Obour Institute Journal
for Engineering and Technology
Journal homepage: https://oijet.journals.ekb.eg
Volume (1), Issue (1), December 2023

Heat-Mitigation Strategies In Open Public Spaces To Enhance Human Thermal Comfort

Open access

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Received August 16, 2023, Revised September 12, 2023, Accepted September 25, 2023

Abstract

Public spaces are the most appealing urban locations where people interact with their surroundings and organize the links between population, economics, and resources. The quality of public spaces is directly proportional to encouraging people to remain longer and offering a variety of activities. Parks and green areas, for example, give possibilities for a variety of physical exercise behaviors such as recreational strolling and sports play. It is important for people to have a thermally comfortable environment in outdoor urban places. Thermal comfort has been demonstrated to be the bedrock of a vital and functional outdoor environment.

The research's major goal is to investigate and quantify the impact of numerous aspects on microclimate and human thermal comfort, as well as the impact of Urban Heat Island phenomena (UHI) and how to create Urban Green Space (UGS).

The research will look at the climatic factors that influence thermal comfort, as well as the implications of different methods for improving thermal comfort in urban public places. Among these measures are shade buildings, vegetation, and water bodies. Mean (radiant temperature, wind speed, and wind direction) are the most essential meteorological parameters defining outdoor thermal comfort in a microclimate.

Key Words: *Air temperature, humidity, Vegetation, Urban Heat Island, Public Spaces.*

Methodology

This study's research technique will include doing a literature analysis and examining concepts, tactics, applications, and issues linked to urban public spaces. The research will explore also some global Case studies of open public spaces and how it copes with microclimate and strategies made to reach the thermal comfort then concludes by examining these applications in one of Cairo public space.

1. Introduction

The importance of the need for thermal comfort in open areas must be carefully evaluated.

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Print ISSN, 2974-4539, Online ISSN: 3062-5270

because it’s necessary for open spaces users in both hot and cold seasons, On the other hand Thermal discomfort reduces the power of thinking and concentration of people.

Green areas in cities, town squares, and parks all have a good impact on the environment, society, and the economy. Thermal comfort in open spaces is crucial and must be carefully considered when planning an open space because it is influenced by a wide range of elements.

Microclimate has a considerable impact on urban spatial settings, which describe activities in public open areas. Thermal comfort is an important factor in enhancing the utilization of open public spaces because their benefaction is associated with the outdoor thermal condition. Therefore, Optimizing the thermal condition of urban public spaces is crucial to the success of urban planning, landscape design and behavior setting of people to fulfil their needs and requirements.

Traditionally, outdoor thermal comfort studies have relied on both subjective questionnaire surveys conducted in the study area and field measurements of environmental factors such as wind speed, relative humidity, black ball temperature, and other environmental factors such as outdoor air temperature and temperature. The goal of the field measurements was to figure out what kinds of temperatures are pleasant or acceptable for locals, as well as to learn about their opinions of thermal comfort. The case studies focus on establishing how livable the outdoor thermal environment is, as well as the implications of urban shape, ventilation, and heat islands on outdoor thermal comfort. (Thorsson, 2004)

1.1. Problem Definition

The relationship between people and open public spaces enhancing the quality of social life, in Egypt suffer from great deterioration physically and functionally due to poor urban design, informal street vendors, in addition to the lack of maintenance, public spaces neglecting the basic human outdoor needs leading to pedestrians' discomfort. This problem is greatly reflected in in Cairo.

In my research I will discuss the strategies to reach heat mitigation on Egyptian open spaces (outdoor) by comparing between open spaces on the same area and analysis the climatic parameters on each of them to emphasize the importance of green design strategy to enhance human thermal comfort.

