Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 05, May, 2022

Phases of Urban Development Impact on the Assessment of Thermal Comfort: A Comparative Environmental Study

Hala Hussein Musa [1], Aseel Mezher Hussein [1], Ammar N. Hanoon [1*], Mahir M. Hason [2], Ali A. Abdulhameed [1]

[1] *Department of Reconstruction and Projects, University of Baghdad, Baghdad, Iraq.*

[2] *Disaster Information Management Center, Ministry of Science and Technology, Baghdad, Iraq.*

Received 11 February 2022; Revised 19 April 2022; Accepted 25 April 2022; Published 01 May 2022

Abstract

Millions of pilgrims and visitors from numerous parts of the world flock to Karbala (one of the most prominent ideological and religious places in central Iraq) each year to visit the holy shrines in Karbala due to their sanctity. Many improvements have been made to the Two Holy Shrines (THS), the Shrines of Imam Husayn and Imam Abbas, and the area between them (ATHS), due to the high temperatures in this region and to improve pedestrian thermal comfort. Studies on improving outdoor thermal comfort in Karbala are scarce. Hence, this research aims to look into historical and current architectural changes and how they affect thermal comfort. On the hottest summer day, the ENVI-met software program was used to simulate the building design and calculate the impact of vegetation on outdoor thermal comfort. According to the findings, trees of medium-density in a compacted arrangement should be used nearby built-up structures in newly planned urban regions. In existing urban plots, the best approach is to use free blank areas (e.g. car parks) to set trees of medium-density, as well as plant along large pedestrian and driving routes.

Keywords: Thermal Comfort; ENVI-Met; Urban Climate; Urban Planning.

1. Introduction

Since 1930, the topic of thermal comfort has been studied and discussed quite widely [1]. The canopy zone climate in dry environments is affected by three key factors: solar protection, cooling processes, and ventilation [2]. Solar access, which is affected directly by the solar radiation amount, is a crucial demand for the influence of solar heating on buildings. In urban planning, solar radiation exposure is one of the primary key parameters that affect microclimate circumstances. Roads and semi-enclosed locations are usually more exposed to solar radiation than wide areas such as parks. Solar access control may be broken down into two categories: solar access for pedestrians and buildings. Building components such as arcades and canopies, as well as trees and plants, protect pedestrians from direct sunlight. Shades can be created by restricting the width of the roadway, planting trees along the sidewalks, or employing pedestrian arcades connected at the street level of the nearby buildings [3].

Numerous studies show that green impacts play a vital role in the technique of environmental cooling in urban planning, as well as in conserving energy and improving human thermal comfort [4]. Due to the clustered design with

* Corresponding author: anh@uobaghdad.edu.iq

http://dx.doi.org/10.28991/CEJ-2022-08-05-08

cool green islands and the wind flow through the main canyons, the comfort levels were sufficient and the cooling was reasonable for various orientations of the metropolitan area [5]. Shading surfaces aid in the reduction of temperature and mean radiant temperature, which enhances thermal comfort. Shading surfaces can also deliver the energy conserved at night, which might contribute to providing thermal comfort for walkers the next day [6].

The importance of the history of the holy religious shrines goes back to the establishment and development of the religious shrine cities. Besides, it stems from the positive impact that these shrines have on the surrounding communities. This was due to their close connection with the beliefs of those peoples, which creates close cohesion and spiritual integration that leads to building bridges between the peoples of different nations [7]. The areas of life and perhaps the most prominent of these roles are the religious, cultural, social, political, economic, artistic, and urban roles. These roles deserve to be discussed scientifically, and they deserve to be devoted to volumes that are handled by specialists in various social and scientific sciences, as the research is not limited to those I referred to, but there are also psychological and other scientific matters that there is no room here to explain in this quick introduction. The topic to which this research is devoted is the study of the effect of architectural developments on the distribution of thermal comfort zones for the Imam Husayn shrine in Karbala, Iraq.

The holy Karbala is recognized as one of the well-known religious cities across the Islamic world due to the presence of the two Holy Shrines of Imam Husayn and Imam Abbas (Prophet Mohammed’s grandsons) [7]. The number of visitors to this city has been gradually growing due to more than 36 holy events all over the year. Thus, 8 to 30 million people visit the place twice a year for two events that are considered the most overelaborate. Over the previous two decades, shrines in the Middle East have grown in numerous ways: the number of visitors, the proportions of the building's areas, the management of the mass movement, and newly created events. For holy shrines, visitors have significantly increased and faced severe impacts, especially during religious ceremonies. For instance, the canceled spatial barriers between Al-Haram and the open-to-sky courtyard, which previously created a transitional area, can produce an isolated building, including a static space, which visitors occupied during activities and ceremonies, as we have seen at holy shrines. Visitors may also have to travel long distances between outdoor and indoor spaces due to a lack of transitional spaces. Low-quality amenities, improper zoning, extreme environmental situations between the two shrines, and consequently inequity planning are all possible hazards to the shrine's forms and components.

Many studies have dealt with the issue of urban development in the city of Karbala in terms of the functional performance of religious tourism, as presented by Hassan and Yassin [8]. Additionally, Alobaydi et al. examined the environmental influence in terms of wind movement by making a comparison between the old and the modern urban fabric of the city, and also studied the effect of changing the dynamics of air movement [9]. However, no studies have considered the issue of the impact of urban development on the feeling of thermal comfort in the city. Therefore, the current study attempts to shed light on the effect of urban alteration on the feeling of thermal comfort and to try to give the best solutions to reach the desired goal.

Many architectural developments (e.g. demolition and destruction) have taken place at the shrine of the *THS* to accommodate large numbers of pilgrims and visitors. The shrine's growth and development are a continual process that faces specific challenges related to the spaces, hierarchical order of space, and events. The importance of the current paper appears from investigating the effect of architectural modifications on thermal comfort spaces due to high temperatures in the city of Karbala. Besides, the present research suggests giving some solutions to positively increase the sense of comfort and provide rest areas for the pilgrims and visitors of this place.

As a result of the urban change that the holy city of Karbala has undergone, many intensive studies about that city have been conducted from an architectural point of view, to monitor the effect of changes in the urban structure on the circulation of airflow velocity, and so on. However, the study of the impact of urban alteration on temperatures and thermal comfort areas has not received great attention. Consequently, the current study focuses on comparing two phases of architectural developments and giving solutions and treatments to achieve the optimal values of thermal comfort areas to serve the largest number of pilgrims and visitors to the city.

2. Methodology

The methodology approach followed in the current study included a literature survey, historical information, data collection, and simulations using the ENVI-MET software. Figure 1 displays a schematic depiction of the methodology approach adopted in the current study.

