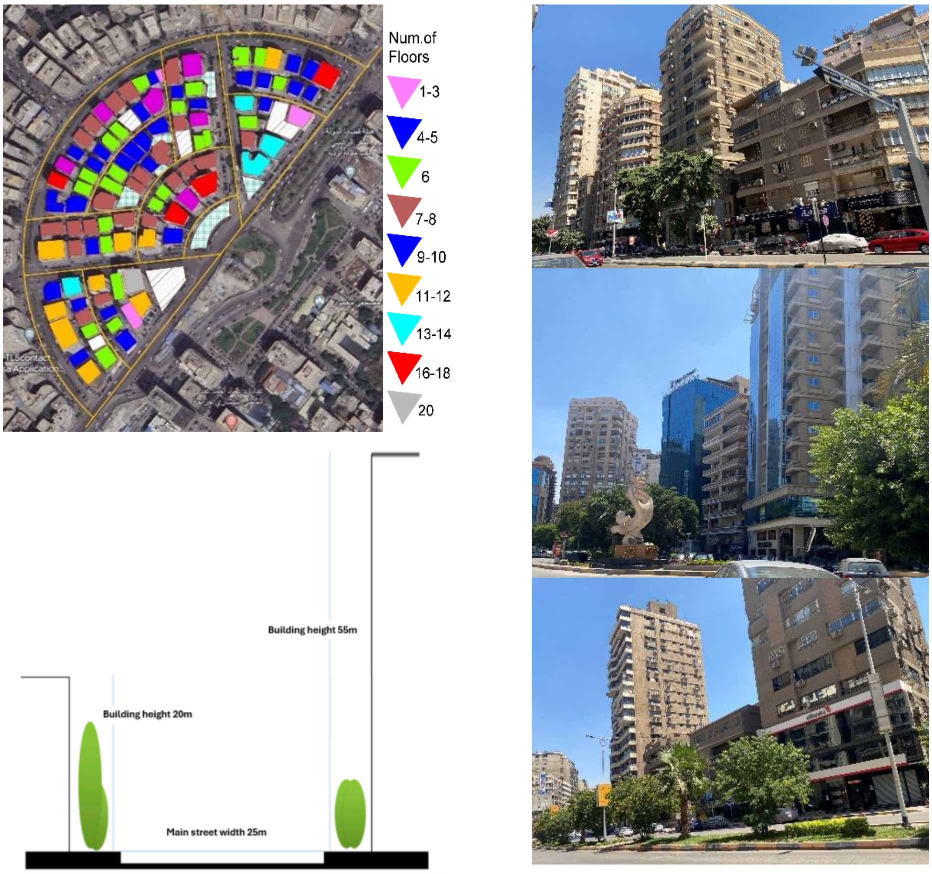


Figure 9 Buildings height of case study 2 and Images form site. Source researcher

6.3 Types and heights of trees

Case study 1 features a diverse variety of tree species, as detailed in the accompanying figure and described in table (1). On average, approximately 30% of the area is covered by vegetation. But the second study area has a different array of tree species that spread in an apparently random arrangement throughout the landscape. Nevertheless, it is important to mention that the proportion of greening in this area remains very small, barely surpassing 3% of the whole land surface.

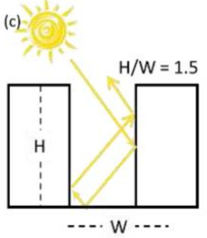
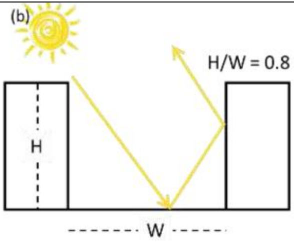
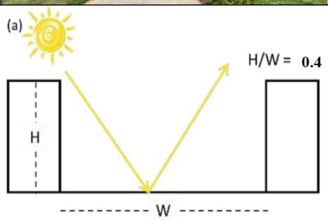
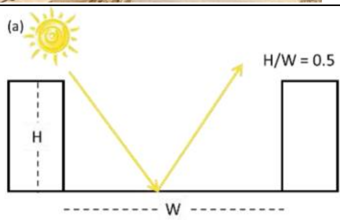
Table (1) shows the Types and heights of trees. source researcher.

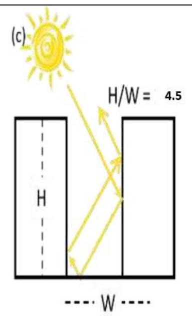
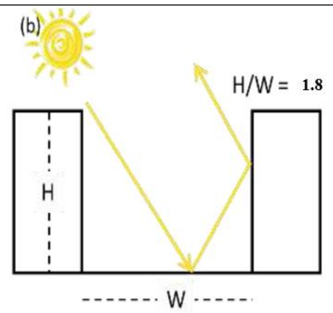
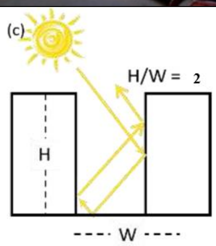
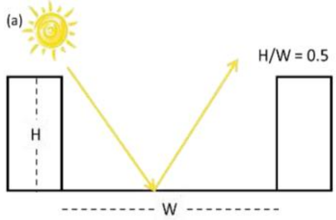
Specification	Name of Tree		
	 Tecoma stans	 Leucaena	 Ficus Nitida
Location	Case study 1	Case study 1 and 2	Case study 1 and 2
Tree height	12 meters	10 meters	12 meters
Albedo	0.2	0.2	0.15
Specification	 Cassia nodosa	 Dwarf English Boxwood	 Natural grass
Location	Case study 1 and 2	Case study	Case study 1
Tree height	9 meters	0.9 meter	-
Albedo	0.2	0.15	0.2

6.4 Street width

Consequently, the width of streets and the height of surrounding buildings must be carefully considered to optimize thermal comfort in urban design. The case study 1 we have four different aspect ratios. But In case study 2 we found various aspect ratios because of the different heights of buildings; table (2) demonstrates four different aspect ratios.

Table (2) demonstrates four different aspect ratios for both case studies. source researcher.

Case study 1	
	
	
Street with 1.5 aspect ratio	Plaza with 0.8 aspect ratio
	
	
Acourtyard with 0.4 aspect ratio	Acourtyard with 0.5 aspect ratio
Case study 2	
	

	
Narrw street with 4.5 aspect ratio	Main street with 1.8 aspect ratio
	
	
Sub street with 2 aspect ratio	Main street with 0.5 aspect ratio

6.5 Material

The materials used in urban spaces significantly impact thermal comfort, making it essential to study their effects in our case study 1. The urban space comprises various structural elements, including walls, floors, roads, and pavements. The walls, representing buildings, are constructed from concrete blocks and finished with paint. The floors include roads made of asphalt and grassy areas. Additionally, the pavements are crafted from interlocking pavers. And in case study 2 consists of concrete blocks, asphalt, and curtain walls, as shown in table (3).

Table (3) shows the used materials in both case studies. source researcher.

Case study 1		
Building	**Pavement**	**Roud**
		
The buildings are constructed from concrete and finished with a layer of paint, with some sections incorporating glass.	The pavement throughout the hard-scape areas is made from interlocking pavers.	The roads are covered with as-phalt, providing a durable and smooth surface for vehicular traf-fic.
Albedo:0.4 for paint, 0.7 for glass	Albedo of interlocking pavers about 0.3	Albedo of asphalt about 0.1
Case study 2		

Building	Pavement	Roud
		
Some buildings are finished with paint and made of concrete, while others have curtain walls.	The pavement is made from interlocking pavers.	The roads are covered with asphalt.
Albedo:0.4 for paint, 0.7 for curtain walls	Albedo of interlocking pavers about 0.3	Albedo of asphalt about 0.1

7 Results and discussion:

In order to accomplish the objectives of this study, a comprehensive comparative assessment will be carried out on two urban areas to ascertain which one offers the most efficient rate of thermal comfort. This evaluation will provide valuable insights into the aspects that contribute to urban comfort and help determine the most ideal urban environment.