2. Methodology

- **Using The Quantitative** Method to measure heat radiation, Humidity and Thermal The sensation of public spaces
- **Using the analytical methods in comparing the results of the two open public spaces**
- **The precise study procedure is as follows: -**
- **The first phase** involves selecting open public locations and gathering information on microclimate factors and heat reduction tactics.
- **second stage** is Measuring the microclimate in the chosen public locations.
- **The third step** is the analysis of outdoor thermal comfort
- **The fourth step** is the comparison of the measurements

3. Preliminary Data

3.1 Thermal comfort is influenced by a number of variables, the most important of which are environmental and individual characteristics. (Tzu-Ping, L 2010)

3.1.1 Environmental factors

Human activity has a big influence on the climate of an urban area The long-term behavior of the atmosphere, which includes elements such as temperature, pressure, wind, precipitation, cloud cover, and humidity, determines the climate of a place. An urban region is one that has a higher density of man-made structures than the areas around it.

a- Humidity

High humidity is the term used to describe the amount of water in the air. By preventing sweat from evaporating from the skin, these help us stay cool.

Thermal comfort is unaffected by relative humidity levels between 40% and 70% (the ratio between the amount of water vapor in the air and the maximum amount that can be contained at a given air temperature).

b- Air temperature

The temperature of the air surrounding the body, generally measured in degrees Celsius, is referred to as air temperature. A thermometer is used to determine this.

Temperature of the sun, the warmth that radiates from a heated item such as the sun, radiators, hot surfaces and machinery and so on is known as radiant temperature or thermal radiation. The heat radiation from the sources raises the temperature in space, even though the air temperature in the other spaces is same. (Nouran Naguib 2020)

c- Air velocity

The presence of cities modifies natural wind conditions at regional, local and microclimatic scales. A city represents an ensemble of convoluted aerodynamic obstacles in forms of buildings, and mitigates wind velocity at regional and local scales. However, at microclimatic scale buildings can also call forth substantial increase in wind velocity. Urban morphology results in numerous microclimates even within one city quarter, that are shaped by sun-shade, airflow–wind shelter, temperature and humidity—the quasi “invisible” but perceptible elements of architecture. Architects and planners need to consider climatic and human aspects during the design process; otherwise, urban spaces will not function and operate according to the architectural concept. High wind speeds combined with shade and cold temperatures can have negative biometeorological effects in the Irish climate, such as lowering public space usage.

3.1.2 Personal factors

a- Clothing insulation

Thermal discomfort can be caused by wearing too many or too little garments for the environment. Even if the atmosphere isn't particularly hot, overdressing might result in heat exhaustion.

b- Metabolic heat

The more heat you create, the more physically active you are. The metabolic rate of each person will have an impact on their thermal comfort. You should also think about their physical attributes, such as their height, weight, age, gender, and degree of fitness, since these might affect how warm or chilly, they feel. (AlaaElDin, 2021)

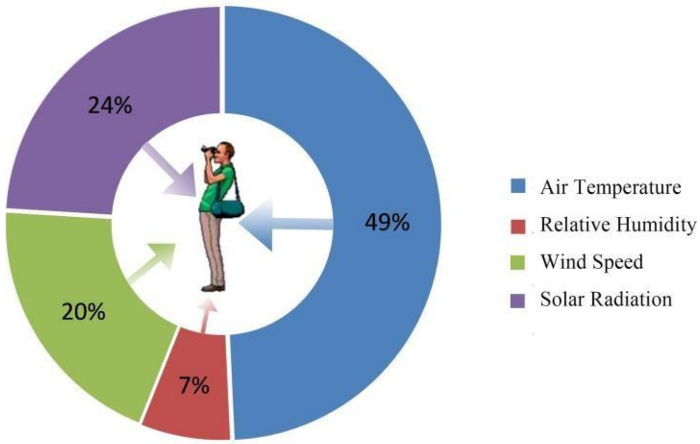

Figure 1: The ratio for each thermal comfort factor.

4- Thermal Comfort in the Outdoors

5. Strategies to Reduce Heat in Public Spaces

A benchmark for thermal comfort in urban architecture and planning is based on microclimate components that affect local circumstances (Koch-Nielsen, 2002). Furthermore, activities both inside and outside of space are influenced by the degree of thermal comfort. In order to enhance the standard of living in urban communities, where residents can rate their level of happiness on a scale, thermal comfort evaluation is necessary to become an urban design guide (Koerniawan, 2015). The ideal temperature for people to be comfortable ranged between 27 and 28°C with a humidity of 40%, and the environment is suitable for a standard value of temperature humidity index (THI) estimated between 21 and 27. Thermal comfort is undoubtedly influenced by a number of variables, including air temperature, wind speed, humidity, sun exposure (radiation), and other specific active human features.

