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Shading Strategies for Outdoor Waiting Areas in Hot Climates: Improving Thermal Comfort and Healing Environments in the Post-Pandemic Era

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ABSTRACT

The design of hospitals has become a critical issue in the post-pandemic era, especially for waiting areas where people tend to gather and increase the risk of disease transmission. Outdoor waiting areas are emerging as viable alternative to indoor spaces, as they can reduce crowding and improve ventilation. However, in hot climates, achieving thermal comfort in outdoor spaces is a major challenge for designers, as it affects the healing environment and the well-being of patients and visitors. This paper explores the role of different shading strategies to enhance the thermal comfort of outdoor waiting areas in hospitals, using Al-Nasr Specialized Hospital in Port-Said as a case study. The paper simulates five shading scenarios that combine shading devices and trees, and evaluates their impact on air temperature (TA), predicted mean vote (PMV), and physiological equivalent temperature (PET). Results show that the best scenario is semi-shaded case with trees, which lowers TA by more than 1.5 °C, reduces PMV by 28.7%, and shifts PET from a hot state to a warm state. This study enriches basic research on outdoor thermal comfort for hospital users and offers guidance for the design of outdoor healthcare settings in hot climates.

Keywords: Healing Architecture, Post-Pandemic Design, Outdoor Waiting Areas, Thermal Comfort, Shading Strategies.

1 INTRODUCTION

The COVID-19 pandemic is one of the world's most recent pandemics, but it will not be the last [1, 2]. However, it appears that there is some concern about whether present designs are adequate to secure future human presence in cities [3]. The COVID-19 pandemic has imposed drastic changes on our lives as our priorities and perspectives have changed to respond constructively to the COVID-19 pandemic [4, 5]. This means that traditional architecture will never be the same [6], particularly regarding how huge public places, such as airports, hotels, hospitals, gyms, and businesses, are gathered and used [7, 8]. The healthcare system is one of those places that has been severely impacted. Healthcare institutions have experienced some of the most stressful and intensive waves of people seeking treatment for the pandemic as well as other illnesses [9]. Sefano C. et al. (2020) explored different design strategies for existing and new hospitals to cope with emergency situations and post-pandemic scenarios, emphasizing the need for flexible indoor and outdoor spaces with preventive measures, such as waiting areas [10].

To investigate the current state of research on this topic, we conducted a database search using this topic “post-pandemic architecture of healing environments in hospitals” and retrieved 715 architecture publications from 2020 to 2023. We used the VOS viewer to create a bibliometric network based on the keywords of these publications. Figure 1 shows the network visualization. In this paper, we focus on the following keywords: post-pandemic architecture, hospitals, thermal comfort, and healing environments.

In hospitals, waiting area is considered the first place that patients will experience when they visit any hospital [11]. Patients may spend a long time in waiting areas [12]. They are places for gatherings of patients who are likely to catch any infection, and there is no clear mechanism to separate infected patients from others [13, 14]. Therefore, hospital waiting areas should be designed to face any current or future pandemics. In post-pandemic architecture, one of the most important new design recommendations is to increase physical distances and reduce gatherings [15]. So, it's reasonable to think that concerns about future pandemics will encourage architects to design buildings with open areas [16]. This encouraged the presence of outdoor waiting areas by extending to receive more patients at one time without risking their safety [3].

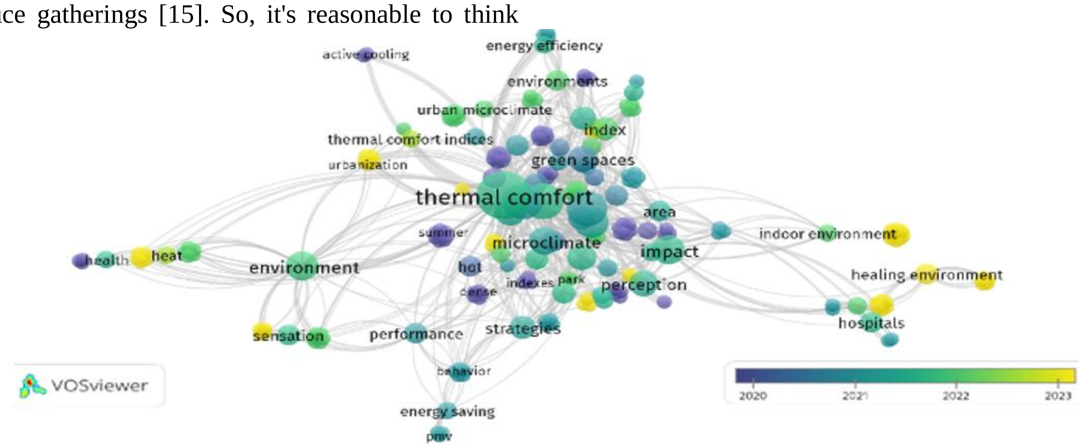

Figure 1: Bibliometric map for keywords "post pandemic architecture for hospitals"

Credit or Source: VOS viewer

Many previous studies investigated the advantages of designing outdoor waiting areas to achieve their occupants' comfort, well-being, and safety [17-22]. Accordingly, the study is interested in investigating the design of outdoor waiting areas in hospitals. Taking into consideration that these spaces should be designed to create a healing environment as well [23]. Many previous studies dealt with the importance of the role of architecture in the healing process in health facilities. Hospital design is now shifting from focusing on functionality to providing an appropriate and supportive healing environment for patients [4, 5]. Healing environmental design is a concept to improve conditions for the physical and mental well-being of people. This means that the design of hospital spaces should be designed to be places of recovery and healing [24]. Noise control, air quality, thermal comfort, lighting, communication, color, texture, privacy, and a view of nature are all physical variables to consider while creating a healing environment [25-28]. Jennifer D. et al. develop the concept of healing by dividing it into emotional, psychological, social, behavioral, and functional [29]. But due to climate change, which is a critical issue in our time, optimizing thermal performance in design spaces takes on paramount importance for healing environment parameters [30, 31]. According to the 2021 IPCC report that climate change is widespread, rapid, and intense [32]. The hot outdoor environment has a great impact on human health [33]. A study by Başak E. et al. (2019) investigated the impact of climate change, which led to many health problems for individuals [34]. In hot climates, achieving thermal comfort is one of the most important challenges that designers can face when designing such outdoor spaces. So, the study aims to improve thermal comfort of outdoor waiting areas in hospitals, Figure 1 shows a graphical introduction.