Simulations were performed at 6:00 AM, 9:00 AM, 12:00 PM, 3:00 PM, 6:00 PM, and 9:00 PM for both the peak summer day (July 1) and the peak winter day (January 1) in Cairo, representing the warmest and coldest days of the year respectively. The simulations were conducted to examine the influence of various urban pattern configurations on thermal comfort levels by modeling the urban tissue. The duration of each simulation was 15 hours, commencing at 6:00 AM and terminating at 9:00 PM. The simulation is conducted on an hourly basis at five receptors in both case studies, as seen in figure (10&11). The urban blocks under investigation were included into ENVI-met as a 2D model grid of 100×100×30, with each grid cell having a resolution of 2 m×2 m×3 m. The simulations were initiated using weather data specifically obtained from Cairo, Egypt.

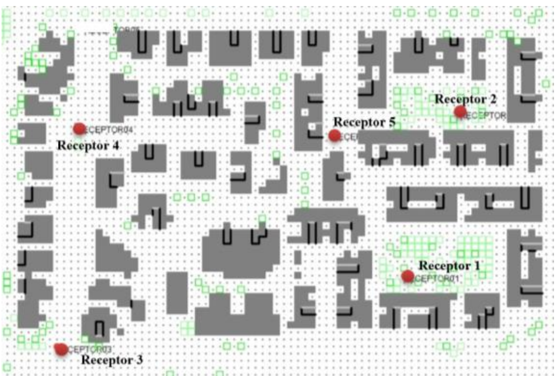


Figure 10 shows Receptors place in case study 1:

- Receptor 1: in courtyard with aspect ratio 0.4
- Receptor 2: in courtyard with aspect ratio 0.5
- Receptor 3: in street with aspect ratio 0.8
- Receptor 4: in street with aspect ratio 0.8
- Receptor 5: between buildings with aspect ratio 1.5

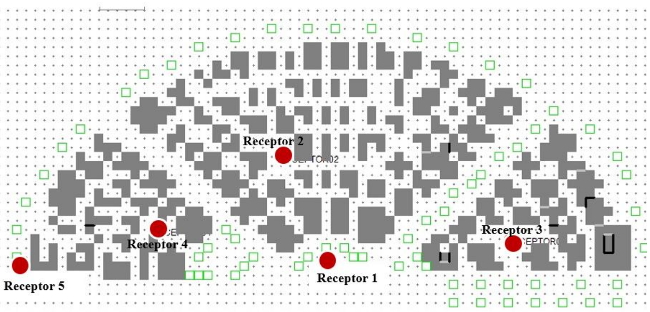


Figure 11 shows Receptors place in case study 2:

- Receptor 1: in piazza front of buildings with aspect ratio 1.8
- Receptor 2: in street with aspect ratio 0.5
- Receptor 3: between buildings with aspect ratio 1.5
- Receptor 4: between buildings with aspect ratio 2
- Receptor 5: in main street with aspect ratio 0.5

7.1 Summer results

7.1.1 Thermal comfort analysis for potential air temperature:

In Case Study 1, the observed temperatures showed significant fluctuations, with a range of up to 16°C. Temperatures started at 27.08°C at 6 AM in receptor 1, peaked at 43.63°C at 4 PM in receptor 2, and dropped to 39.28°C by 9 PM in receptor 1. While In Case Study 2, temperatures also varied significantly, with a range of up to 18°C. Starting at 26.22°C at 6 AM, temperatures peaked at 44.48°C at 4 PM in receptor 5 and fell to 39.12°C at 9 PM in receptor 4. According to Givony's model, these substantial temperature variations can impact comfort levels negatively. High daytime temperatures can lead to overheating, and warm nighttime temperatures can affect sleep quality. Both studies emphasize the importance of considering temperature changes throughout the day to improve overall comfort and indoor environment quality.

Upon evaluating the temperature data, we see a clear and noticeable difference in the two study areas. Case study 1(Fifth Settlement (Retaj Compound)) has a notable rise in temperatures from 6 AM to 4 PM. On the other hand, case study 2 in (Mohandessin) has lower temperatures during these hours due to the shadows created by the design of urban tissue, as shown in figure (12). This leads to an average decrease of one and a half degrees Celsius.

In contrast, between 5 PM and 9 PM, the temperature patterns exhibit a reversal. The case study 1 demonstrates lower temperatures in comparison to the second case study. The existence of courtyards and a suitable ratio enables efficient airflow and the release of heat stored in buildings and floors, facilitating smooth wind movement. In case study 2, the increased height of the buildings, narrow streets, and overall urban tissue design contribute to trap heat, resulting in temperatures that are, on average, two degrees Celsius higher.

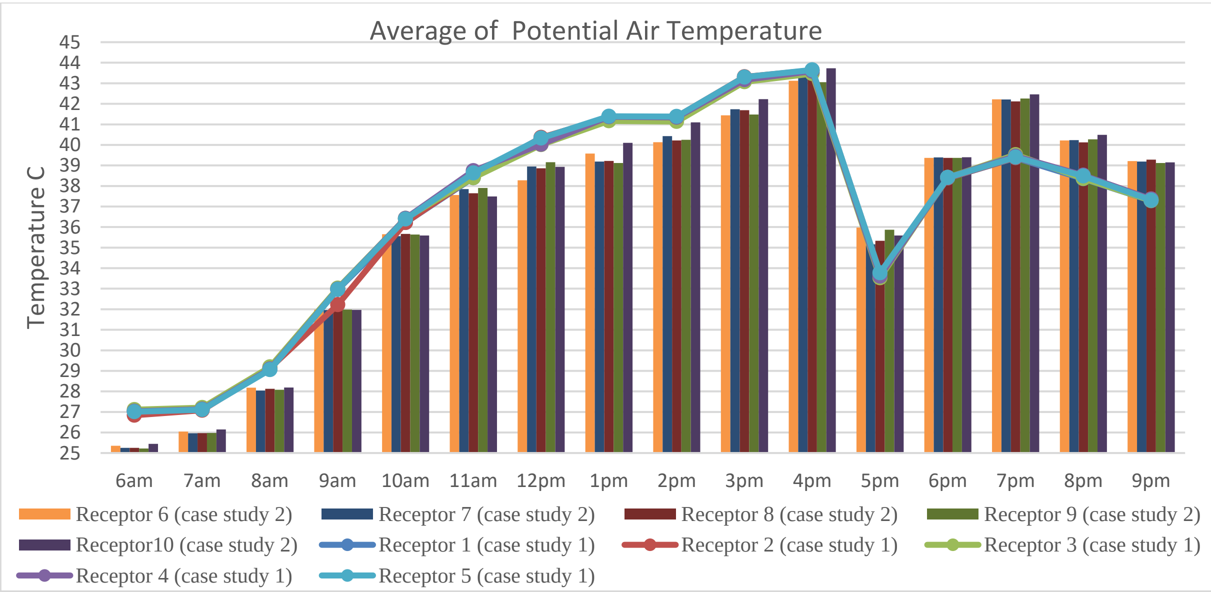


Figure 12 Average of potential air temperature for all receptors in summer source researcher.

7.1.2 Thermal comfort analysis for wind speed:

The research examined variations in wind speed in two specific cases, with wind velocities being measured at five different sites in each case study. Case Study 1 recorded wind speeds ranging from 0.97 to 6.62 m/s. The greatest wind speed of 6.62 m/s was seen at Receptor 3 at 5 PM, while the lowest wind speed of 0.95 m/s was observed at Receptor 2 at 10 AM. Case Study 2 documented wind velocities ranging from 0.89 to 6.65 m/s. The greatest recorded speed of 6.65 m/s occurred at Receptor 10 around 5 PM, while the lowest speeds of 0.89 m/s were seen at Receptors 7 and 8. as shown in figure (13). Wind velocity was impacted by factors such as urban layout, wind direction, and urban characteristics. Both studies found that courtyards with low aspect ratios hindered the passage of wind, but areas close to major roadways and towers promoted wind acceleration. These results emphasize the need to comprehend wind patterns to enhance urban design for improved ventilation, comfort, and environmental quality.