Table 1: show the relation between heat stress and excersise limits. (Yoram Epstein,2014)

Heat Stress Category (WBGT)	Moderate Work		Hard Work	
	Work/Rest Cycle	Water Intake Per Hour	Work/Rest Cycle	Water Intake Per Hour
White ≤76.9°F (≤24.9°C)	60/15 MINUTES	300 ml (1/3 qt)	40/20 MINUTES	500 ml (1/2 qt)
Green 77-81.9°F (25-27.7°C)	60/15 MINUTES	750 ml (3/4 qt)	40/20 MINUTES	1000 ml (1 qt)
Yellow 82-84.9°F (27.8-29.4°C)	40/20 MINUTES	1000 ml (1 qt)	30/30 MINUTES	1000 ml (1 qt)
Red 85-88.9°F (29.5-31.6°C)	30/30 MINUTES	1000 ml (1 qt)	**Exercise is forbidden. Very high risk for heat casualties.**	
Black ≥89°F (≥31.7°C)	**Exercise is forbidden. Very high risk for heat casualties.**			

5.1. Vegetation

Vegetation, which is a natural landscape feature, is one of the most commonly used green design solutions. It aids in the achievement of the two study goals (the improvement of the microclimate and human thermal comfort in the outdoors). There are four main ways to modify the urban microclimate through vegetation, particularly the use of trees: first, by changing the solar radiation intensity; second, by changing the reflected radiation from the ground and other surfaces; third, by changing the relative humidity; and finally, by changing the wind. (Shahidan M F, 2007)

The major influence of vegetation on thermal comfort is its shading effect, in which trees diminish thermal radiation via reflection and absorption, as well as blocking a large portion of incoming shortwaves and reducing longwave radiation due to lower surface temperature values. As a result, the shape, position, and leaf density of the trees are important characteristics. Humidification via the evapotranspiration process, which is the total of two evaporation and transpiration processes, is another mechanism that influences the microclimate. Previous research has shown that in a dry climate, vegetation can improve local RH by 3% to 6% when compared to places that are devoid of vegetation. Several research have looked at the significant role that vegetation plays in microclimate change. found that trees can reduce air temperature under their canopy by 1.5 degrees Celsius compared to the surrounding region in a simulation conducted in Mediterranean environment.

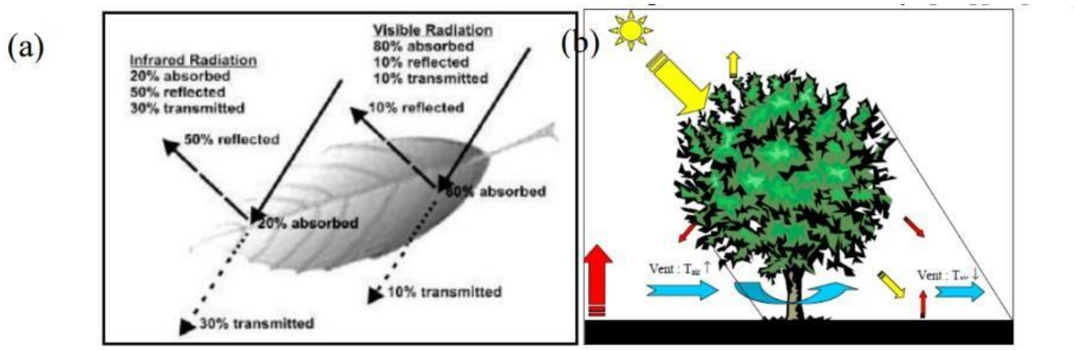

Figure 2: (a) Absorption, transmission and reflection of solar radiation by foliage, (b) Modification of the transfers of heat around a tree. (Vinet, 2000)

5.2. Water Attractions

Water features are also an important part of green design concepts. Their significance arises from their capacity to improve spatial perception within their placement in the arrangement of spaces, as well as their potential to improve a place's quality and, as a result, its psychological impact on users. Artificial lakes, water fountains, and water features in outdoor places as a bioclimatic approach to improve the microclimate are an effective strategy in hot dry circumstances, however research on the influence of water surfaces on the microclimate is considerably fewer than that on vegetation.