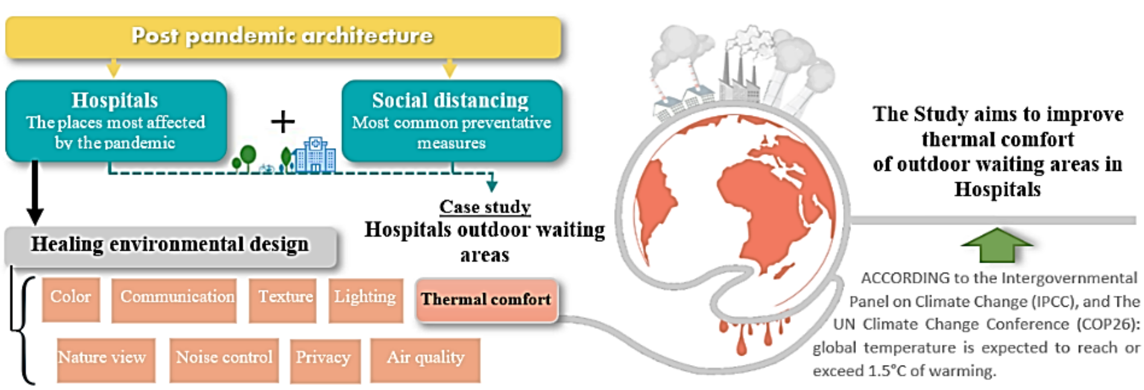

Figure 2: A graphical introduction

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2 LITERATURE REVIEW

2.1 Thermal comfort strategies

Thermal comfort refers to "the state of mind that expresses the human body's feeling satisfaction" [35]. It considered one of the most important factors that help improve the comfort that affects the satisfaction of users of outdoor waiting areas of hospitals and the healing process [31]. So as a result, priority in this paper was given for improving thermal comfort in outdoor waiting areas in hospitals. Thermal comfort of outdoor areas is influenced by different environmental factors such as air temperature, relative humidity, wind speed, and solar radiation [36-38]. Much of the literature reviews various studies on strategies to improve the thermal performance of outdoor areas. A study by Lai et al. (2019) reviewed four strategies to enhance outdoor thermal comfort that are summarized in planting vegetation, the use of the cool surface, water elements, and the changing of urban geometry that have been the most influential [39]. Some other studies were based on studying urban morphology parameters to improve the thermal performance of outdoor spaces, such as orientation, surrounding building heights, and open area ratio [40-44]. Numerous investigations concentrated on the positive effect of using different shading strategies, such as self-shading urban forms and the shade of trees [39, 45-47]. A review by Taleghani, M. (2018), focused on studies that dealt with vegetation cover and the use of reflective materials for outdoor areas and concluded that the use of vegetation showed better results for improving thermal performance [48]. The same conclusion about the importance of planting vegetation as an effective strategy has been demonstrated by the review of Pardeep K. (2020) [49]. Huang et al. (2019) investigated the importance of shading strategy with field measurements and a questionnaire on a university campus in Mianyang, China [50]. The shading strategy is an effective strategy in hot climates and can help reduce direct solar radiation [51]. Table 1 summarizes optimization strategies of outdoor thermal comfort-related studies that can be applied in outdoor waiting areas in hospitals.

Table 1. Selected papers review several outdoor thermal comfort strategies.

	Ref.	Year	Country	Climate	Strategy	Method	Main conclusion
Planting and tree shading	[52]	2021	Norway	Oceanic	• Planting changing surface material	• Field measurements • ENVI-met	The increments of building albedo of the surface materials have a little impact on outdoor thermal comfort.
	[53]	2016	Arizona	Hot dry	• Photovoltaic Shading • Tree shade	• Field surveys	Thermal comfort improved by Shading strategy, where lowered thermal sensation votes by around 1 point on a semantic differential 9-point scale.
	[54]	2020	Bangkok	Hot-humid	• Building geometries • Tree shade	• Simulation, ENVI-met	One of the factors affecting outdoor thermal comfort is the ratio between width to height and direction.
	[55]	2021	Philadelp-hia	Humid	• Tree shade	• Rayman model	Shade trees add significantly cooling benefits in enhancing the thermal comfort.
	[56]	2019	China	Hot	• Use vegetation	• Simulation, ENVI-met	While trees undoubtedly enhance both thermal comfort and air quality in outdoor spaces, they may increase the effect of wind-blocking.
	[57]	2020	China	Hot	• Use vegetation	• Meteorological monitoring survey	The air temperature factor is the foremost critical one that influences thermal comfort.
	[58]	2019	China	Hot	• Use vegetation. • changing pavement material	• Site measurement • Simulation, ENVI-met	Increased tree coverage effectively improves outdoor thermal comfort. The change in PET values spanning from a maximum of 8.2°C and a minimum of 0.02°C.
Shading	[59]	2023	Cordova	summer	• Shading	• Field monitoring	The results showed lowered Ta in courtyards by more than 9 °C and increased comfort hours by 45-66% according to the PET. Moreover, the shading strategy resulted in a significant 31% reduction in cooling energy demand across 69%.
	[47]	2021	Egypt	Hot-humid	• Shading	• Simulation, ENVI-met	Using shading of 60% in outdoor courtyard, Ta decreased by 0.5 °C, also the PMV values were decreased by 0.6.
	[46]	2020	Iran	Hot	• Shading	• Questionnaire • ENVI-met.	The study determines the range of external thermal comfort in PET values between 19.6

						• Rayman model	°C to 30.9 °C PET.
	[60]	2023	Southern China	Hot	• Shading	• On-site meteorological observations • Surveys • Simulation, envi-met	The findings demonstrate that shading devices effectively decreased mean radiant temperature, Physiological Equivalent Temperature, and Universal Thermal Climate Index by as much as 24.8 °C, 12.0 °C, and 5.9 °C, respectively.
Shading and	[45]	2020	Egypt	Hot dry	• Shading • Planting vegetation	• Simulation, ENVI-met	Using shading and increasing the density of trees can reduce temperatures by 0.7 °C.
	[61]	2022	Egypt	Hot dry	• Shading • Tree shade Canyon's ratios	• Field monitoring • Simulation, ENVI-met	The results concluded that a significant decrease in PET values was achieved by using hybrid scenarios that include vegetation and shading by (50%).

Previous studies, as shown in Table 1, have identified vegetation cover and shading strategies as the key factors that affect outdoor thermal comfort. However, they have also pointed out a research gap in understanding how these factors specifically influence the thermal comfort of outdoor spaces. Therefore, this paper aims to explore the potential role of various shading strategies to enhance the thermal comfort of outdoor waiting areas in hospitals.

3 METHODOLOGY

The study focuses on investigating the effectiveness of different shading strategies to enhance outdoor thermal comfort in the waiting areas of El-Nasr Hospital in Port Said for outpatients, emergency department visitors, and staff. The methodology involves two main steps, see Figure 3. Firstly, the study examines the existing thermal comfort levels in the outdoor waiting areas, particularly during high-temperature conditions. This provides a baseline understanding of the current thermal conditions experienced by outpatients, visitors, and hospital staff. Secondly, the study investigates various proposed shading strategies, including vegetation, shading, and hybrid strategies. The ENVI-met simulation software version 5.0.3 lite is utilized to model and simulate these shading strategies. The study analyze the climatic factors such as temperature, humidity, wind speed, and average radiant temperature, which directly influence thermal sensation indices such as predicted mean vote (PMV), and physiological equivalent temperature (PET).[62]. By analyzing the simulation outputs, the study aims to identify the optimal shading strategy that can effectively enhance thermal performance of the outdoor areas in hospitals, particularly in hot and humid climates.