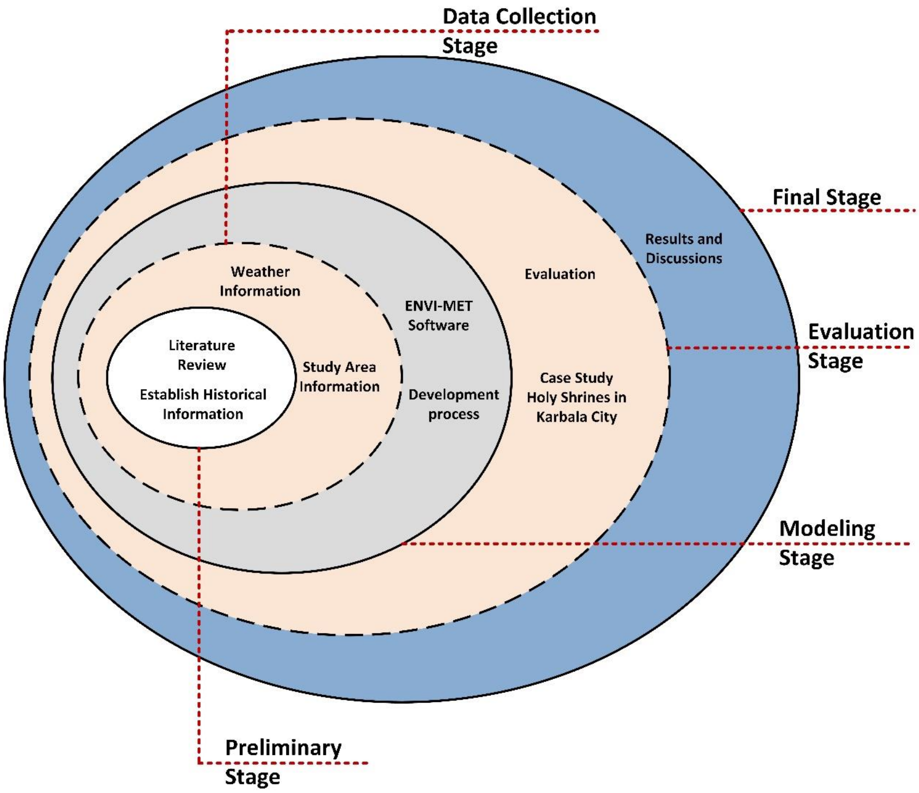


Figure 1. A diagrammatic illustration of the research approach

2.1. Study Area

Karbala is located on the bordered transient between the stable and unstable platforms. The Two Holy Shrines (*THS*) and the area between them (*ATHS*), which represent herein the study area, are located about 92 kilometers southwest of Baghdad (the capital) between Longitude 44.03700-44.03200 to the East and latitude 32.61800-32.61560 to the North [10] as shown in Figure 2. The climate in the area stands up to envelop the western desert climate according to the climatological elements. Iraq's climate is described by hot, dry summers and cold, wet winters [11].

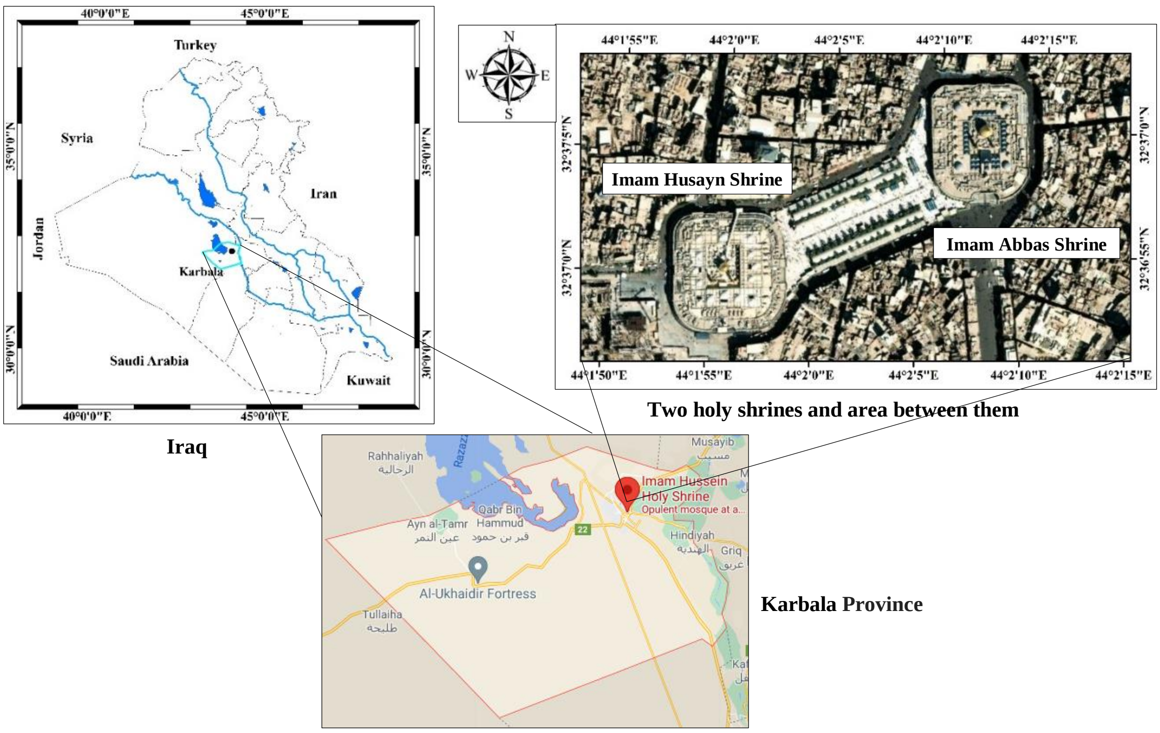


Figure 2. The Geographic location of the study area (Karbala city)

The area between the *THS* has a long distance of 378 meters. It is said to be the exact place where the fighting in the Battle of Karbala took place. The area between the two shrines was previously not abandoned as it is currently; it had a single main street and multiple lanes with domestic and commercial structures (see Figure 3). The buildings between the two shrines were demolished before 2003. After 2003, the administrations of Karbala, the two shrines embarked on further developing the study area in order to produce a largely united boundary for the Karbala holy sites, including the study area.