Water bodies are excellent heat drains, especially during the day's peak thermal stress times. The presence of water induces evaporation, which causes a rise in latent heat, resulting in improved cooling throughout the day. These bodies of water can be considered effective sources of cooling for the areas surrounding them. The area, depth, and shape of the water features, as well as their influence on microclimate, are physical properties. (Taleghani, M., 2018)

According to Singaporean study, air temperatures surrounding water features like as ponds, pools, and water walls can be up to 1.8°C cooler than adjacent urban built-up areas on sunny, clear days. Furthermore, it was determined that the air temperature above an urban water pond ranged between 1°C and 2°C.

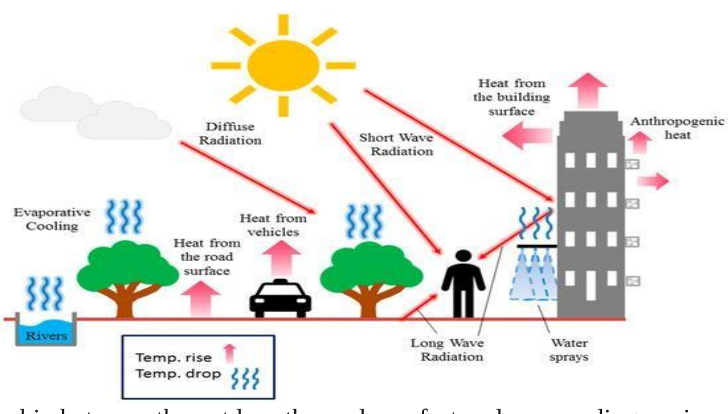

Figure 3: show Relationship between the outdoor thermal comfort and surrounding environmental settings

During the day, it is lower than the surrounding park. However, while the evaporation process took place, humidity levels rose, resulting in a cooling effect that might help to moderate temperatures in hot desert places. Water as a mitigation strategy must be attentive to the problem of water shortage in our region, which must not be overlooked. As a result, one potential option may be to use the grey water system as a mitigation approach.

5.3. Shading Effect

Controlling sun radiation is the most essential aspect influencing outdoor thermal comfort, particularly in hot weather. Outdoor thermal comfort was tested in the two urban squares of Naghshe- Jahan and Jolfa in the hot desert climate of Isfahan, Iran. They discovered that Jolfa has more comfortable hours due to the shade impact of its walls using field measurements and questionnaires. Using the RayMan program, they demonstrated that shade is recommended in the summer, spring, and fall but not in the winter. As a result, they advocated for deciduous trees. (Watanabe, S., 2014)