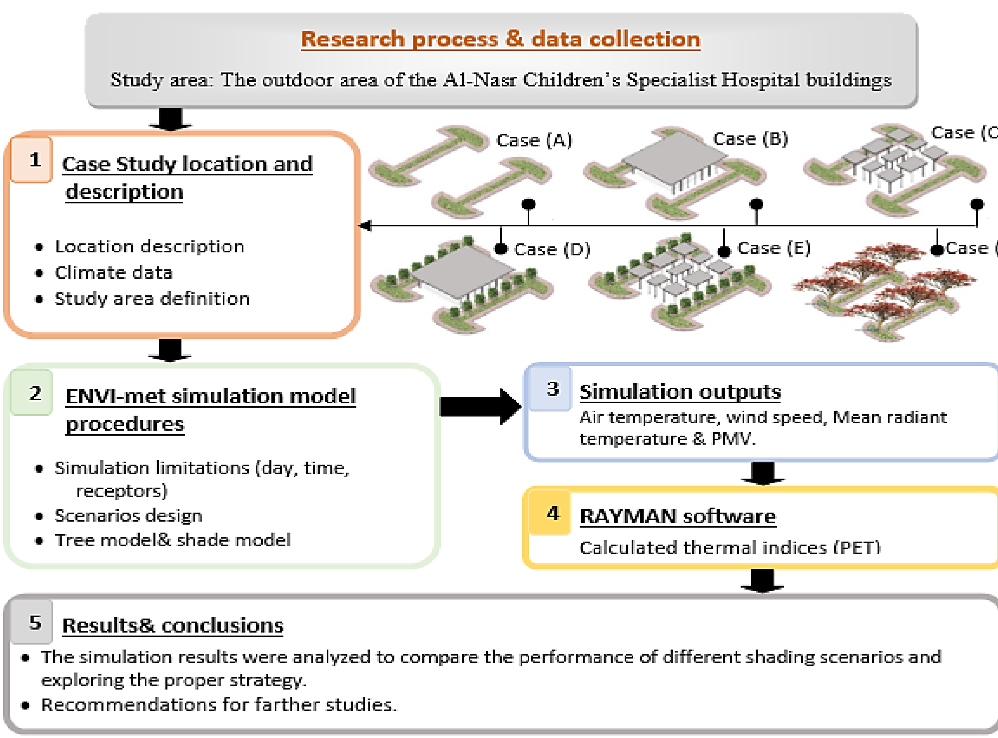


Figure 3: The Methodology of the study

Credit or Source: the author

Some thermal indices, such as the Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET), has significantly contributed to the understanding and assessment of outdoor thermal conditions in hot and humid climates. These indices consider various environmental and personal factors to provide a comprehensive evaluation of thermal comfort, allowing for a more nuanced analysis of outdoor thermal conditions. In Table 2, a compilation of selected papers highlights the application of these indices in summarizing the outdoor thermal environment in hot and humid climates. PMV is an index that aims to predict the mean value of votes of a group of occupants which ranges from −3 indicates too cold, and +3 indicates too hot. The Predicted Mean Vote (PMV) is a critical index in thermal comfort assessment. It indicates the average thermal sensation perceived by a group of occupants in a given space [63]. The PET index gathers on various parameters such as environmental factors (temperature, humidity, wind speed, radiant temperature) and personal factors (clothing, meteorological metabolic rate). So, this scale is considered the most comprehensive in outdoor areas, which ranges from <4°C–>41°C [63], and from <14°C–>42°C in hot areas and Asian countries [61, 64].

Table 2. Selected papers summarize the outdoor thermal index in hot and humid climates.

Ref.	Year	City	Type	Index	Season
[65]	2011	India -Chennai	Multi-storied buildings	PMV	summer
[66]	2011	Kebangsaan- Malaysia	university hospital	PMV	May, and June
[67]	2013	Kebangsaan- Malaysia	Medical Center	PMV	May, and June
[68]	2019	Guayaquil-Ecuador	Social housing	PMV	During 2019
[69]	2021	The southeast coast- India	Apartment building	PMV SET	May and December
[70]	2019	Taiwan	offices& classrooms	PMV&TSV	The spring period
[71]	2020	Kolkata- India	Neighborhoods	PET	During summer & winter
[46]	2021	Ahvaz, Iran	Urban canyons	PET	July 2018
[72]	2016	Tainan, Taiwan	Traditional settlement	PET	All the year
[73]	2016	Dar es Salaam, Tanzania	urban park	PET	September 2013 & January 2014
[74]	2019	Guangzhou- China	street canyons	PET	July and August
[75]	2023	Shahrood, Iran	University campus	PET	summer
[76]	2023	1. KOREA	local climate zones	PET&UTCI	August 2017

There is some other indicators, such as the UTCI (Global Thermal Climate Index), which is also a commonly used indicator, such as the PET, both of which are designed to evaluate thermal conditions in outdoor environments. a study by Zare, S., et al (2018) indicated that UTCI had strong correlations with PET (r = 0.96) [77]. In general, PET could be more suitable for studies that focus on thermal perception and comfort.

3.1 Location data

Port Said is situated in the northeastern region of Egypt, (31.27°N latitude and 32.3°E longitude). The city is located meters above sea level. This specific case study area selected for this paper is the Manakh Department, situated within the Al-Zehour district of Port Said. This area encompasses the hospital buildings of Al-Nasr Specialized Hospital as well as its associated outdoor spaces, see figure 4.

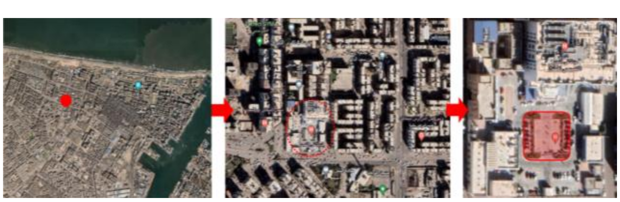


Figure 4: Case study location

Credit or Source: (adapted by Author)

3.2 Climate data

The climate of Port Said can be characterized as the Mediterranean. The winter is mild, and the rain is scarce. In addition, the temperature never drops underneath freezing. Summer is hot and humid. The direction of the prevailing wind from the north. Occasionally, wind from the desert can bring noteworthy increments in temperature, see figure 5.

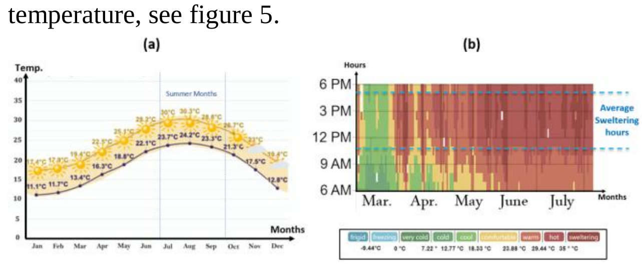


Figure 5: Port Said climate 2022 (a) The monthly temperature variations "weather-atlas 2022" (b) Hourly Temperature variations "weather-spark 2022"

Credit or Source: (adapted by Author)

3.2.1 Study area

The area of the Hospital buildings is 26,000 m^2 for a total area of 11,673 m^2. The hospital includes a ground floor and to three floors. The hospital is a U-shaped building block consisting of a main building and annexes (mortuary and waste; laundry and kitchen; water tank; power station) with a central open area between the buildings, which includes the entrance area, parking, and outdoor area in-between the buildings.

During the spread of the COVID-19 pandemic, the hospital exploited the outdoor areas to set up tents to accommodate the number of patients. Currently, there are an area which is a tent for receiving COVID vaccinations. And the second is a small and far shaded area for patients waiting. The third is the proposed case study area. The net dimensions of this central open area are 20 x 17 meters, which was originally designed for parking, but now it is a closed area to be prepared for any emergency action. The emergency department is the first entry point to the hospital, and there is always a waiting room available, in addition to the outpatient clinic's department, which is always crowded with a variety of patients. These are the places where you should specifically avoid the presence of infectious people. Therefore, the study suggests converting it to external waiting areas due to its proximity to the main entrance to the hospital and to the entrance of outpatient clinics and emergencies, see figure 6.