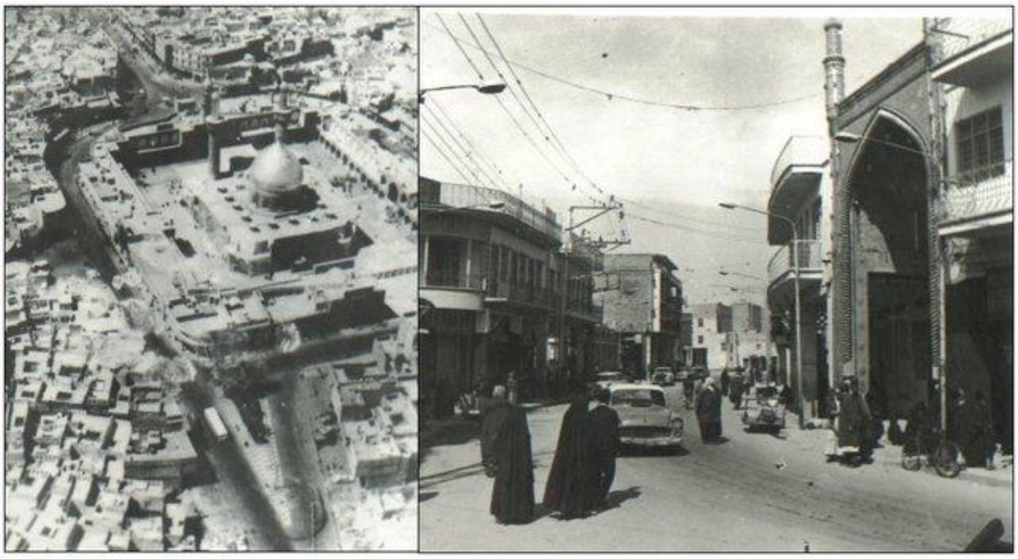


Figure 3. The urban fabric of the old Holy Shrines

2.2. Weather in Karbala Iraq

Karbala has a hot desert climate, with summers that are scorching hot and dry and mild winters. Although no month is particularly wet, Nov. to Apr. receives nearly all of the annual precipitation. This average weather in Karbala is based on a statistical investigation of previous hourly weather records and model reformations from the early beginning of Jan. 1980 to late Dec. 2016 [12].

In Karbala, the Summer is long, sweltering, arid, and clear. On the other hand, Winter is cold, dry, and mostly clear. The temperature generally ranges from 6°C to 44°C throughout the year, with temperatures rarely falling below 2°C or rising over 47°C. The ideal times to visit Karbala for warm-weather actions are in April, May, September, and October (see Figure 4). The average daily high temperatures for hot and cool seasons are more than 38°C and below 21°C, respectively. The hot and cool seasons continue for about 3–9 months (May, 25 to Sep., 23) and 3–4 months (Nov., 23 to Mar., 3), respectively. Jul., 27 and Jan., 1 are the hottest and coldest days of the year, respectively, with average high and low temperatures of 44°C and 30°C, respectively for the hot season and average low and high temperatures of 6°C and 16°, respectively for the cool season as illustrated in Figures 5 and 6. It is worth mentioning that the temperature of 51.80ºC was used to simulate the proposed models. This temperature represented the hottest day that was recorded on Jul. 28, 2020, based on IMOS (Iraqi Meteorological Organization and Seismology).

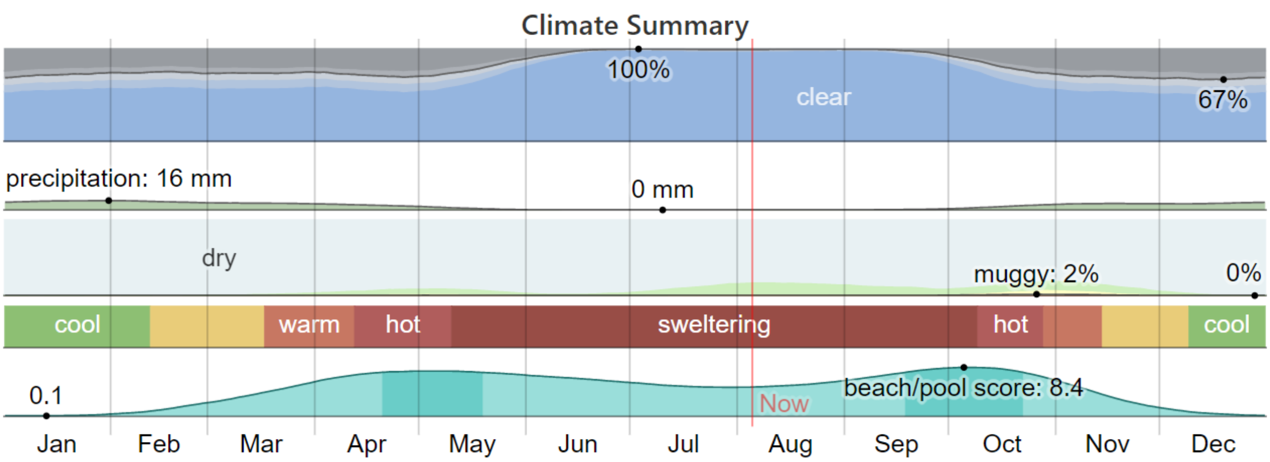


Figure 4. Climate summary of the study area [12]

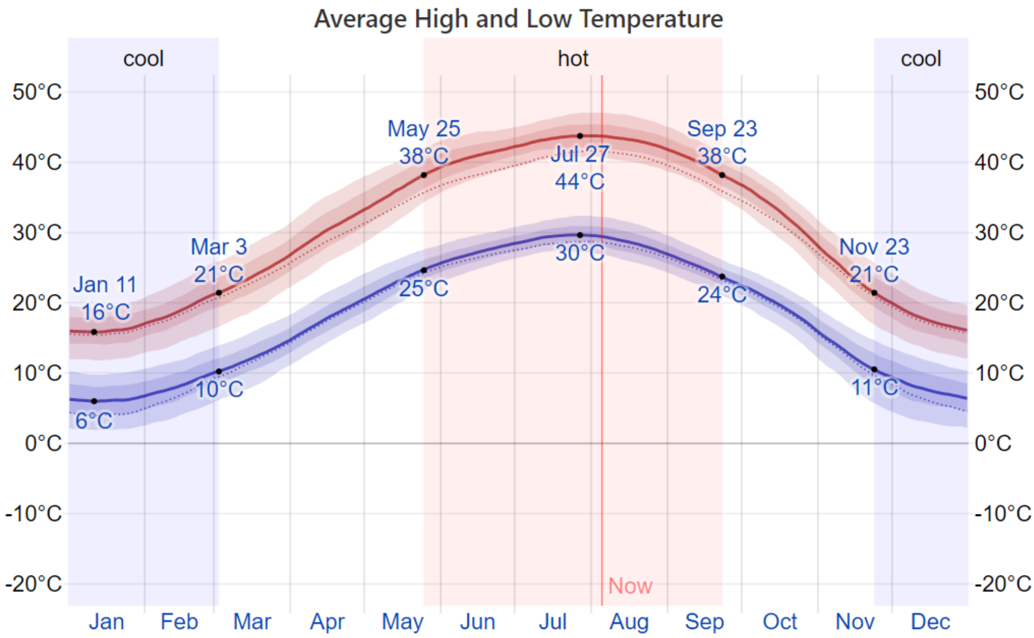


Figure 5. Average high and low temperatures for the study area [12]