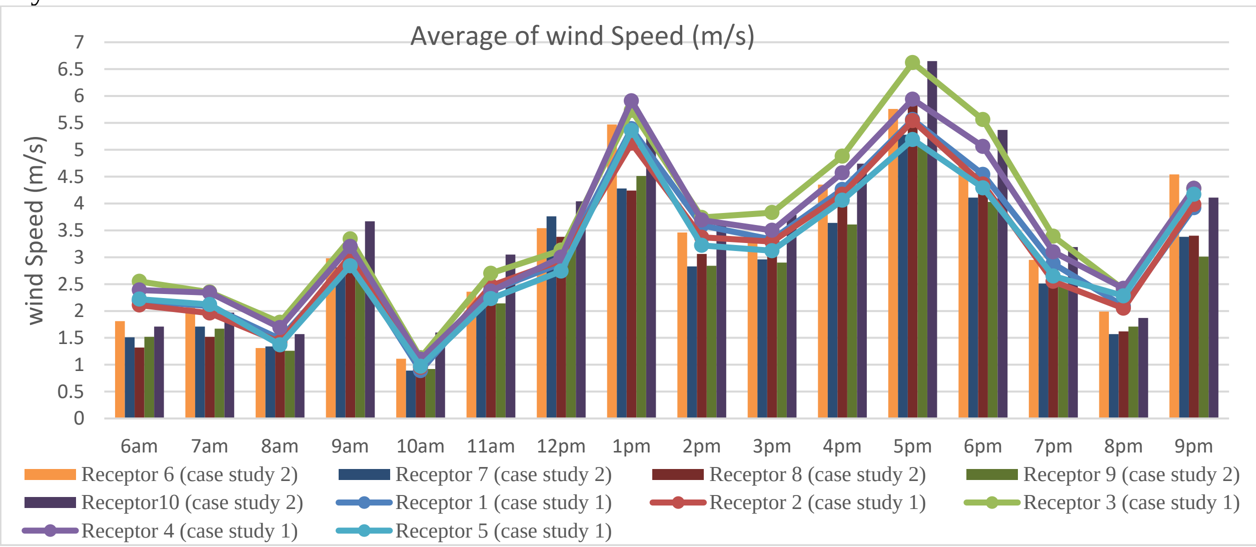


Figure 13 Average of wind Speed (m/s) for all receptors in summer source researcher.

7.1.3 Thermal comfort analysis for Relative Humidity:

The figure shows stable humidity levels at different time intervals. In case study 1, the highest percentage of humidity was recorded at 42.49% at 8 a.m. in receptor 1, and the lowest at 14.33% at 3 p.m. in receptor 5. The oscillations indicate different degrees of moisture in the air, with the highest humidity at 8 a.m. indicating a more humid climate, which could affect comfort and air quality. Conversely, the lowest humidity at 3 pm, measuring 14.33%, indicates a drier environment, which may impact indoor air quality and comfort. In case study 2, the highest recorded value was 43.05% at 8 a.m. at receptor 8, the minimum at 13.8% at 4 p.m. at receptor 7, affecting comfort and air quality, and the lowest at 4 p.m., affecting indoor air quality and comfort. as shown in figure (14).

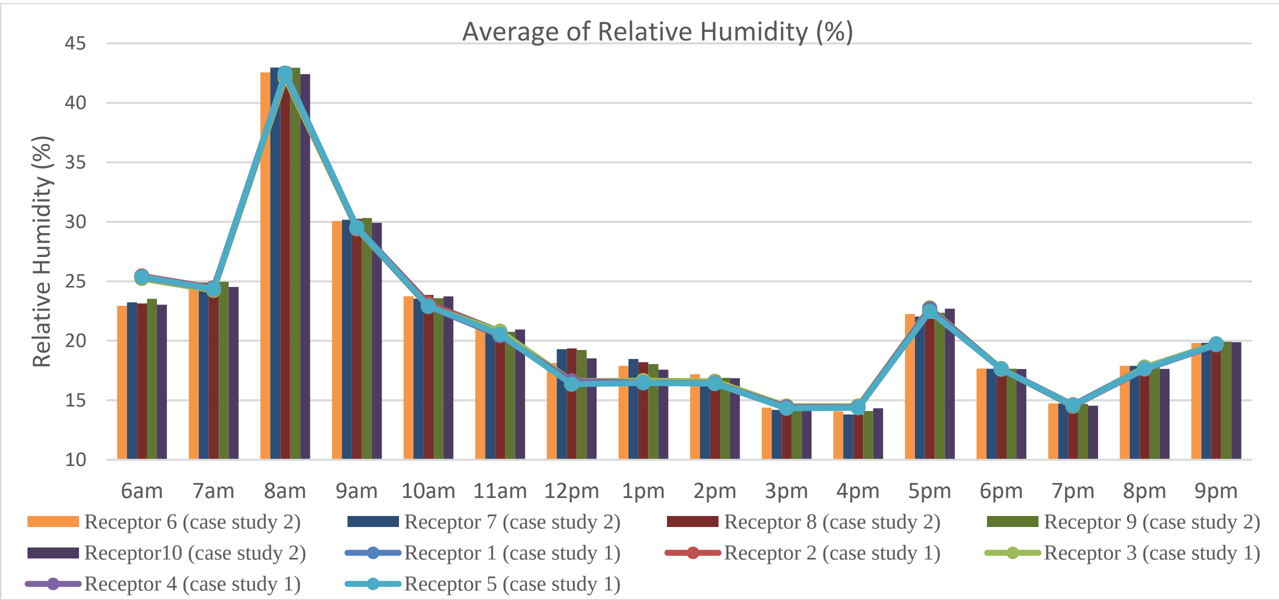


Figure 14 Average of Relative Humidity (%) for all receptors in summer source researcher.

7.1.4 Simulation of Potential Air Temperature in summer at 6am, 9am, 12pm, 3pm, 6pm and 9pm in case study 1and 2.

Table (4) shows Potential Air Temperature simulation **for case study 1**: source researcher.