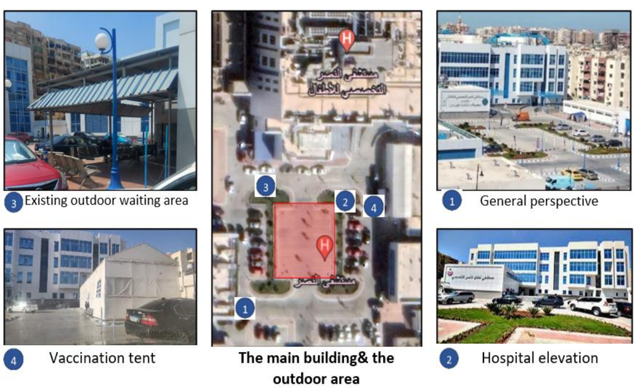


Figure 6: Different pictures of the hospital

Credit or Source: (adapted by Author)

3.3 ENVI-met simulation model procedures.

3.3.1 Computational domain and grid size

This study examined the microclimate conditions of Al-Nasr Specialist Hospital's outside space using Envi-met V5.0.3 lite. The initial case represents the current condition of the hospital, was modeled in ENVI-met with a total area of (75 m × 75) m. The model was simulated with a (50 × 50 × 25) grid unit at (1.5 × 1.5 × 1). With the use of this software, one may simulate three-dimensional buildings and examine how various approaches affect, TA, WS, MRT, and PMV [78]. Envi-met is an effective tool for calculating a value model of the local climate and simulating many different scenarios [79]. It has been shown in a number of earlier studies that ENVI-met is the best tool for modelling genuine scenarios with thorough investigations. Other comparative studies concluded that ENVI-met is the most effective, accurate, and efficient tool in simulating the local climate, especially when studying the effect of using different plants and materials in outdoor areas [78-81].

3.3.2 Model validation

Validation model in ENVI-met. The program has been validated in many studies conducted on urban spaces in Egypt, such as the study conducted by Mahmoud H et al, (2020), which showed the similarity between the results of observations and simulations [82]. In another study in Egypt by Abdallah A. et al, (2020) the value of the limitation factor (R2) was documented as 0.80 as an average for various locations between simulation and measurement [45]. In addition, a study by Abdallah A. et al, (2022) in Egypt recorded the value of the limitation factor (R2), the air temperature at points 1 and 2 as 0.98 and 0.99, respectively, so it is considered promising for a result that is close to real conditions [61].Another study by Elgheznawy D. et al, (2021) has the same conditions and characteristics as the current study, as it was conducted in the city of Port Said (the same city as the case study), and in a location very close to the current location of the hospital, and in one of the hotter months. In this paper, field measurements were made and compared to the simulation results using the software. The coefficient of determination's value (R2) was recorded for values of 0.84 and 0.95 [47].

In this paper actual outside air temperature measurements were used to validate the ENVI-met model by A Bappu-Evo multi-measuring device in the proposed receptor points on July 16, 2022 at 12pm and 2 pm, (as one of the hottest days of the year in Port Said, leading to peak solar power production). Figure 6 shows the coefficient of determination (R2) results which recorded as 0.83 and 0.93. The air temperature measurement range for the Bappu-Evo is between 20 and 50 °C, while the tolerance range is between 0.5 °C [47]. Previously, results of ENVI-met can be considered reliable, see figure 7.

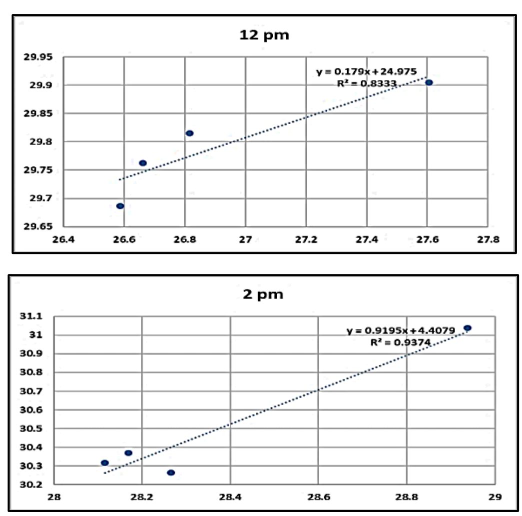


Figure 7: Temperature regression coefficient result for measurement and simulation

3.3.3 Simulation settings (day, time, receptors)

The study investigates various scenarios for outdoor open spaces in the outdoor waiting area at El-Naser Hospital. The simulation was conducted on July 16, 2022, as it is one of the hottest days of the year in Port Said, leading to peak solar power production, in order to conduct the evaluation under extreme conditions [47].

The simulation period is set from 10:00 a.m. to 4:00 p.m. as it is the most crowded time with patients because it is the outpatient clinic appointment in the hospital. And the timing of dispensing medicines to the beneficiaries of the comprehensive health insurance system. In addition to being the time when the temperatures are at their peak. Referring to the 2022 weather data on July 16, the average minimum temperature (Tmin) is 24°C and the average maximum temperature (Tmax) is 30°C. At 34.6°C, the average heat index is calculated, but it could rise by 8°C due to direct sunshine, humidity (68%), and wind speed (18 kph). The various points are covered by the simulation time in the outdoor area of the hospital to be measured based on sun exposure, shading cover, and proximity to trees. Four receptor points have been selected for measurement, and the following are the spatial and thermal characteristics of the receptor points: Receptor Point no. 1 it is the reference point outside the study area for improving thermal performance. Receptor point no. 2 is totally in a sun-sail-shading condition in all cases except the initial case (case A) and case F. Receptor point no. 3 is exposed to sun in most cases (cases A, C, E, and F).Receptor point No. 4 is always located near the trees in most cases (cases D, E, and F). Figure 8 shows the locations of the five receptor points, see figure 7 and Table 3 shows the Input details for ENVI-met simulations.

Figure 8: Receptor points in the proposed outdoor area of the hospital

Credit or Source: (adapted by Author)

Table 3. Input details for ENVI-met simulations.

	Parameter	Definition	value	
Existing configuration	Total area	Case study area with the surrounding buildings	75 m× 75 m	
	Outdoor waiting area	The net area of the case study area	20 m× 17 m	
	Buildings	U shape (main building with height 16 m and separate buildings with height 5m)	Walls	Moderate insulation
			Roof	Tile
			Geometry	Plain surface
	Shading in the proposed study area	None	None	
	Vegetation in the proposed study area	Grasses on the sides	None	
Model parameter	Main data	Domain size	50*50*25	
		Cell size	1.5*1.5*1m	
	Simulation time	location	Port said (31.27°N, 32.3°E)	
		Start date	16.7.2022	
		Start time	10.00 am	
		Total simulation time	6h	
	Microclimate	Model rotation out of grid north		
		Minimum Ta	24°C	
		Maximum Ta	30°C	
		Relative humidity%	68%	
		Wind speed	5 m/s	

3.3.4 Scenarios design

Case (A) is the initial case as in the real surveys of the study area. Case (B) using full shading of the outdoor area Case (C) using a semi-shading about covering 50% of the outdoor area. This percent of shading was used based on the optimum percentage concluded in previous studies [47, 83]. Case (D) adding trees with full shading (mixed strategy). Case (E) adding trees to compete with semi-shading (mixed strategy), Case (F) adding trees to provide more shade. The percentage of trees used, and their distribution are based on the results of previous studies, which recommended the use of 20- 30% as a percentage, which leads to improving the thermal performance of outdoor spaces [84, 85]. Other studies concluded that it is possible to increase the percentage of trees to 50% to reduce the air temperature [85, 86].