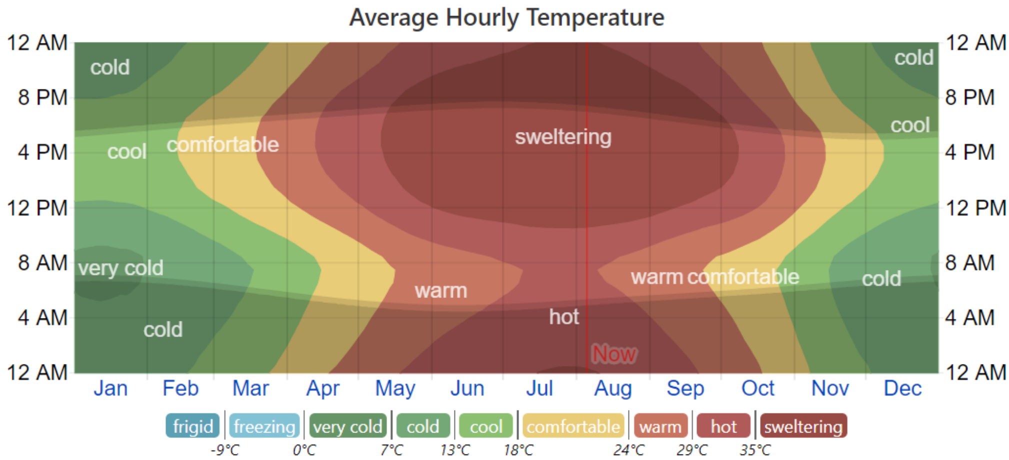


Figure 6. Average hourly temperature for the study area [12]

2.3. Development Process

The area between the Two Holy Shrines (*ATHS*) has witnessed several stages of change and development. In the middle of the last century, it was made up of small alleys interspersed with the main street called Ali al-Akbar Street, which has many markets, including the Al-Sayyagh market, the merchants' market, and the Abbas market. In 1978, it consisted of alleys and markets linking between *THS*, as presented in Figure 7. The design was made for expansion in its time and direct implementation and compensation of buildings, but the work only continued for a short period. The situation remained the same until 1991 when the forces of the former regime (the rule of Saddam Hussein) demolished all the buildings and shops after the revolution against his rule, which left a lot of debris and demolition (see Figure 7).

Figure 7. The study area after the demolition in 1991

By 2013, the *ATHS* was paved with stone. The floor of the area was covered with Italian marble, as depicted in Figure 8. The development included many parts such as infrastructural installations, auditory designs, and cooling systems. The stones used in the *ATHS* courtyard were identical to those used in the Masjid al-Haram courtyard. Furthermore, the development of the shrines form is a continuous process of evolution and change that encounters unique challenges, mostly associated with the spaces, hierarchical order of space, and activities. The significant developments process of the study area before and after 2013 are shown in Figure 9.

Figure 8. The floor of the ATHS

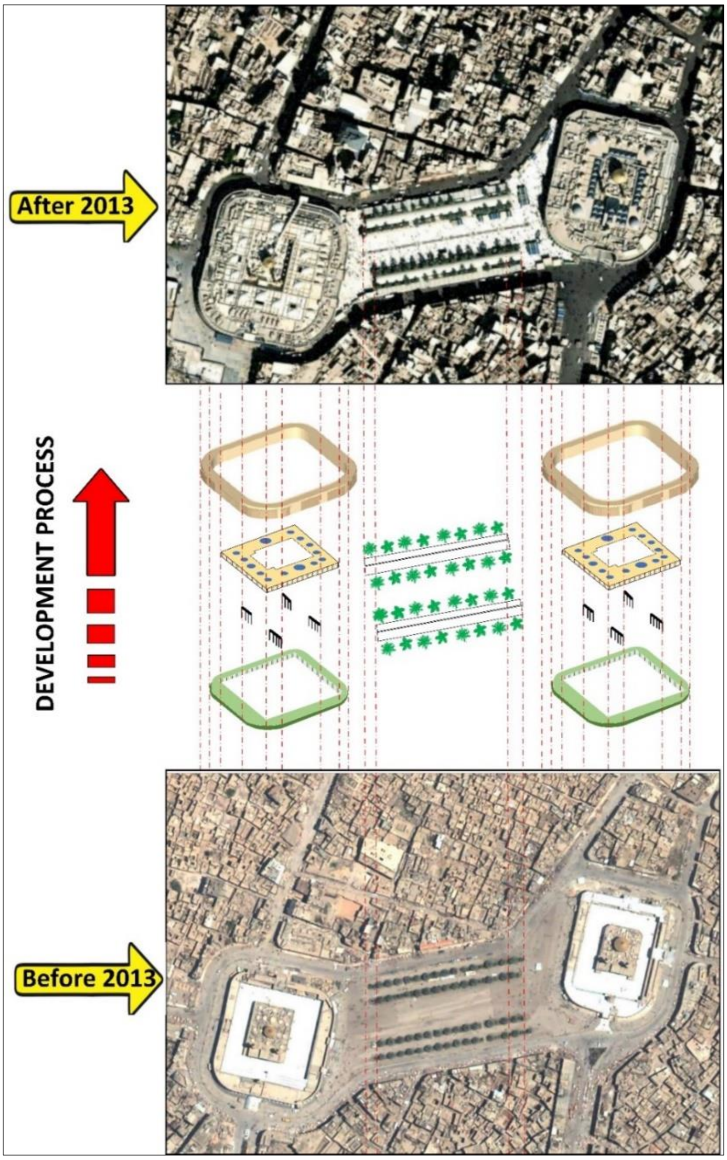


Figure 9. Important developments in the study area

2.4. *ENVI-met* Models

ENVI-MET is a program that may be used for outdoor microclimate simulation in open areas, as well as wind turbulence, vegetation impact on the microclimate, pollutant dispersion, and bioclimatology input. The simulation model created by *ENVI-met* is according to a list of factors (e.g. clouds, structures, and soil data). A daily and hourly time range is defined by the default basic settings, including the simulation's total duration, relative humidity, wind direction and speed, and external temperature, throughout the starting and end of the simulation. Many studies have shown the trustworthiness of *ENVI-met* findings for modeling outdoor thermal spaces. These examinations revealed that the data collected at local meteorological sites appeared to match the predicted outcomes with accurate and reliable validation [13-17].