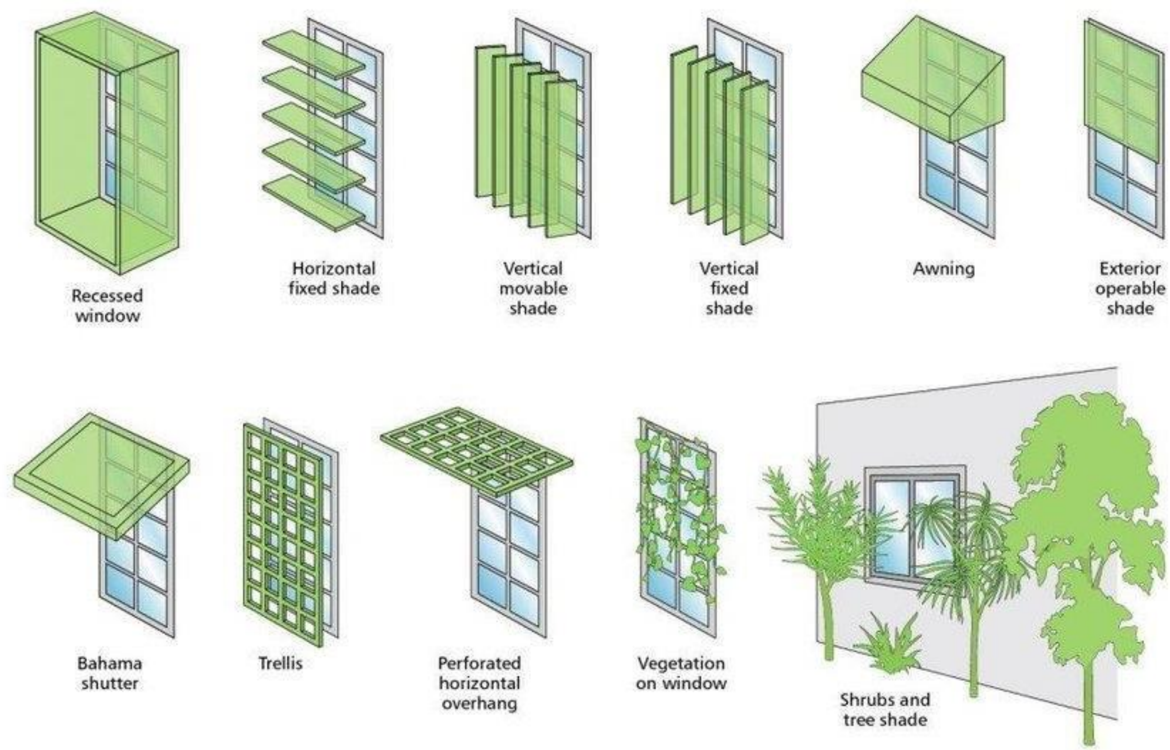

Figure 4: depicts various types of external shading devices.

The shade of objects or structures is one of the most important aspects to consider when avoiding thermal discomfort caused by direct sun radiation in outdoor areas. The geometric shape of the surface thought to define the cover originating from an object or building influences the amount of this energy. Furthermore, building geometry produces shadows that are analogous to the sky view factor (SVF). As a result, there is a strong association between road shape, SVF, and surface temperature, which has the potential to reduce local air temperature. Maximizing shade reduces the urban heat load caused by the land cover surface in tropical areas. (K. Yeang, 2006) Previous studies have discovered a cooling effect brought on by the shade component of tree structure and characteristics. Based on the direction of the lighting, shades are divided into two categories: vertical shading angels (VSA) and horizontal shading angels (HSA). (Hoffman, M. E., & Shashua-bar, L., 2003)

5.4. previous Studies

- **Ng, 2012** and Cheng used outdoor measurements to assess thermal comfort in Hong Kong's hot and humid climate. They discovered that at 29.7 °C, surfaces exposed to direct radiation had surface temperatures in the 50-60 °C range, whereas shaded surfaces had temperatures in the 30-34 °C range.
- **Watanabe,2014 et al**. examined thermal comfort in both shaded and unshaded areas on the University of Nagoya's campus in Japan. Under solar-radiation intensity of 800 W/m2, building shade reduced the universal-effective-temperature index by 18.4 °C and pergola shading reduced it by16.2 °C.
- **Morakinyo et al. (2013)** conducted an experiment on the exterior thermal conditions of two buildings (one with and one without tree shadowing) at Akure University in Nigeria (tropical environment). They noticed that the air temperature surrounding the building was consistently higher without tree shading than it was with shading.

The majority of investigations on the influence of urban canopy shade on outdoor thermal comfort took place during the summer. In the winter, certain canopies decrease the quantity of sunshine and cause heat discomfort. As a result, both warm and cold seasons should be investigated to see how shading affects thermal comfort.

6. Implementation in Public Spaces in Egypt

Selecting three public spaces in same region

- first one has features of heat mitigation strategies (vegetation – water -shading) selecting four different points in the public space close to shading and water at different intervals of time in the same day to measure temperature and humidity.
- second one has features of heat mitigation strategies (vegetation - shading) selecting four different points in the public space close to shading and green at different intervals of time in the same day to measure temperature and humidity.
- third one is green public area selecting one point in the public space to measure temperature and humidity. (Researchers 2023)

6.1 Measuring Instrument

- Using Heat Stress Monitors are designed to quickly and accurately evaluate potential heat stress environments. These devices provide high-performance monitoring by utilizing Wet Bulb Globe Temperature (WBGT) sensing technology, the industry standard for heat stress management, and calculating a WBGT Index value.