3.3.5 Trees model

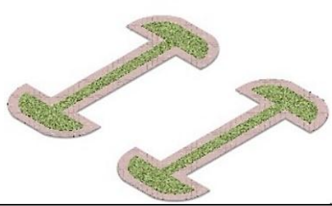
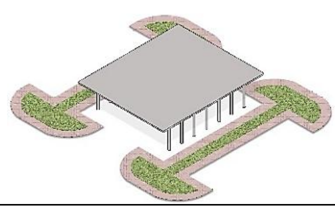
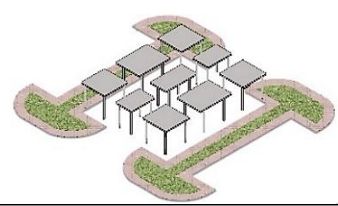
The current model used Ficus Microcarpa / Nitida tress and Deloix Regia / poinciana trees. They are the main trees found in the streets and gardens of Port Said city. Ficus trees are among the most famous ornamental trees in Port Said city, as they are fast-growing plants with a bright green color and a high ability to cut, shape and trim to all shapes, do not like excessive watering and can resist environmental conditions, as well as do not lose their leaves or green color throughout the year [87]. Delonix regia trees are fast-growing trees with an umbrella shape. Usually, evergreen. This tree is one of the most widely cultivated ornamental plants in the world, due to its bright red flowers and their excellent shade. Different parts of the plant are customarily utilized to treat diver's sicknesses such as inflammation, bronchitis, fever, and pneumonia [88]. So, using these trees can improve overall health and well-being, supporting the healing landscape concept [89].

3.3.6 Shade model

Various shading strategies are examined to improve the thermal comfort of outdoor waiting areas in hospitals while responding to the requirements for flexibility and adaptability in an aesthetic way. So, the paper proposes the use of sun-sails for shading.

Some studies have investigated the impact of using sun sails to improve thermal comfort [90-93]. A study by Nevado E et al, (2020) recommended the use of sun sails as an effective strategy to improve thermal comfort in outdoor spaces in developing countries as a simple and technically cost-effective solution [94]. This is in addition to the features that distinguish the solar sails, which include strength, flexibility, softness, durability, thermal insulation, low weight, water absorption/resistance, dye ability, and chemical resistance. In addition, the sun sail is considered a removable textile solar protection. There are some factors that affect the characteristics of solar sails, the most important of which are color, openness, and spatial distribution [95]. Despite these characteristics, in addition to sun sails being considered a traditional shading strategy in Mediterranean cities [94], studies on sun sails, especially in Egypt, are still limited. In this study, shading is used by sun sails at a height of 4 meters, which gives a sense of openness to the external spaces, and it is the common shading height in other shading areas in El-Naser hospital. Also the study used black shading according to the results of a study by Nevado E et al, (2020), which proved that the thermal performance of black sun sails is better than white ones in all his study scenarios [94], in addition to the study by Elgheznawy D. et.al. (2021), which proved the effectiveness of the strategy of using solar sails, which was applied to a case study in Port Said [47]. Besides that, black sun sails are the most common type in Port Said. Table 4 shows Six scenarios' description and inputs.

Table 4. Six scenarios' description and inputs.

Name			Case (A)	Case (B)	Case (C)
Description			The initial case 	Full shaded 	Semi shaded 
Vegetation	Simple plants	Type	[XX] Grass	[XX] Grass	[XX] Grass
		Height	0.25	0.25	0.25
		Width	--	--	--
		Albedo	0.2	0.2	0.2
		Leaf type	Grass	Grass	Grass
	3d plants	Type	--	--	--
		Height	--	--	--
		Width	--	--	--
		Albedo	--	--	--
		Leaf type	--	--	--
Street		Type	[ST] Asphalt Road	[ST] Asphalt Road	[ST] Asphalt Road
		Albedo	0.2	0.2	0.2
Sidewalk		Type	[KK] Brik Road	[KK] Brik Road	[KK] Brik Road
		Albedo	0.3	0.3	0.3
Shade		Type	[SU] PVC Sun sail	[SU] PVC Sun sail	[SU] PVC Sun sail

Name			Case (D)	Case (E)	Case (F)
Description			Full shaded with trees 	Semi shaded with trees 	Trees provide more shade 
Vegetation	Simple plants	Type	[XX] Grass	[XX] Grass	[XX] Grass
		Height	0.25	0.25	0.25
		Width	--	--	--
		Albedo	0.2	0.2	0.2
		Leaf type	Grass	Grass	Grass
	3d plants	Type	[T2] Ficus Nitida	[T2] Ficus Nitida	[T1]
		Height	5m	5m	12m
		Width	3m	3m	11m
		Albedo	0.18	0.18	0.6
		Leaf type	Conifer leaves	Conifer leaves	Deciduous leaves
Street		Type	[ST] Asphalt Road	[ST] Asphalt Road	[ST] Asphalt Road
		Albedo	0.2	0.2	0.2
Sidewalk		Type	[KK] Brik Road	[KK] Brik Road	[KK] Brik Road
		Albedo	0.3	0.3	0.3
Shade		Type	[SU] PVC Sun sail	[SU] PVC Sun sail	[SU] PVC Sun sail

4 RESULTS AND DISCUSSION

As mentioned before, the study aims to enhance the outdoor waiting areas at Al-Nasr Hospital’s thermal performance in Port Said city. Therefore, six case studies were proposed, focusing on applying shading and greening strategies. The main objective is to find the best scenario presented from the proposed case studies that can be applied to the outdoor spaces of hospitals, which would effectively mitigate the negative effects of thermal discomfort in hot and humid climates. This section discusses variations in thermal behavior and presents the findings from the suggested case studies, considering a variety of parameters, such as temperature and thermal comfort indices. Where the original case (case A) was compared to the rest of the case studies: case B (full-shaded), case C (semi-shaded), case D (full-shaded with trees), case E (semi-shaded with trees), and case F (trees provide more shade). The alterations in thermal behavior for each suggested case study were displayed in the following results:

4.1 Air temperature (Ta)

The results will be displayed from 10 a.m. to 4 p.m. every two hours to obtain noticeable results (10 a.m., 12 p.m., 2 p.m., and 4 p.m.), on July 16, 2022, at a height of 1.50 m. The results were analyzed by monitoring the results with the four receptor points.

The air temperature data at each receptor point during the simulated hours are displayed in Figure 9. The results showed an increase in air temperatures in general, especially at receptor point 1 (the reference point). This is due to the increase in solar radiation at such a time in Egypt, in addition to the use of asphalt in the floors, which in turn absorbs heat and then releases it in the absence of shading strategies or trees. At receptor point No. 1, it was noted that there is no significant temperature difference between case studies due to the location of the receptor point outside the limits of improvement strategies in the study area. Overall, it was found that there were no significant differences in the temperature reduction between case B (full-shaded) and case C (semi-shaded 50%), which corresponds to the results of previous studies mentioned in the Scenario Design section [47, 61]. But the results show the need for more vertical shading, as the southern facade in Egypt is the direction most exposed to solar radiation [96]. Despite this, the results showed that case D (full shading and trees) did not achieve the desired results, as temperatures rose in this case due to low wind speed and low natural ventilation because trees work as a wind block, trapping the air inside and preventing it from circulating. This can cause the air to become warmer than the outside air in addition to impeding heat dissipation by convection, resulting in high temperatures inside the space. These results are the opposite of case E (semi-shaded by trees), where semi-shading allowed air movement within the space in addition to the shade of the trees. The use of trees has a positive effect on improving the temperature of the air, as it works to absorb moisture from the site, and humidity has an inverse relationship with the air temperature. This is consistent with the study of Abdallah et al. (2022), which drew the same conclusion: that the use of hybrid strategies of trees and shading together is the most efficient strategy. Where the average reduction in temperature using a condition was approximately 1.9°C [61]. Also, this is a similar result to the study of Mahmoud Rajab (2020), whose study concluded a reduction in temperatures of 2.1 °C using a hybrid strategy of shading and trees [82]. The results also showed a good improvement using case F (trees with wide shading), where a greater amount of shading is given while allowing natural ventilation. But it was also not the most successful strategy, as the shade of the trees was not enough to completely shade the area.