2.5. Data for the Proposed Models

The IMOS provided the data used to simulate the suggested model. As we mentioned previously, the maximum and minimum temperatures of 51.80ºC at 4 pm and 24.8ºC at 6 am were adopted to simulate the suggested models. This temperature depicted the hottest day in Karbala registered on 28 July 2020, according to IMOS. Hence, the main conditions of the climatology environments were 315º and 3.90 m/s for wind direction and wind speed, respectively. The minimum and maximum relative humidities were 24% (at 4 pm) and 36% (at 6 am). The simulation was Held for 24 hours. A pre-processing step of the district in AutoCAD was performed before commencing the work in ENVI-met. This software was able to reconstruct the entire district using a bitmap image as a base from the AutoCAD data. The model area f was calculated using a grid size with dimensions x, y, and z of 50, 50, and 20, respectively. This grid size is denoted in a grid cell of d_x, d_v, and d_z by 10, 4, and 2 m, respectively. The model has been twisted 45ºC based on building adjustments and typical streets for a dry environment.

3. Models Configuration

The study area was chosen because of its great importance since it gathers millions of people throughout the year, especially in times of religious seasons. Due to the increasing number of pilgrims and tourists annually, many urban changes have been made to the city. Changing urban morphology affects climatic factors, which, in turn, determine external thermal comfort [18]. The work concentrates on enhancing the outdoor thermal comfort for a 100,000 m^2 by simulating a particular urban region in the actual district of the holy city of Karbala during the hottest summer day. The height of the two shrines and dome are 12 m and 20 m, respectively, as presented in Figure 9. Table 1 shows the details of the finishing materials used in the study area for the proposed models.

Table 1. Finishing materials

Description	Model I	Model II
1. Middle yard between the two shrines	Dark concrete pavement	marble tiles
2. Roofs of the two shrines	Reinforced concrete	RC and glass in certain areas
2. Sheds	-	Steel
3. Floor of the courtyard of the two shrines	Marble tiles	
4. Roofs of the surrounding buildings	Concrete tiles	
5. Walls of the: • Two holy shrines • Surrounding buildings • Yard	 Bricks Bricks Bricks	
6. Streets that: • Surrounding the two shrines • Connecting yard	 Asphalt pavement Asphalt pavement	
7. Trees	Palm trees	

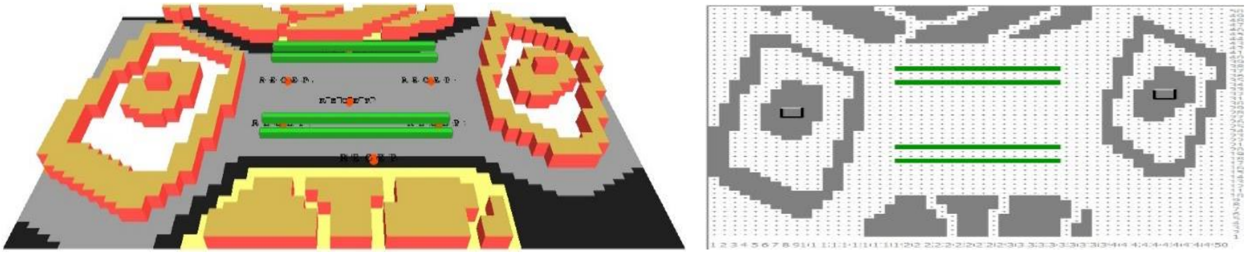
4. Results and Discussions

In this research, three scenarios (models) have been adopted. To reach the best thermal comfort area of the THS and *ATHS*, the proposed models were analyzed, evaluated, and compared. The first and second models represent the development stages of the study area, while the third model represents a research proposal to improve the results of the two models. In the suggested models, numerous phases were considered, such as adding shadows to the middle path for the *ATHS*. These shadows are in the form of a grid to preserve the visual extension and provide appropriate lighting. This area is characterized by a high crowd of pedestrians. The suggested model also includes adding trees in specific locations along the yard (Figure 10). The surface energy balance and the hydrosphere-atmosphere water vapor cycle are both influenced by tree transpiration. It is also the primary cause of the ecological effects of trees, such as cooling and humidification [19].

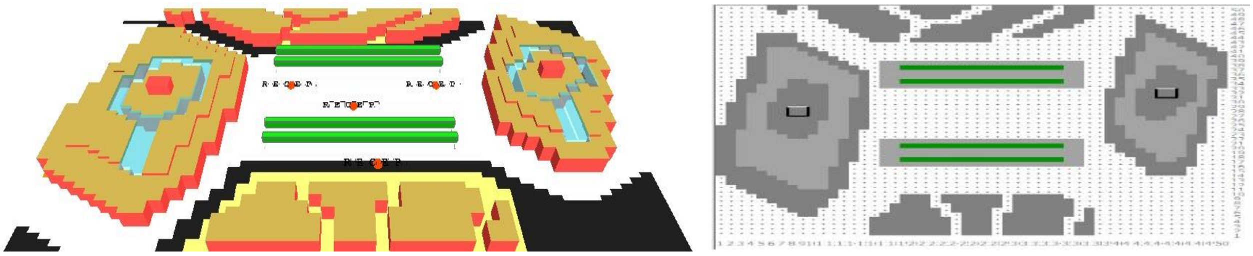
Figure 10. Palm tree

4.1. Model I and Model II

Model I represents the stage of constructing the first courtyard before adding shades and roofs for the ***THS***. Model II denotes the stage of adding shades and roofs. Finally, Model III is the suggested model for increasing the thermal comfort area. Based on the parameters lists such as building, clouds, and soil data, *ENVI-met* was applied to simulate the models. Figure 11 shows the input grid model for the district of the study area for Model I and Model II.