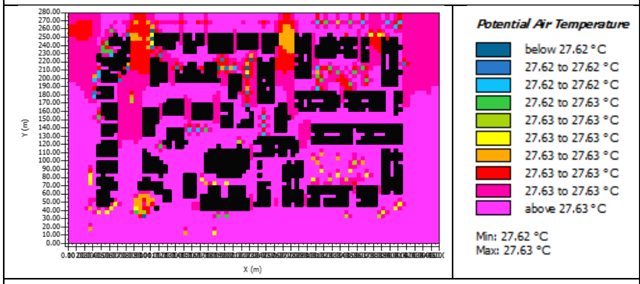
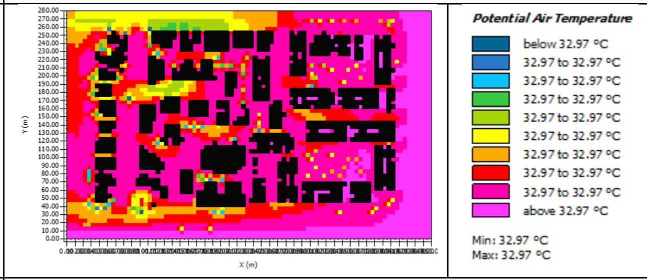
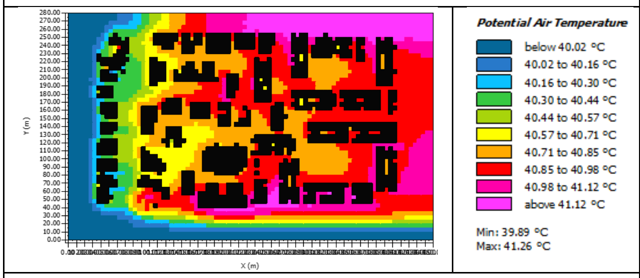
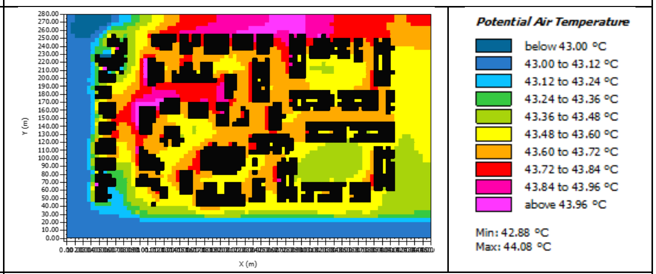
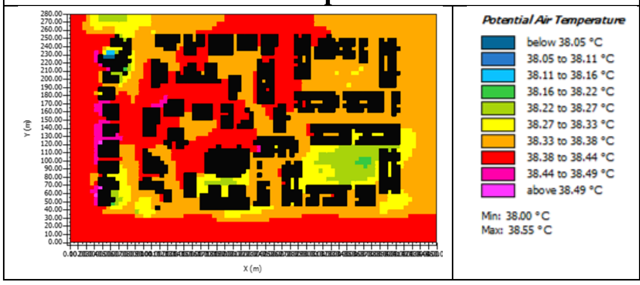
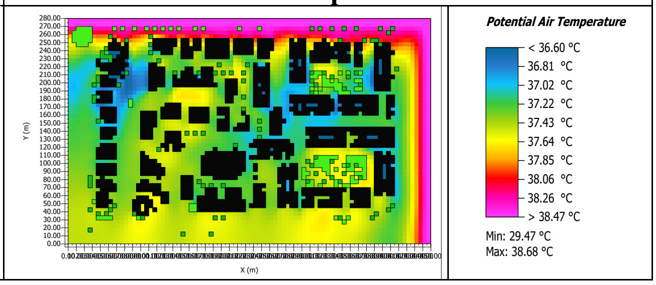
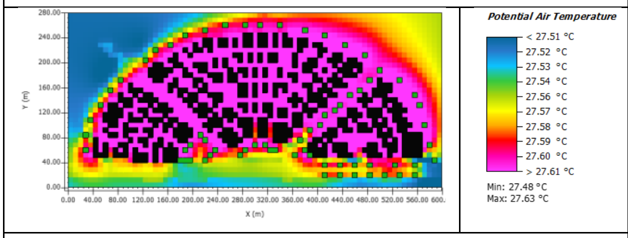
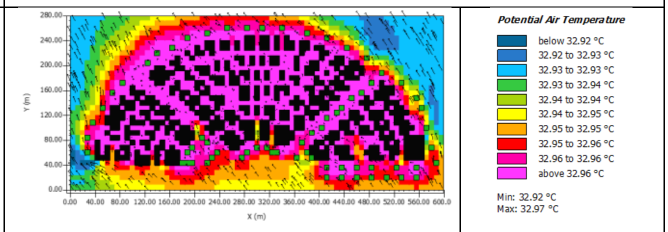
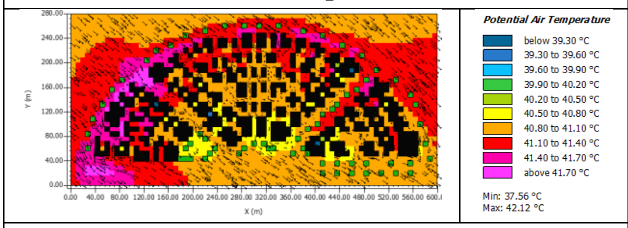
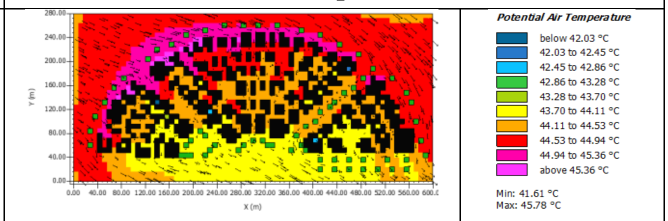
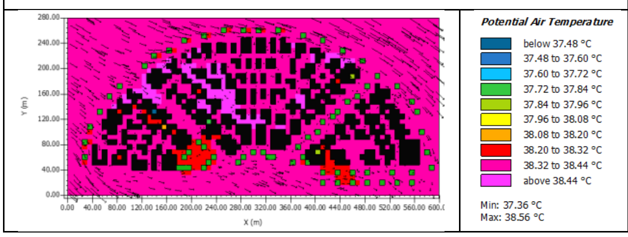
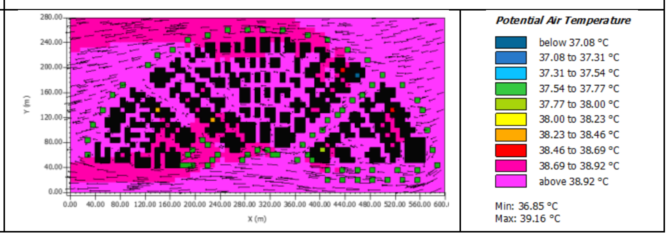
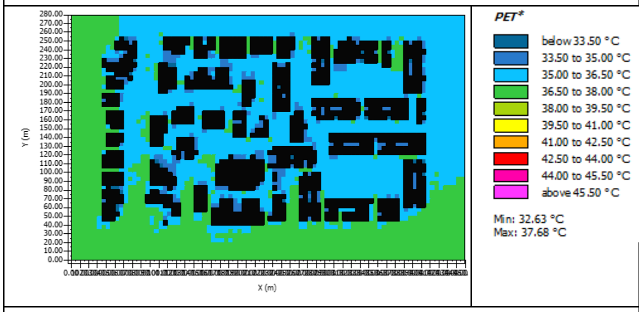
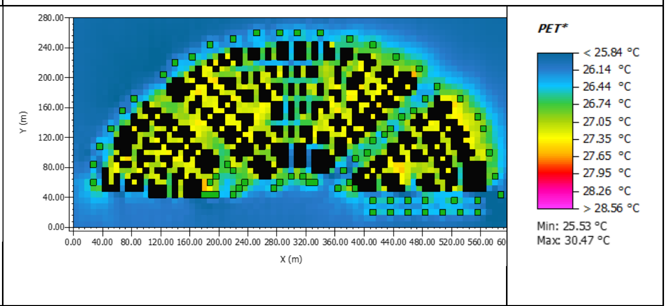
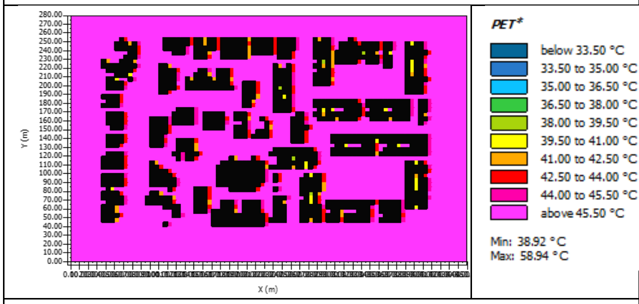
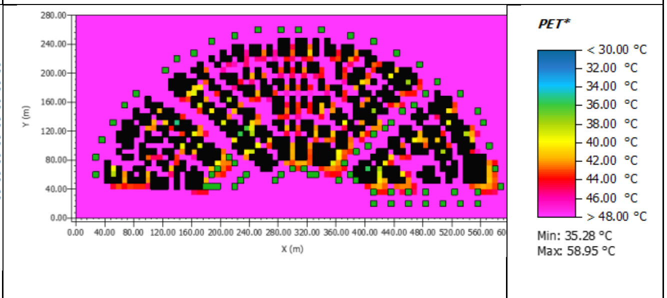
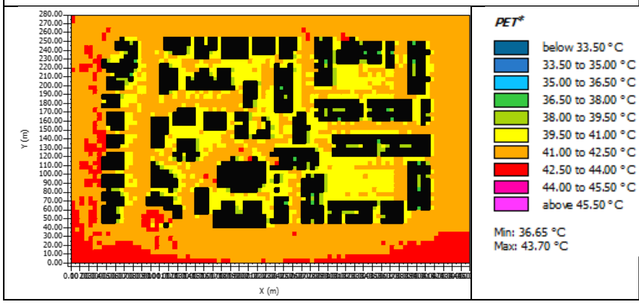
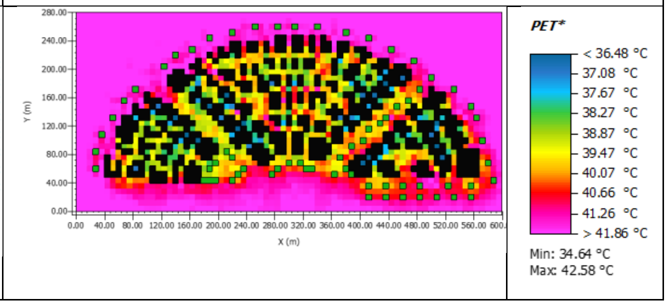
<table>
<tr><th>6am</th><th>9am</th></tr>
<tr><td></td><td></td></tr>
<tr><th>12pm</th><th>3pm</th></tr>
<tr><td></td><td></td></tr>
<tr><th>6pm</th><th>9pm</th></tr>
<tr><td></td><td></td></tr>
</table>

Table (5) shows Potential Air Temperature simulation **for case study 2**: source researcher.

<table>
<tr><th>6am</th><th>9am</th></tr>
<tr><td></td><td></td></tr>
<tr><th>12pm</th><th>3pm</th></tr>
<tr><td></td><td></td></tr>
<tr><th>6pm</th><th>9pm</th></tr>
<tr><td></td><td></td></tr>
</table>

7.1.5 Simulation of physical equivalent temperature (PET) for case study 1 and 2, in summer at 6am, 12pm and 6pm.

Table (6) shows PET at 12am, 12pm and 6pm. source researcher.