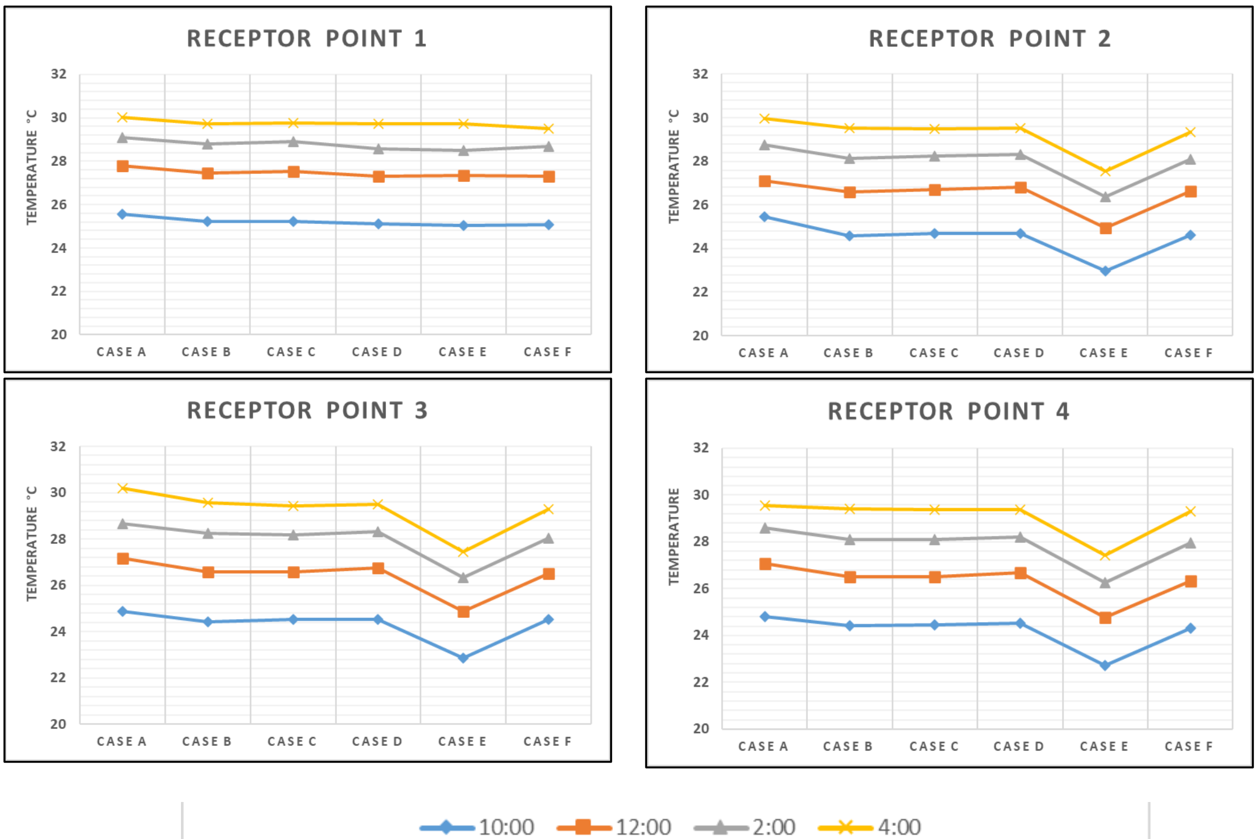


Figure 9: Air temperatures values at each receptor point over the simulation's hours

Credit or Source: by author

4.2 Wind speed (WS)

As has also been mentioned before, the wind speed in Port-Said city is about 5 m/s, which is relatively weak, especially in the hospital's main building location and the wind direction, which can obstruct and slow the wind. Despite this, wind speeds and temperature are significant variables that can be used to study thermal comfort [97], so it makes sense that even a slight shift in wind speed can affect thermal sensation [98]. Figure 10 depicts the absolute difference in wind speed values between case E and case D. The calculated difference is approximately 0.6 m/s, indicating a notable variation in wind speed between the two cases. This corresponds to numerical investigation by Jingxian Xu et al. (2021) confirms that the wind direction influences the convective heat transfer coefficient of the human body when the airspeed is 0.5 m/s or more [48]. Also, it corresponds to a simulation study by Aboelata et al. (2020) which demonstrated that the presence of trees in both the 20% and 50% scenarios in the southeast orientation leads to an increase in air temperature compared to the reference case. The temperature rises by approximately 0.2 K and 0.3 K, respectively. Because of the impact on reducing wind speed and natural ventilation, where the wind speed in these two scenarios was 0.22 m/s and 0.38 m/s, respectively. So, wind speed is one of the main factors affecting air movement and helps distribute air masses and prevent stagnant pockets, in addition to promoting internal and external air exchange [99].

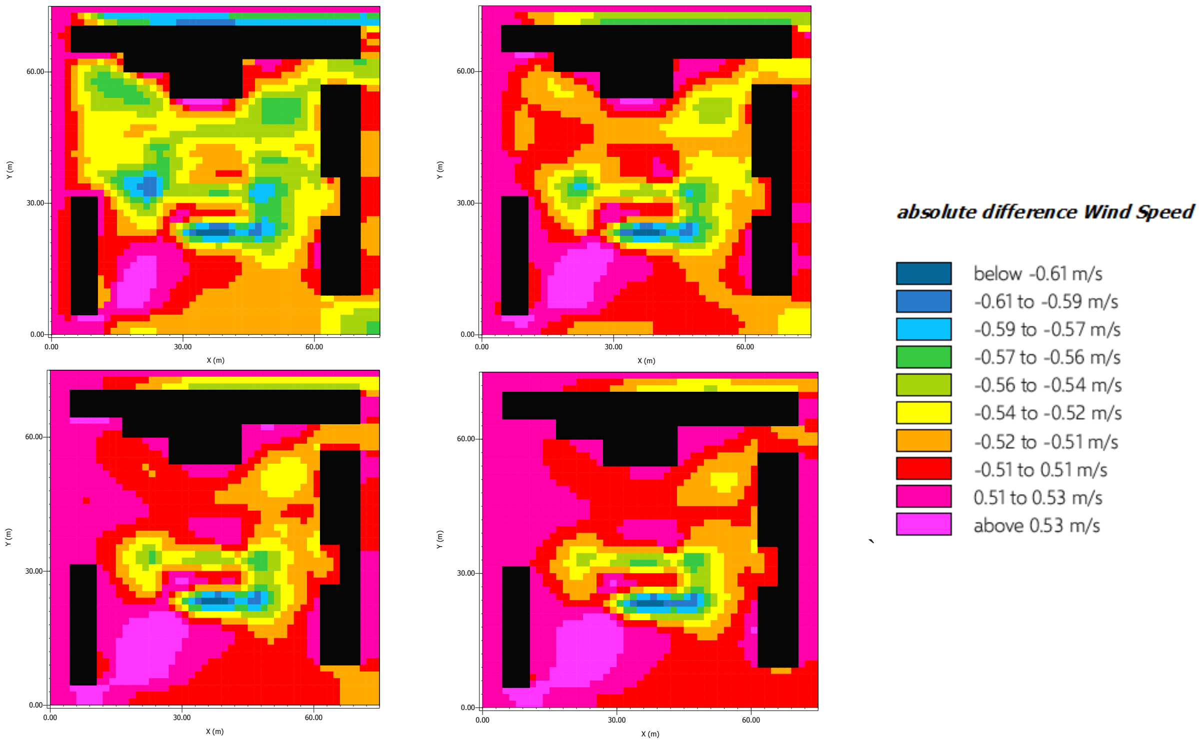


Figure 10: The absolute difference wind speed values (a comparison case E with case D)