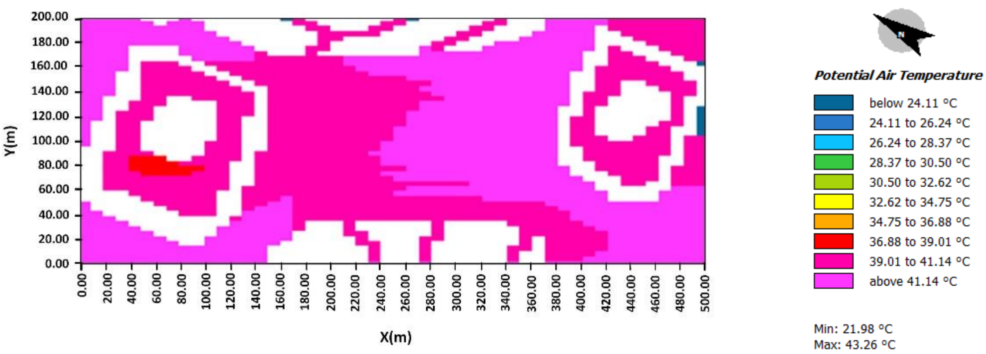
(a) Model I



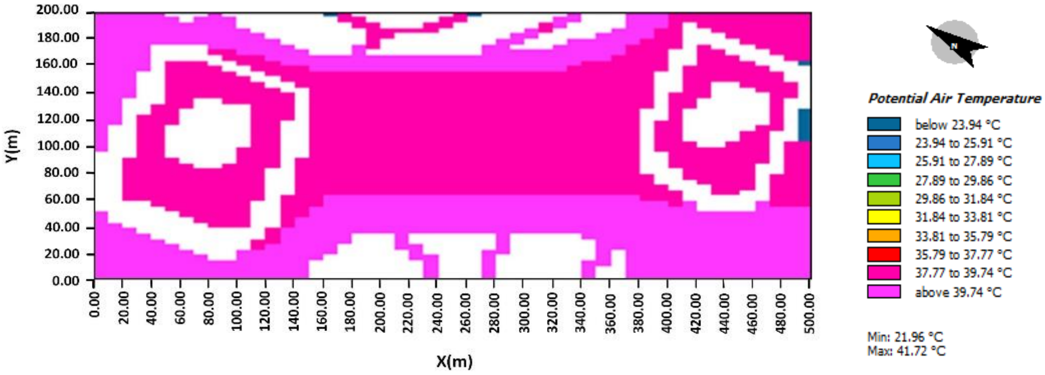
(b) Model II

Figure 11. Input grid

As mentioned previously, the real temperature at noontime was measured at 52 ºC. According to Figure 12, a reduction of about 2 ‑ 3 ºC was observed since the concentrated air temperature of the urban area ranges between 39 ºC and 41 ºC and 37 ºC and 39 ºC for Model I and Model II, respectively. This figure graphically depicts the temperature distribution at the height of 1.5 meters above the ground, which represents the human thermal sense level. We noticed that the lowest air temperatures were observed in the courtyards since the courtyards present an important part of the cooling system by reducing the air temperature.



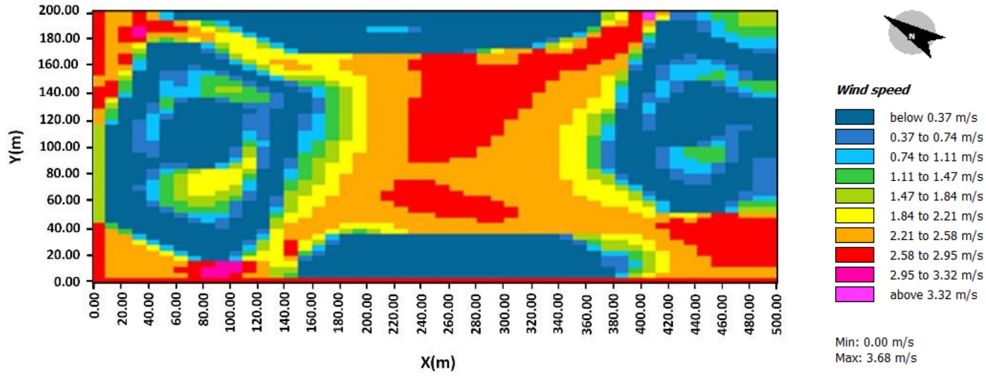
(a) Model I



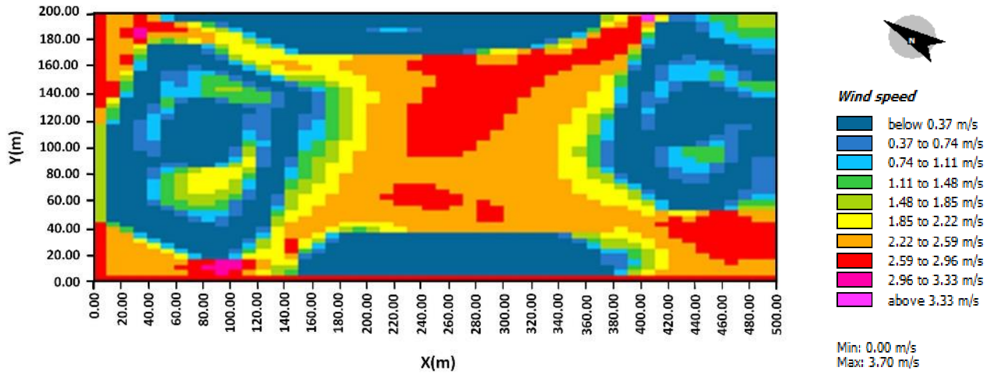
(b) Model II

Figure 12. Air temperature distribution

Due to variations in surface roughness, the wind speed of the urban layer is lower than that in the rural regions. The terms "urban canyons" or "sky view factor (SVF)", which are defined by the ratio of building height to street width, are generally beneficial because they enhance wind speed [20], which favors comfort and pollution dispersion. Because the average height of the buildings within the streets and blocks surveyed was approximately 30 m, the height-to-width ratio remained around 3, which did not result in a significant concentration on flow. The real wind speed that was used in the simulation of Model I and Model II was 3.9 m/s. It is observed from Figure 13 that the wind speed is around 2.2–2.9 m/s in the center yard area; this is due to the presence of vegetation, which causes the airflow to be obstructed. The lowest airspeed is recorded inside the shrine area, reaching 0.37 m/s. The SVF in the center of the ***ATHS*** yard ranges between 0.85–0.94.