The working theory of the device converts thermal energy into electrical energy Thermal stress is measured using **three** thermometers

1. Dry thermometer: It measures dry air

2. Wet thermometer: It monitors the amount of moisture in the air.

3.Thermometer Globe: This device measures radiant heat.

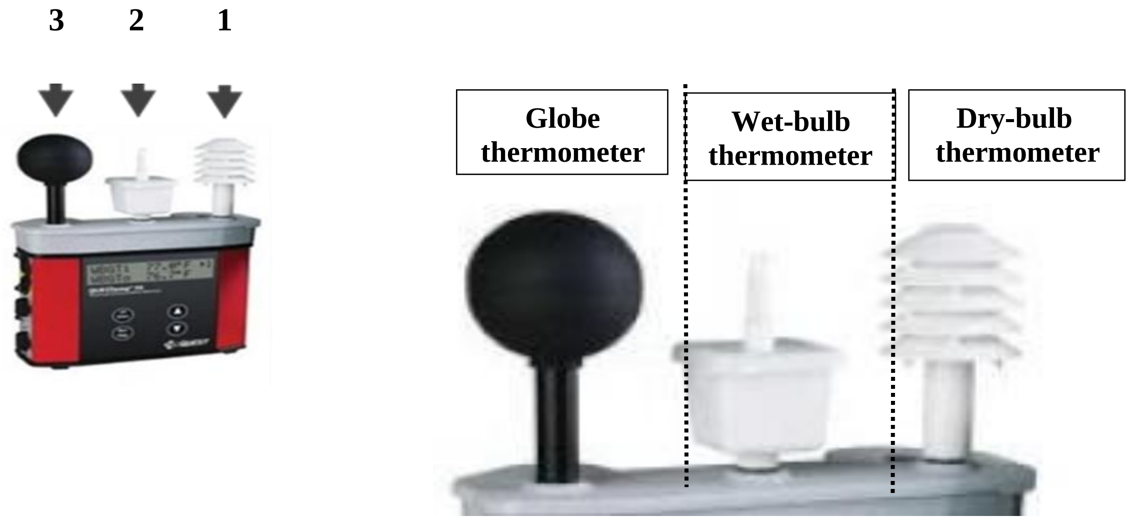

Figure 5: depicts (WBGT equipment). (Researchers 2023)

6.2 Study urban areas

6.2.1. First space Granada garden

a-Information

Area:4700 m2

Strategies: water features (Roxy fountain) -shadings (4pergolas)-vegetation (trees & grass)

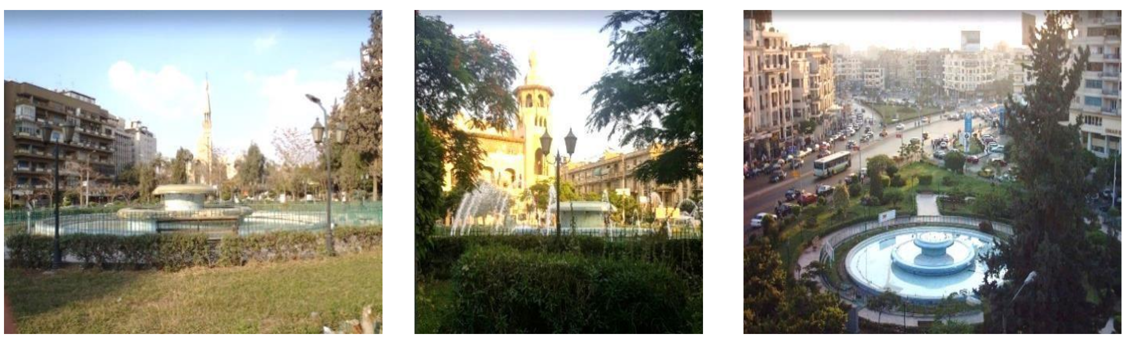

Figure 6: show the location Strategies. (Researchers 2023)