Credit or Source: by Author

4.3 Mean Radiant Temperature (MRT)

MRT is a measure of the average temperature of the surfaces that surround a certain point. MRT affects how we feel because we are constantly either absorbing heat or radiating it from our bodies [100]. While other parameters such as Ta, PMV, and PET contribute to the overall understanding of thermal conditions [101]. In a study by Kántor et al. (2019), it was found that the MRT is a better predictor of outdoor thermal comfort than Ta [102]. Figure 11 shows results for all forms of MRI findings at 12:00 and 2:00 pm (the most significant hours). It was observed that the results of MRT almost followed a similar pattern to the results of Ta. The reduction in MRT results was observed in general using shading strategies and trees in all cases. Through the results, it was found that cases D and E gave the best results in terms of reducing MRT values, where the reduction of MRT from cases D and E at 12 p.m. is 6.5% and 6.7%, and at 2 p.m. is 12.7% and 16.8%, respectively. This supports the use of hybrid strategies of shading and trees. In the case of a fully shaded condition (case D) with limited air circulation, the MRT values are higher compared to a semi-shaded condition (case E). This is because the reduced air circulation restricts convective heat transfer, potentially leading to higher surface temperatures and higher thermal radiation emissions.

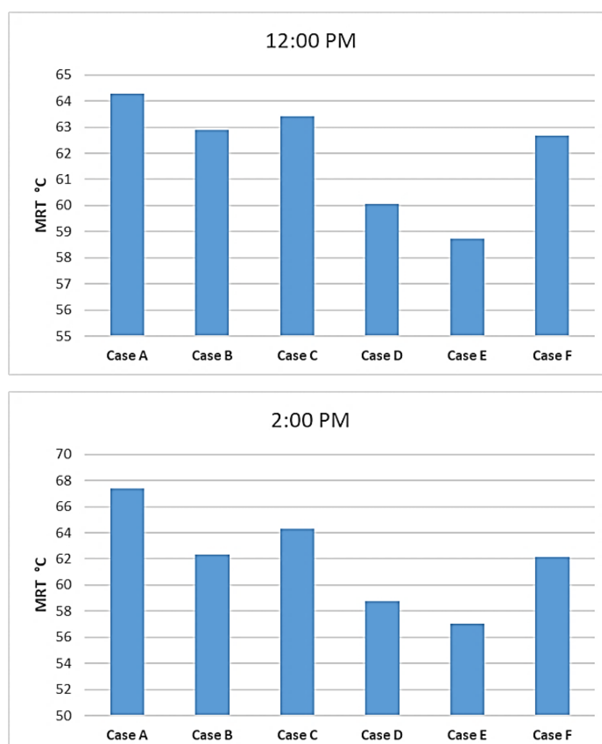


Figure 11: The results of MRT at 12 pm and 2 pm

Credit or Source: by Author

4.4 Predicted Mean Vote (PMV)

The most used measure for determining thermal behavior is air temperature, but it is also not the only indicator for assessing thermal comfort and heat stress. There are also other factors affected by thermal comfort that should be considered [86, 103, 104]. PMV is a commonly used index for assessing thermal comfort in indoor and outdoor environments. It considers factors such as air temperature, humidity, air velocity, clothing insulation, and metabolic rate to estimate the thermal sensation experienced by occupants [105].

Through Figure 12, we notice an increase in PMV values in general, which may reflect the heat inconvenience of outpatient patients waiting in the proposed location. In general, the use of the suggested strategies improved PMV values. When comparing instances B and C to the original case A at the receptor points, the average decrease in PMV values is around 9.7% and 7.6%, respectively. The results indicate that shading intensity affects thermal comfort, with the semi-shaded scenario exhibiting different thermal sensations compared to both the full-shaded and the base conditions.

Also, the results of the reduction from case D, E and F are about 15.5%, 26.7%, and 7.7% respectively. These results suggest that when trees are included together with shading strategies, there are significant variances in how thermal comfort is perceived and have a discernible impact on the PMV values, thus influencing the thermal comfort experience.

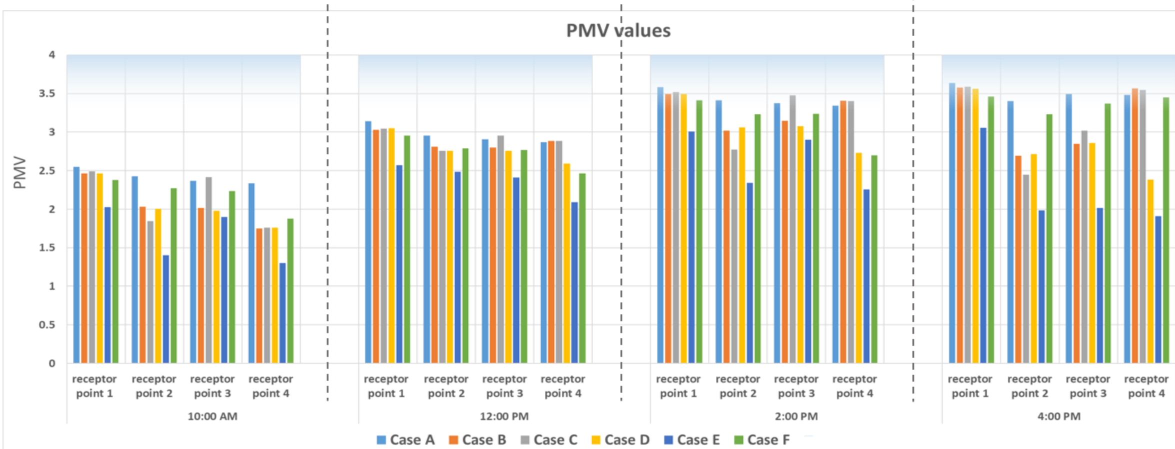


Figure 12: PMV values during the simulation hours for every receptor point.

Credit or Source: by Author

4.5 Physiological Equivalent Temperature (PET)

(PET) analysis provides an assessment of the overall thermal stress on the human body, considering factors such as air temperature, humidity, and radiant heat exchange. The PET values reflect the thermal sensation as perceived by the human body [106, 107]. From figure 13, the results of the PET analysis showcased similar trends to the PMV analysis. Overall, the results of PET values revealed that despite the implementation of different shading strategies, PET values remained relatively high across all case studies except the results at 10 am. This suggests that the thermal stress levels were not significantly reduced to a comfortable range in the outdoor waiting areas of hospitals in hot and humid climates. While the PET values did not show a significant decrease, it is important to note that some improvement was observed among the different case studies. The maximum improvement achieved was from case E, which transitioned from a state of hot to a state of warm, indicating a moderate enhancement in the thermal conditions at 12 pm, 2 pm, and 4 pm with an improvement of about 8.5%, 12.4%, and 14.5% respectively. And transitioned from a state of warm to a state of neutral at 10 pm with an improvement of about 19.3%.