(a) Model I



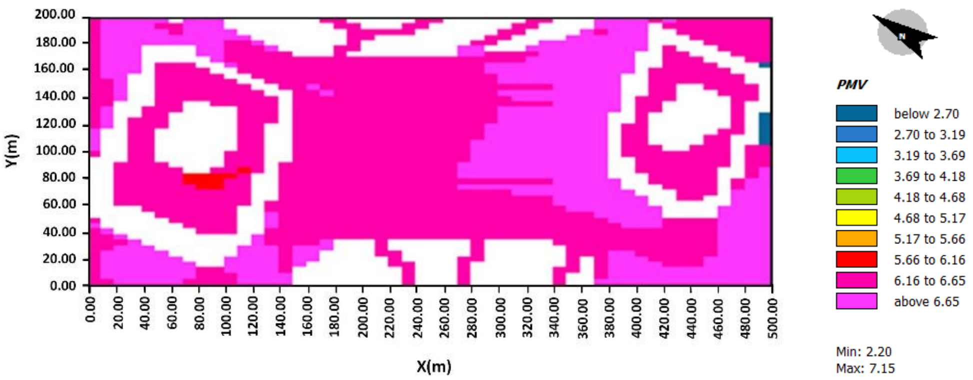
(b) Model II

Figure 13. The mid-day percentage of wind speed

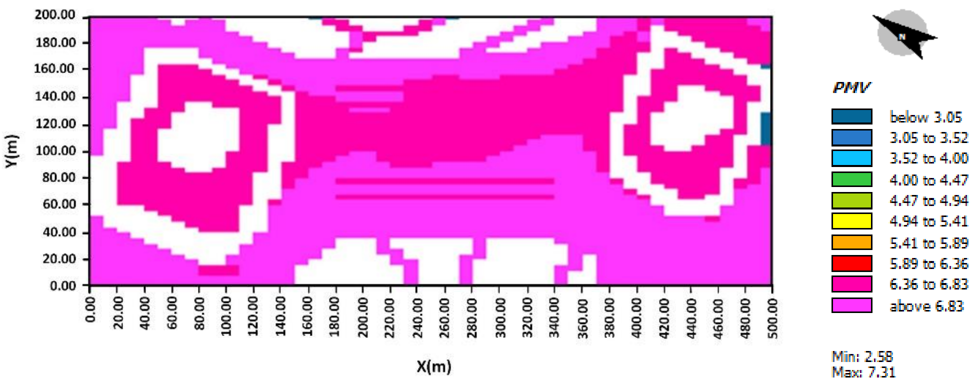
Thermal comfort refers to "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation [21]. A standard thermal index called PMV (Predicted Mean Vote) can be utilized to assess thermal comfort for a particular space and quantify its worth. Typically, the PMV can be expressed as extremely cold, extremely hot, and thermal comfort (neutral) with values of -4, +4, and 0, respectively (see Table 2). When the PMV equation is applied to outside situations under the stress conditions of summer temperature, high PMV values of above +4 ($\geqslant$+8) can be obtained [22]. The average rate of PMV of Model I in the courtyard area and part of the yard of ATHS averaged between 6.3 - 6.8, while the average in the rest of the yard and other parts of the site reached 7.3. Figure 14 depicts the PMV distribution for the suggested urban design at midday (12h 00 min). It is noticed that these results are similar to what [22] reaching. As the proposed treatments of shading and vegetation contributed to a decrease in the temperature, the wind speed, and also in the values of SVF, it led to an increase in the value of PMV, thus improving the feeling of thermal comfort.

Table 2. Thermal sense declarations (qualitative and quantitative) [23, 24]

PMV values	Thermal description
-4	Extremely hot
-3	Hot
-2	Warm
-1	Moderately warm
0	Thermal comfort
+1	Moderately cool
+2	Cool
+3	Cold
+4	Extremely cold



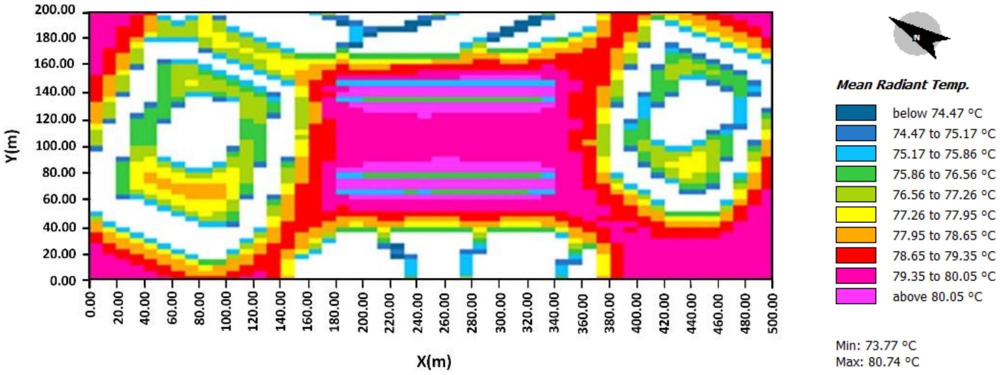
(a) Model I



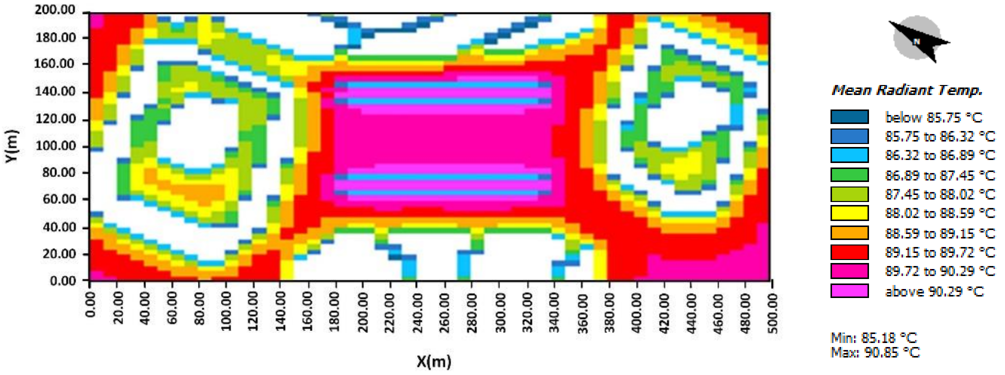
(b) Model II

Figure 14. Thermal comfort index as PMV

The results of the MRT (Mean radiant temperature) show a remarkable agreement for both models. For Model I, the MRT values are found between 79ºC to 80ºC at 12:00 pm, on Jul. 28th, 2020, as presented in Figure 15-a. Similar results of MRT values for Model II are recorded (Figure 15-b). It was observed that the shaded area (at trees) exhibits the lowest values of MRT below 85ºC. This temperature range, in general, indicates that exceptional thermal values would be performed during the day, leading to thermal discomfort for tourists and pilgrims, which causes unreasonable energy expenses to produce sufficient operational conditions. Therefore, it can be determined that the surface is resistant and asphalt-coated; however, the building's height plays a significant role in air cooling and providing thermal comfort for this region, as displayed in Figure 15.



(a) Model I



(b) Model II

Figure 15. Mean radiant temperature (MRT) at midday

According to the results shown through the models' analysis, several solutions are proposed to improve and increase the thermal comfort area. This was performed by adding some large shades, such as those used in the Prophet's Mosque in Madina city of Saudi Arabia (see Figure 16).