<table>
<tr><th>PET at 6am, Case study 1</th><th>PET at 6am, Case study 2</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>PET at 12pm, Case study 1</th><th>PET at 12pm, Case study 2</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>PET at 6pm, Case study 1</th><th>PET at 6pm, Case study 2</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

7.2 Winter results

7.2.1 Thermal comfort analysis for potential air temperature:

The study evaluates five locations during winter, focusing on January 1st. The results show minimal air temperature variation, with only a 1°C difference at the same hour. However, In Case Study 1, temperatures showed significant diurnal changes, with a maximum temperature variation of 10°C. The initial temperature was 9.68°C in receptor 2, and the temperature peaked at 19.69°C in receptor 3, then decreased to 12.15°C by 9 p.m. in receptor 2.

In Case Study 2, temperatures showed pronounced diurnal fluctuations, with a maximum deviation of 8°C. The highest temperature was 18.72°C in receptor 9, and the temperature dropped to 13.09°C by 9 p.m. in receptor 10. These fluctuations could significantly affect comfort levels in the area.

Due to the difference in the urban tissue of the two case studies, we find that it has a significant impact on the temperatures during the daytime hours.

After comparing the two case studies, we find that from 6:00 am to 3:00 pm, the temperatures rise relatively in case study 1 due to the sky view factor, which allows the sun's rays to reach the urban features and work to warm the area by approximately two degrees Celsius.

As for after 3:00 pm, we find that the proximity of the buildings and the proportion of urban structure contributed to preserving and storing the heat and feeling relatively warm in case study 2, and the temperatures decreased as shown in the figure (15).

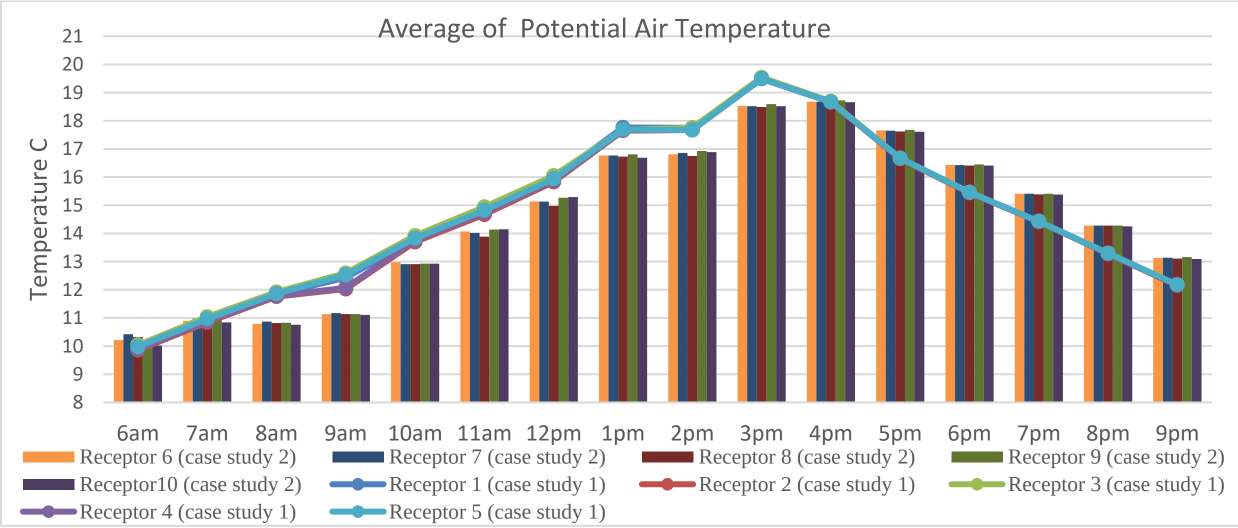


Figure 15 Average of potential air temperature for all receptors in winter, source researcher.

7.1.2 Thermal comfort analysis for wind speed:

In case study 1, the wind speed changes observed at all five places varied between 0.49 and 7.77 m/s, indicating a range from a gentle breeze to a moderately strong breeze during the research period. At 2 pm, Receptor 4 recorded the highest wind speed of 7.77 m/s, while Receptor 1 recorded the lowest wind speed of 0.49 m/s at 6 am. While in case study 2, the wind speed fluctuations recorded at all five locations ranged from 0.38 to 6.49 m/s, showing a transition from a mild breeze to a fairly strong breeze over the duration of the study. Receptor 6 recorded the maximum wind speed of 6.49 m/s at 2 pm, while Receptor 9 recorded the minimum wind speed of 0.38 m/s at 6 am, as shown in figure (16).

Wind patterns in urban settings may be influenced by the presence or lack of both natural and manmade elements, such as trees and buildings. Understanding these interactions may provide valuable insights for improving urban design to optimize ventilation, comfort, and overall environmental quality in different parts of the city.

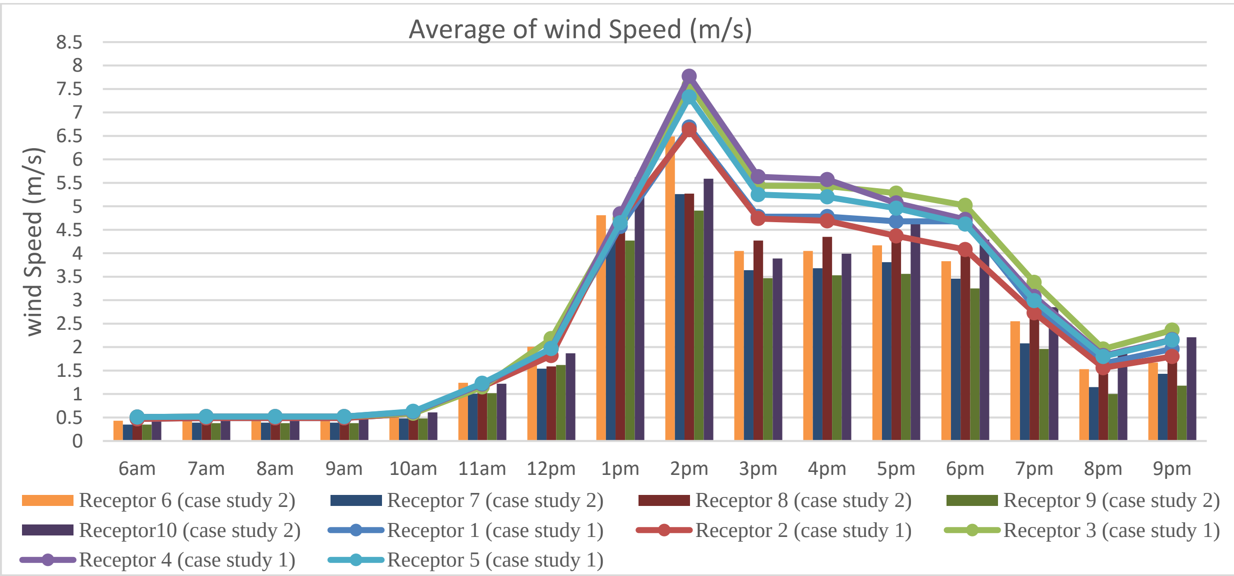


Figure 16 Average of wind Speed (m/s) for all receptors in winter, source researcher.

7.1.3 Thermal comfort analysis for Relative Humidity:

The humidity measurements during the day show a wide range of fluctuations; in case study 1, the highest recorded humidity was 96.21% at 8 a.m. at receptor 2, suggesting a more humid environment, potentially impacting comfort and overall air quality. The minimum humidity at 48.64% at 3 p.m. at receptor 3 suggests a more arid atmosphere, potentially affecting interior air quality and comfort. In case study 2, the highest recorded humidity at 95.88% at 8 a.m. at receptor 7 indicates a more humid environment, potentially affecting comfort and air quality. The minimum humidity was 42.6% at 11 a.m. at receptor 9. All five sites experienced relative humidity above 50% during the simulation period, indicating discomfort. As shown in figure (17).