Figure 7: show the measure points in the location. (Researchers 2023)

point	Description	Wet	Dry	RH	WBGT	GLOB
A	**Point on path way**	**24.6ºc**	**30ºc**	**39%**	**33.5ºc**	**38.2ºc**
B	**Point beside water feature (fountain)**	**23.9ºc**	**30.6ºc**	**40%**	**31ºc**	**34.7ºc**
C	**Point shaded by trees (vegetation)**	**23.4ºc**	**30.5ºc**	**40%**	**32.7ºc**	**36.5ºc**
D	**Point on shading part (under pergola surrounding by trees)**	**23.4ºc**	**30.7ºc**	**40%**	**31ºc**	**34.6ºc**

In this case the most effective solution was shading part (under pergola surrounding by trees) then the water feature then vegetation

6.2.2 second space Basilica Garden

a. Information

Area:3700 m2

Strategies: shadings (2 pergolas)-vegetation (trees & grass)

Figure 8: show the location Strategies. (Researchers 2023)

Figure 9: show the measure points in the location. (Researchers 2023)

Table 3: show measurements on 12 july 2022 ratio (3:00 pm -5:00 pm)

point	Description	Wet	Dry	RH	WBGT	GLOB
A	**Point on shading part(under pergola)**	**24.2ºc**	**31.8ºc**	**34%**	**35.2ºc**	**41.3ºc**
B	**Point on path way surrounding by greening**	**26ºc**	**32.4ºc**	**37%**	**36.1ºc**	**40.5ºc**
C	**Point shaded by trees (vegetation)**	**23 ºc**	**30.8ºc**	**34%**	**31.9ºc**	**39.1ºc**
D	**Point on shading part (under pergola)**	**24.8ºc**	**31.8ºc**	**34%**	**35.2ºc**	**41.3ºc**

in this case the most effective solution was the shade using vegetation then path way surrounding by greening then shading part under pergola without trees

6.2.3. third space Roxy square

a. Information Area:3700 m2 Strategies: green open space

Figure 10: show the location Strategies. (Researchers 2023)

Figure 11: show the measure points in the location. (Researchers 2023)

b. Table 4: show measurements 12 july 2022 ratio (3:00 pm -5:00 pm)

point	Description	Wet	Dry	RH	WBGT	GLOB
A	**Point on the garden**	**27ºc**	**33.8ºc**	**37%**	**35.2ºc**	**41.3ºc**

in this case the garden was green but without any trees so it wasnot effective solution in space

7. Results

- **Table 5:** shows the difference between the thermal solutions. (Researchers 2023)

Thermal solution	temperature difference	WBGT	
Point on shading part (under pergola)	+1	**35.2ºc**	Exercise is Very high risk
Point on path way surrounding by greening	- 0.8	**36.1ºc**	Exercise is Very high risk
Point shaded by trees (vegetation)	-2	**32.7ºc**	Any Exercise is Very high Risk
Point beside water feature (fountain)	-3.5	**31ºc**	Can rest and cycle for 30 min with drink 1L water
Point on shading part (under pergola surrounding by trees)	-3.6	**31ºc**	Can rest and cycle for 30 min with drink 1L water

From the previous table the mosteffective solution is shading part (under pergola surrounding by trees) and the water feature (fountain) in hot days

8. Conclusion

The primary goal of this research was to investigate factors that can affect people's thermal comfort in outdoor spaces. employed a variety of human thermal comfort indices, and used a field measurement study approach.

The heat-mitigation measures that were studied were grouped into four sections: climate variables; impacts of shading; greenery, water features, and bergola shading; and the connection to physical variables.

The greatest influence on outdoor thermal comfort is the mean radiant temperature, which is followed by wind direction and speed. Therefore, tactics that lower mean radiant temperature (such shade) are more successful.

Our measurements show that deploying various types of vegetation, with a focus on trees, is the greatest technique for improving thermal comfort. After vegetation, water features are the second-best strategy.

People's microclimatic and thermal circumstances may be impacted by the various shapes and forms of urban canyons. Thermal comfort and area density are closely related. Due to poor ventilation, heat is trapped in dense areas.

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