However, it is crucial to acknowledge that achieving optimal thermal comfort in outdoor spaces, especially in hot and humid climates, can be a challenging task. Various factors, such as the complex interaction between solar radiation, air movement, humidity, and personal factors, contribute to the overall thermal experience.

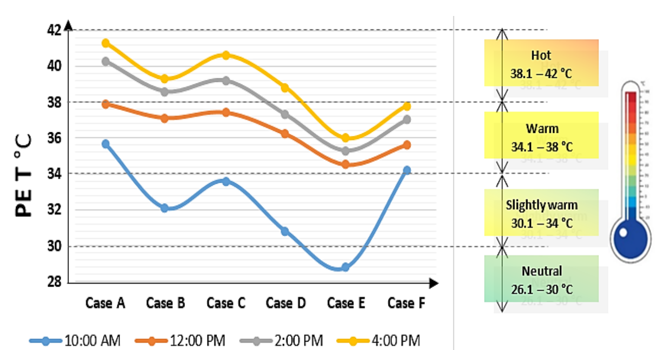


Figure 13: PET values at the simulation hours

Credit or Source: by Author

Finally, based on the results and data obtained from this research, several recommendations can be made to improve the thermal comfort of outdoor waiting areas in hospitals and similar settings.

Implement mixed shading strategies: The study highlights the effectiveness of mixed shading strategies, particularly the combination of semi-shading with trees, in achieving better thermal comfort. Therefore, it is recommended to consider a combination of shading techniques to optimize the balance between solar radiation reduction and air circulation, and a parametric study for case E (optimization for shading and trees ratios).

Consider site-specific factors: Each location has unique climatic conditions and environmental factors that can influence thermal comfort. It is important to consider site-specific factors such as local weather patterns, vegetation types, and building orientations when designing outdoor waiting areas. Conducting site surveys and gathering local meteorological data can provide more accurate inputs for the simulations and lead to better design outcomes.

Incorporate other comfort parameters: While the study focused primarily on thermal comfort, as one of the most important criteria for providing healing environments, it is recommended to consider other comfort parameters such as air quality, noise levels, and personal preferences. Integrating these factors into the design process can create more holistic and comfortable outdoor spaces for patients and visitors.

Evaluate long-term maintenance and cost-effectiveness: When selecting shading strategies, it is essential to evaluate the long-term maintenance requirements and the cost-effectiveness of the proposed solutions. Consider factors such as the durability of shading structures, maintenance needs of vegetation, and the overall lifecycle cost of implementing and maintaining the chosen strategies.

Extend the research to different contexts: This paper focused on a specific region and climate. To enhance the generalizability of the findings, it is recommended to conduct similar studies in different geographical locations with diverse climate conditions. This will provide a broader understanding of the effectiveness of shading strategies in improving thermal comfort.

By considering these recommendations, future research and design practices can further enhance the thermal comfort of outdoor waiting areas, contributing to better patient experiences and overall well-being in healthcare settings.

5 CONCLUSION

This paper refers to the new design requirements of the most critical spaces of hospitals in the post pandemic era, suggesting outdoor waiting areas in hospitals as a solution to align the new design recommendation, emphasizing the importance of thermal comfort in creating healing environments. It specifically addresses the challenges posed by hot and humid climates, with Egypt being a prime example of a hot climate. The paper explores the effectiveness of various shading and greening strategies, including the use of shading and trees, in enhancing thermal comfort. And the feasibility of using these strategies in improving thermal performance. Through the results of the study, the application of effective strategies can be generalized to many hospitals and health centers in Egypt and other countries with hot and humid climates, In addition to comparing some of the results of the simulation study with other similar previous studies in similar locations or climates. The following key conclusions were drawn from the research:

Shading and greening strategies had a significant impact on the thermal comfort of outdoor waiting areas. All the proposed strategies improved the thermal conditions compared to the initial case, but the most effective ones were those that combined shading and vegetation (cases D and E).

Various factors, such as shading, wind speed, and air movement, influenced the thermal comfort evaluation. While case D reduced air temperature, case E contributed to better air circulation, resulting in more comfort. Moreover, cases D and E lowered mean radiant temperature values, indicating less thermal load on the human body.

The predicted mean vote (PMV) values showed that cases D and E enhanced thermal comfort for individuals in the outdoor waiting areas. However, the physiological equivalent temperature (PET) values revealed that the achieved improvements were moderate, with the maximum improvement being a transition from a state of heat to warm.

Case E provided the best thermal performance among all the cases. It also created visually interesting patterns of light and shadow, making it an attractive option for outdoor areas in hot and humid climates.

Future research could conduct more studies to explore other factors that influence thermal comfort in outdoor waiting areas. The findings of this research could also inform the design and planning of other outdoor spaces in hospitals and health centers, such as gardens, courtyards, or terraces, to create more comfortable and healing environments for patients and visitors in hot and humid climates.

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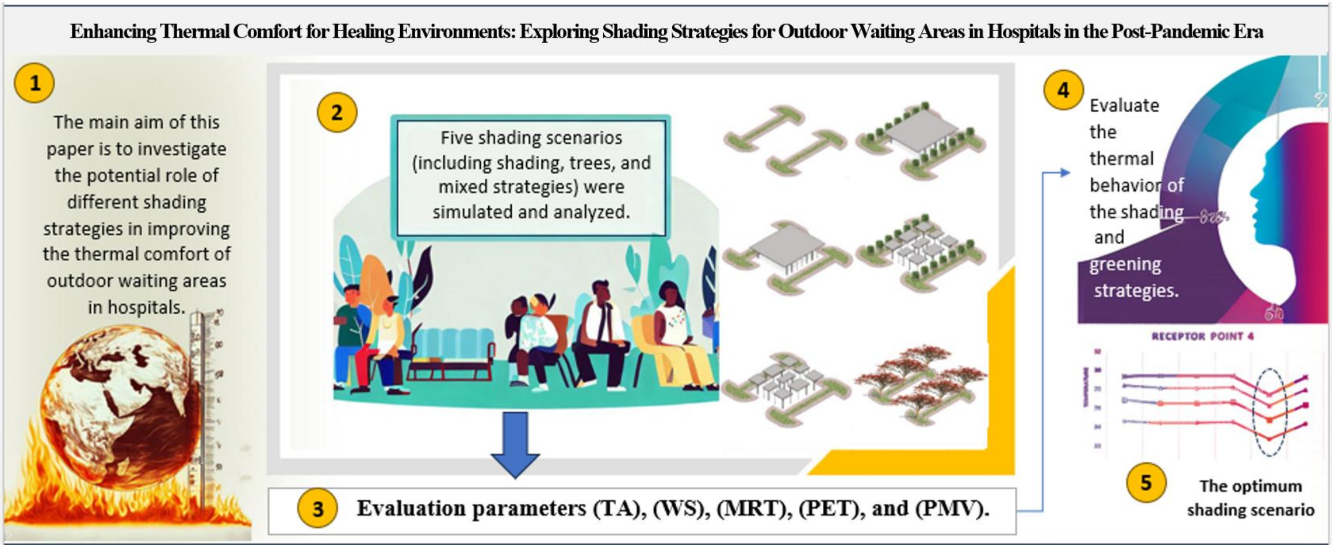
APPENDIX



Graphical abstract: The methodology of the study