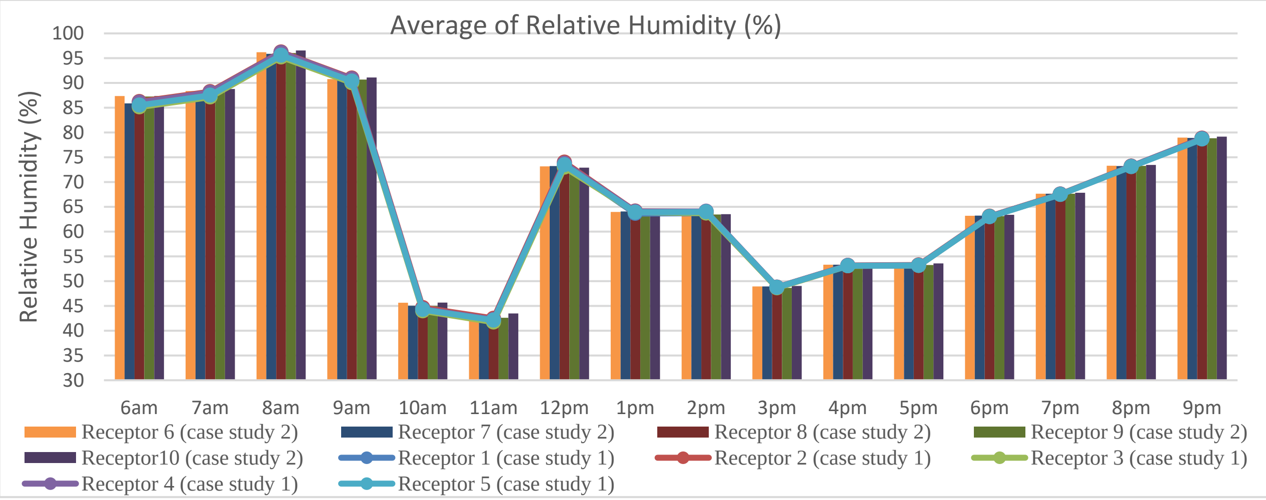
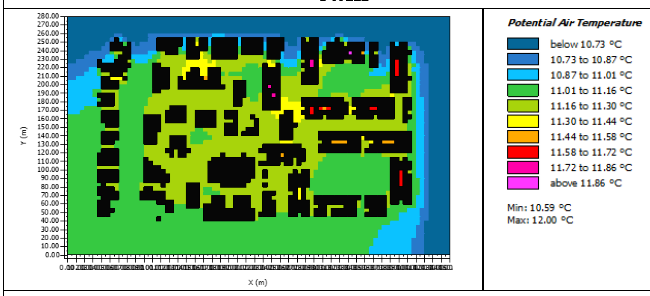
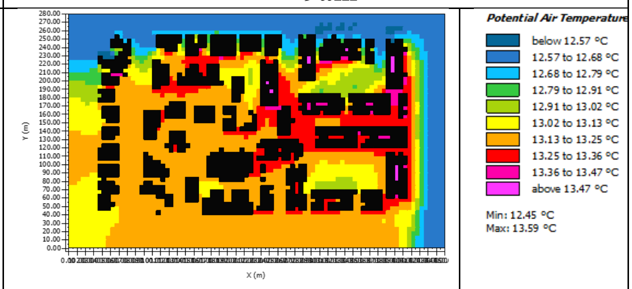
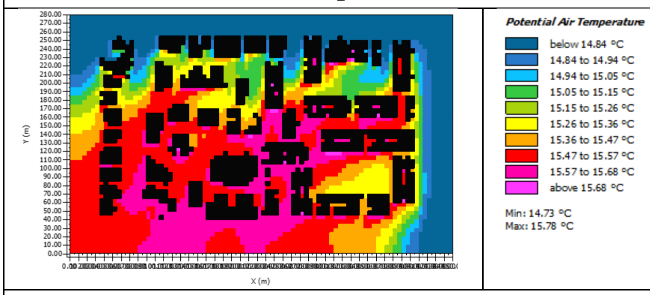
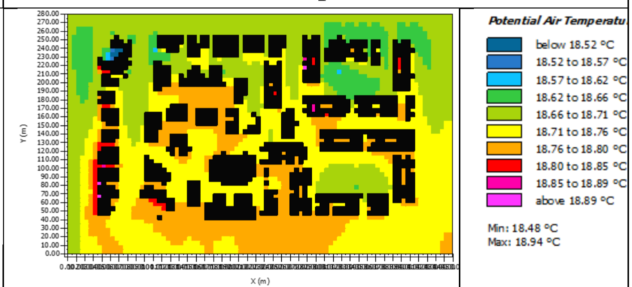


Figure 17 Average of Relative Humidity (%) for all receptors in winter, source researcher.

7.1.4 Simulation of Potential Air Temperature in winter at 6am, 9am, 12pm, 3pm, 6pm and 9pm in case study 1and 2.

Table (7) shows Potential Air Temperature simulation **for case study 1**: source researcher.

6am	9am
	
12pm	**3pm**
	
6pm	**9pm**

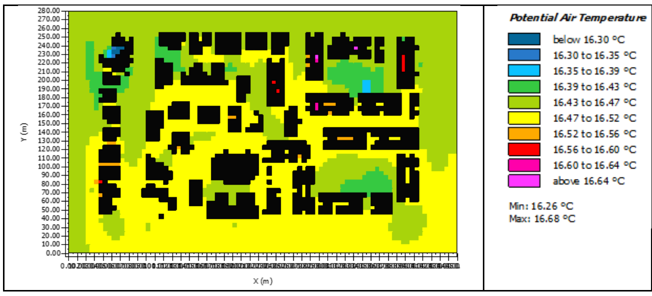
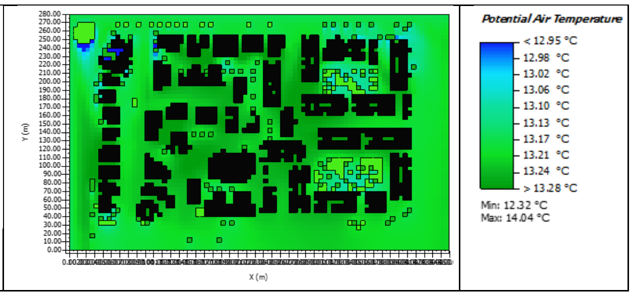
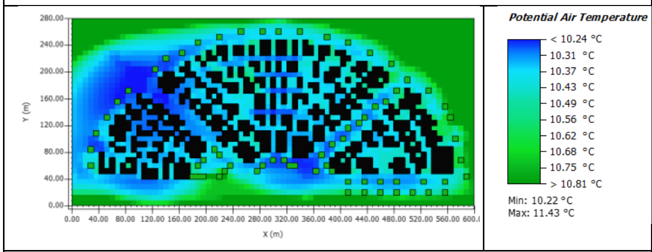
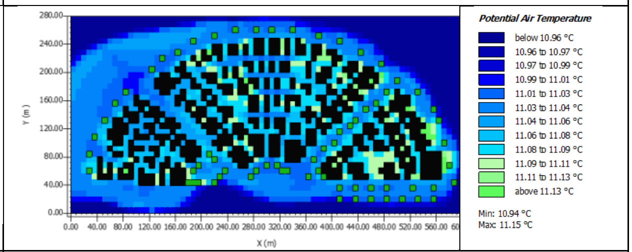
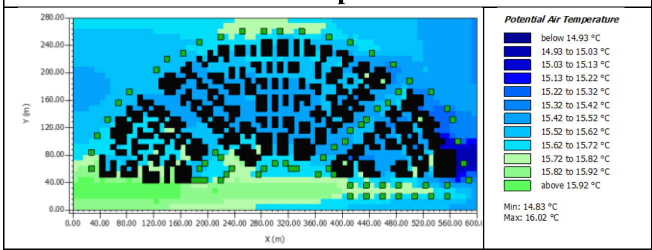
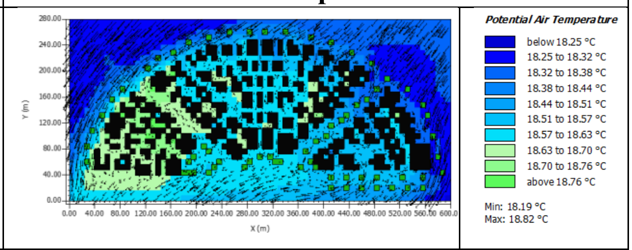
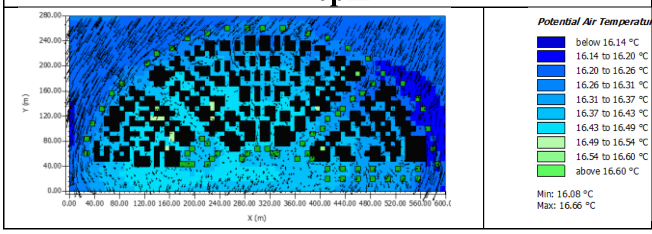
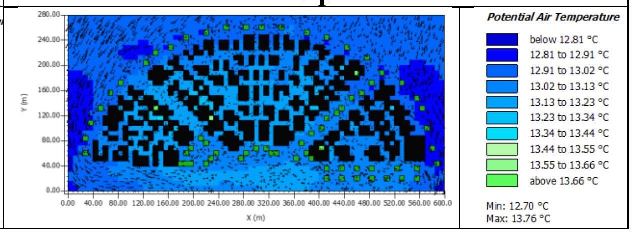
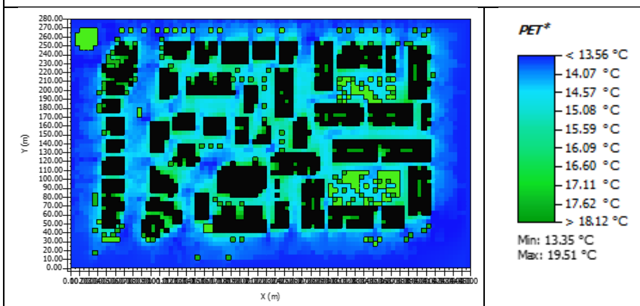
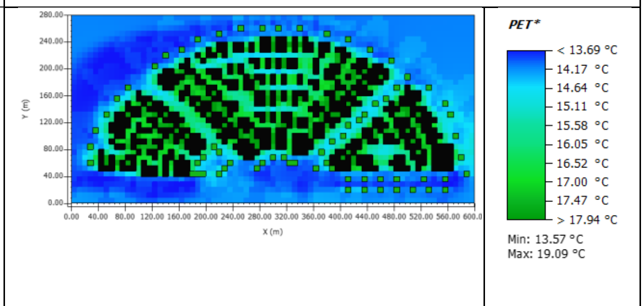
	

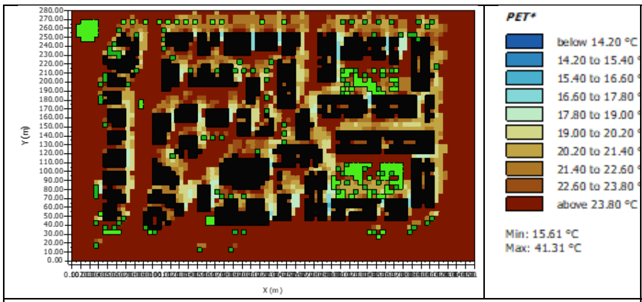
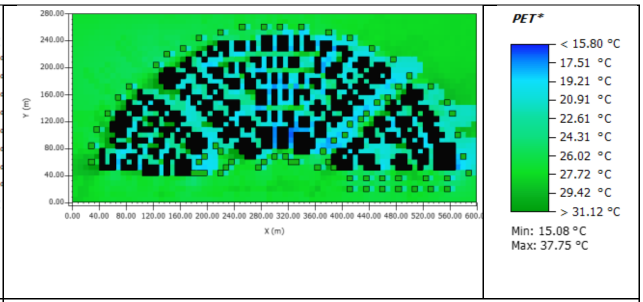
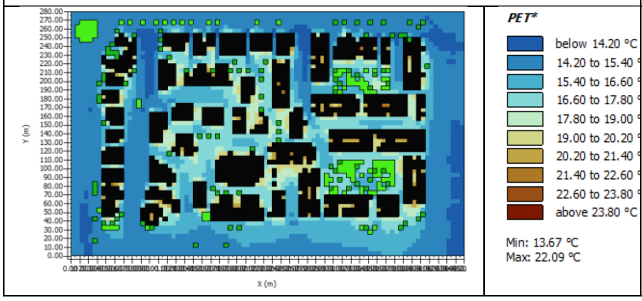
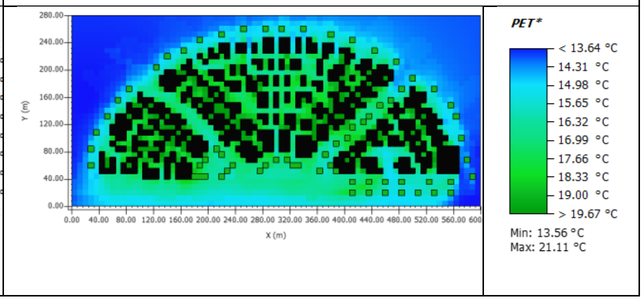
Table (8) shows Potential Air Temperature simulation **for case study 2**: source researcher.

6am	9am
	
12pm	**3pm**
	
6pm	**9pm**
	

7.1.5 Simulation of physical equivalent temperature (PET) for case study 1 and 2, in winter at 6am, 12pm and 6pm.

Table (9) shows PET at 12am, 12pm and 6pm. source researcher.

PET at 6am, Case study 1	PET at 6am, Case study 2
	
PET at 12pm, Case study 1	**PET at 12pm, Case study 2**

	
PET at 6pm, Case study 1	PET at 6pm, Case study 2
	

8 Conclusion

The evaluation of the two cases studies is based on the measurement of four factors, namely potential air temperature, wind speed, relative humidity and PET. Based on Givoni's psychrometric chart, the acceptable range for air temperature comfort is between 20◦C and 27◦C, while the suitable range for relative humidity is between 25% and 60%. The acceptable wind speeds for comfort at the pedestrian level (H = 1.75 m) vary between 2.5 to 5.00◦m/s, as defined by the terrestrial Beaufort scale. The acceptable temperature range for PET is between 20◦C and 30◦C.

In summer, the air temperature during most of the day exceeded the comfortable level values and attained the highest values, in all receptors with different places. Nevertheless, the air temperature is at the case study 1 higher than case study 2 from 6 am to 4 pm. but from 5pm to 9 pm the case study 2 is higher in temperature. The most uncomfortable period was at 4 pm in both sites due to the high air temperature, with a temperature differential of 2◦C.

In both case studies, the wind speed is modest and falls below the acceptable range, but it reaches its peak between 1pm and 5pm. Thus, it is the most ergonomically superior among all receptors.

The relative humidity throughout the simulation hours was within the uncomfortable range in all receivers in the two regions, reaching less than 20%. The most comfortable relative humidity was recorded throughout the day at 8 am, reaching about 40%, then gradually decreasing until 4 pm, then rising relatively at 5 pm.

Ultimately, in both case studies, the thermal comfort indicators (PET) reached the maximum value of the unpleasant threshold, above 35◦C, so indicating that the weather is very hot.

In winter, both case studies presented almost the same outcomes for all receptors at the same hour. The potential air temperature in both case studies were varying during the day. However, the temperature does not surpass 18◦C at 3 pm, and these measurements lie within the range of discomfort.

The wind speed is almost equal in same hour at all receptors, it starts with low values then rise till reach extreme amount at 2pm the case study 1 is higher by nearly 1.5 m/s then decrease slowly after that to 9pm.

The two case studies are uncomfortable, while relative humidity is above 80% (during the morning hours) and 60% (during the evening hours) in all receptors but was good at 10am and 11am with a nearly same value about 40%. Therefore, none of the case studies achieve satisfactory levels due to their relative humidity.

On the other hand, temperature indications for PET vary from frigid to moderately cold throughout the day, disregarding the concept of thermal comfort. The PET readings have shown a high degree of similarity. Based on previous outcomes, it is noted that case study 1 is the best among examined at morning and case study 2 is better at evening; nonetheless, both case studies ignored the thermal comfort. Therefore, it is extremely significant to develop approaches to achieve improvements and to promote a higher level of thermal comfort.

Overall, these results highlight the impact of urban design on thermal comfort. The first study area's design promotes effective cooling, especially in the evening, while the second area's design contributes to higher temperatures and heat retention, underscoring the importance of urban planning in mitigating thermal discomfort. Eventually, to attain thermal comfort in urban tissue, strategies such as incorporating greenery, optimizing urban geometry, providing shade, using reflective and cool materials, maximizing permeable surfaces, promoting compact and mixed-use development, and incorporating water features can be employed. These measures not only help lower air temperatures through shading and evapotranspiration but also minimize heat accumulation and contribute to a cooler environment. By implementing these strategies, urban areas can mitigate the adverse effects of heat without creating urban heat islands.

References

1. Yang, B., Yang, X., Leung, L. R., Zhong, S., Qian, Y., Zhao, C., ... & Qi, J. (2019). Modeling the impacts of urbanization on summer thermal comfort: the role of urban land use and anthropogenic heat. Journal of Geophysical Research: Atmospheres, 124(13), 6681-6697.
2. Khalil, H. A. E. E., Ibrahim, A., Elgendy, N., & Makhlouf, N. (2022). Enhancing livability in informal areas: a participatory approach to improve urban microclimate in outdoor spaces. Sustainability, 14(11), 6395.
3. Duffield, R. (2019). Egyptian urban exigencies: Space, governance and structures of meaning in a globalising Cairo. University of California, Santa Barbara.
4. Paramita, B., & Matzarakis, A. (2019). Urban morphology aspects on microclimate in a hot and humid climate. Geographica Pannonica, 23(4).
5. Abd Elraouf, R., Elmokadem, A., Megahed, N., Eleinen, O. A., & Eltarabily, S. (2022). The impact of urban geometry on outdoor thermal comfort in a hot-humid climate. Building and
6. Baklanov, A., Grimmond, C. S. B., Carlson, D., Terblanche, D., Tang, X., Bouchet, V., ... & Hovsepyan, A. (2018). From urban meteorology, climate and environment research to integrated city services. Urban Climate, 23, 330-341. Environment, 225, 109632.
7. Fallmann, J., & Emeis, S. (2020). How to bring urban and global climate studies together with urban planning and architecture? Developments in the Built Environment, 4, 100023.
8. Nice, K. A., Nazarian, N., Lipson, M. J., Hart, M. A., Seneviratne, S., Thompson, J., ... & Stevenson, M. (2022). Isolating the impacts of urban form and fabric from geography on urban heat and human thermal comfort. Building and Environment, 224, 109502.
9. Obrist, D., Kirk, J. L., Zhang, L., Sunderland, E. M., Jiskra, M., & Selin, N. E. (2018). A review of global environmental mercury processes in response to human and natural perturbations: Changes of emissions, climate, and land use. Ambio, 47, 116-140.
10. Ibrahim, Y., Kershaw, T., Shepherd, P., & Elwy, I. (2021). A parametric optimisation study of urban geometry design to assess outdoor thermal comfort. Sustainable Cities and Society, 75, 103352.
11. Yan, H., Wu, F., Nan, X., Han, Q., Shao, F., & Bao, Z. (2022). Influence of view factors on intra-urban air temperature and thermal comfort variability in a temperate city. Science of The Total Environment, 841, 156720.
12. Nia, H. A. N. (2021). The role of urban aesthetics on enhancing vitality of urban spaces. Khulna University Studies, 59-77.
13. Shooshtarian, S., Lam, C. K. C., & Kenawy, I. (2020). Outdoor thermal comfort assessment: A review on thermal comfort research in Australia. Building and Environment, 177, 106917.
14. Nie, T., Lai, D., Liu, K., Lian, Z., Yuan, Y., & Sun, L. (2022). Discussion on inapplicability of Universal Thermal Climate Index (UTCI) for outdoor thermal comfort in cold region. Urban Climate, 46, 101304.
15. Leal Filho, W., Wolf, F., Castro-Díaz, R., Li, C., Ojeh, V. N., Gutiérrez, N., ... & Bönecke, J. (2021). Addressing the urban heat islands effect: A cross-country assessment of the role of green infrastructure. Sustainability, 13(2), 753.

16. Baklanov, A., Grimmond, C. S. B., Carlson, D., Terblanche, D., Tang, X., Bouchet, V., ... & Hovsepyan, A. (2018). From urban meteorology, climate and environment research to integrated city services. Urban Climate, 23, 330-341.
17. Sezer, N., Yoonus, H., Zhan, D., Wang, L. L., Hassan, I. G., & Rahman, M. A. (2023). Urban microclimate and building energy models: A review of the latest progress in coupling strategies. Renewable and Sustainable Energy Reviews, 184, 113577.
18. Liu, B. (2023). Human Settlement, Inhabitation, and Travel Environment Construction Theory and Technology. In The Trialism and Application of Human Settlement, Inhabitation and Travel Environment Studies: Applications in Water-net Region (pp. 185-267). Singapore: Springer Nature Singapore.
19. Lai, D., Liu, W., Gan, T., Liu, K., & Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. Science of the Total Environment, 661, 337-353.
20. Errell, E. (2008)
21. Lenzholzer (2015)
22. Singh, N., Singh, S., & Mall, R. K. (2020). Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus. In Urban ecology (pp. 317-334). Elsevier.
23. Ellickson, R. C., Been, V. L., Hills, R. M., & Serkin, C. (2020). Land use controls: Cases and materials. Aspen Publishing.
24. Guyot, M., Araldi, A., Fusco, G., & Thomas, I. (2021). The urban form of Brussels from the street perspective: The role of vegetation in the definition of the urban fabric. Landscape and Urban Planning, 205, 103947.
25. Ren, Z., Fu, Y., Dong, Y., Zhang, P., & He, X. (2022). Rapid urbanization and climate change significantly contribute to worsening urban human thermal comfort: A national 183-city, 26-year study in China. Urban Climate, 43, 101154.
26. Blocken B, Roels S, Carmeliet J. Modification of pedestrian wind comfort in the Silvertop Tower passages by an automatic control system. J Wind Eng Ind Aerod 2004;92:849–73.
27. Alavi, N., H. Zhang, & A. Harb (2021). Urban Density and Thermal Comfort: A Review of Recent Advances in 3D Modeling. Sustainable Cities and Society, 74, 103192.
28. Wang, X., C. Qian, & T. Yan (2023). Strategic Urban Density Management for Thermal Comfort in Hot Cities. Cities, 125, 103563.
29. Ma, L., E. Wong, & T. Tan (2022). Regulating Microclimates through Urban Form: Implications for Thermal Comfort. Urban Climate, 41, 101038.
30. Xu, Z., G. Yao, & J. Adams (2024). Urban Form and Its Complex Role on Thermal Comfort and Climate Adaptation. Landscape and Urban Planning, 220, 104364.
31. Liu, H., J. Zhang, & Y. Liu (2020). The Influence of Building Orientation on Outdoor Thermal Comfort in Urban Environments. Building and Environment, 184, 107165.
32. Pochulu, D., T. Soulard, & M. E. Viard (2023). Understanding the Aspect Ratio of Urban Canyons and its Effects on Thermal Comfort. Atmosphere, 14(5), 712.
33. Rivas, R., R. Sanchez, & J. L. Jurado (2021). Cooling Effect of Urban Vegetation: Impacts on Thermal Comfort in the Cities. Urban Forestry & Urban Greening, 59, 126923.
34. Zhang, J., L. Chen, & H. Zhu (2022). Green Spaces as Urban Oases: Effects on Urban Air Temperature and Thermal Comfort. Science of The Total Environment, 816, 151757.
35. Liu, Z., Cheng, W., Jim, C. Y., Morakinyo, T. E., Shi, Y., & Ng, E. (2021). Heat mitigation benefits of urban green and blue infrastructures: A systematic review of modeling techniques, validation and scenario simulation in ENVI-met V4. Building and Environment, 200, 107939.
36. Chandramathy, I., & Kitchley, J. L. (2018). Study and analysis of efficient green cover types for mitigating the air temperature and urban heat island effect. International Journal of Global Warming, 14(2), 238-259.
37. Aboulnaga, M., Trombadore, A., Mostafa, M., & Abouaiana, A. (2024). Assessment of Urban Heat Island in Conjunction with Green Coverage in Large Cities: Cairo, Egypt, and Rome, Italy. Livable Cities: Urban Heat Islands Mitigation for Climate Change Adaptation Through Urban Greening, 495-617.
38. HWEHY, M. M. A., MOURSY, F. I., EL-TANTAWI, A. M., & MOHAMED, M. A. E. H. (2024). Evaluation of the air quality in arid climate megacities (Case study: Greater Cairo). Contributions to Geophysics and Geodesy, 54(1), 95-118.