(a) Side view

(b) Top view

Figure 16. Shades of the Prophet's Mosque (Madina/Saudi Arabia)

4.2. Model III

According to the results shown through the models' analysis, several solutions are proposed to improve and increase the thermal comfort zone than what is found in Model I and Model II. The current section presents some proposals that aim to reach the desired purpose. The current study suggested adding shades to the movement path of the connecting yard between the two shrines (*ATHS*), such as those used in the Prophet's Mosque in Madina city of Saudi Arabia (see Figure 16). These shades are in the form of a grid in order to preserve the visual extension and provide appropriate lighting and ventilation since this area is characterized by a high concentration of pedestrians, especially during the visiting seasons. The proposal also includes adding several Sephora trees in specific locations of the ATHS, especially since increasing the tree coverage can significantly cool the outdoor thermal environment [25, 26]. Figure 17 refers to the input grid Model III for the study area. The grids resolution of x, y, and z are 50, 50, and 20 m, respectively.

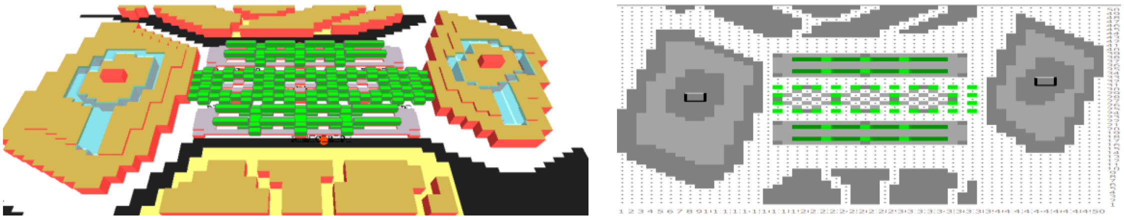


Figure 17. Input grid of Model III

Figure 18 shows the temperature distribution at a 1.5m height over the ground. The concentrated air temperature of the suggested urban area varies between 37℃–39℃ with a 2℃ decrease in air temperature. It was discovered by analyzing Model III that the yard's zone recorded the lowest air temperatures since the cooling system of the simulated urban area relies heavily on the courtyards, which decreases the air temperature.

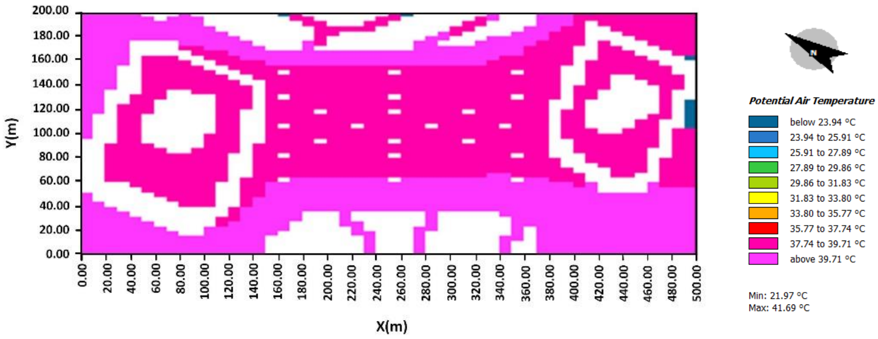


Figure 18. Distribution of air temperature for Model III

The results of the Model III analysis displayed the lowest airspeed movement in the shrines' nave area, where the wind speed reaches 0.37 m/s. It gradually increases to reach 1.4–2.2 m/s in the middle yard area, while the airspeed in the data entered for the model is 3.9 m/s. This change occurred due to the addition of shades and trees that serve as windbreaks. Figure 19 illustrates the wind speed distribution for the simulated study area.

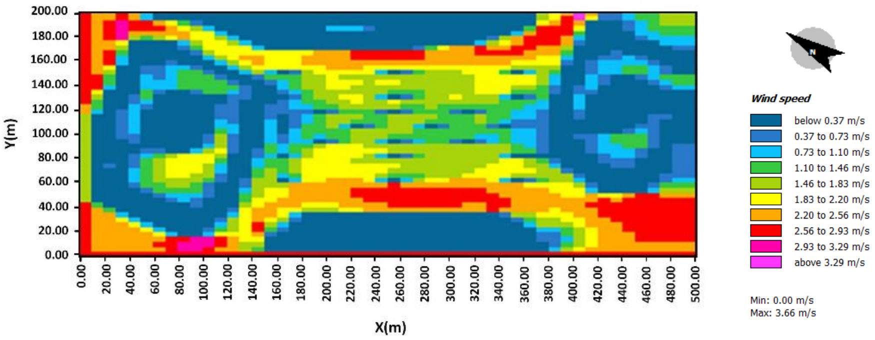


Figure 19. The midday percentage of wind speed for Model III

As a result of adding roofs and trees in the area connecting the two shrines, the thermal comfort areas were increased in this proposed model (Model III). In addition, this covers a larger area of the center yard compared to the previous models (Model I and Model II). The PMV distribution of the suggested urban design at midday is presented in Figure 20. The average value of PMV is between 6.3 to 6.8, and the areas of thermal least comfort have a max value of 7.3.

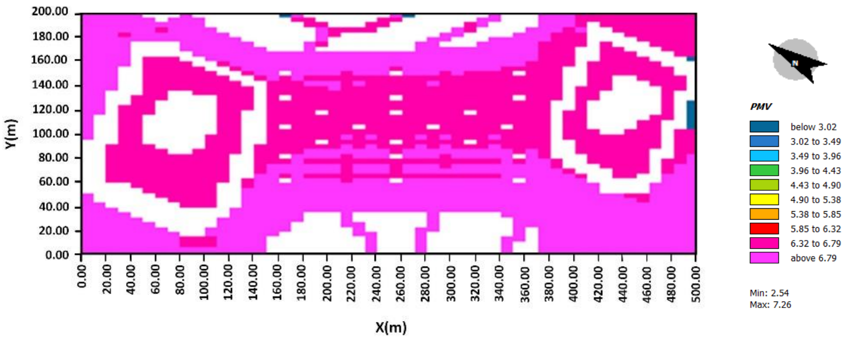


Figure 20. Thermal comfort index (PMV) for the proposed urban design (Model III)

Figure 21 presented the MRT distribution at 12:00 pm (midday) on Jul. 28, 2020. The results demonstrate that the lowest MRT of Model III was recorded in the areas of the trees and shades. Thermal radiation rates decreased in the middle part of the THS relative to the middle part of ATHS and its environs, which ranged between 83–85. The radiant heat values were lower in Model III than they were in the previous two models due to the addition of shades and Sephora trees, where the heat radiation rates in the shaded areas of trees reached 81ºC.

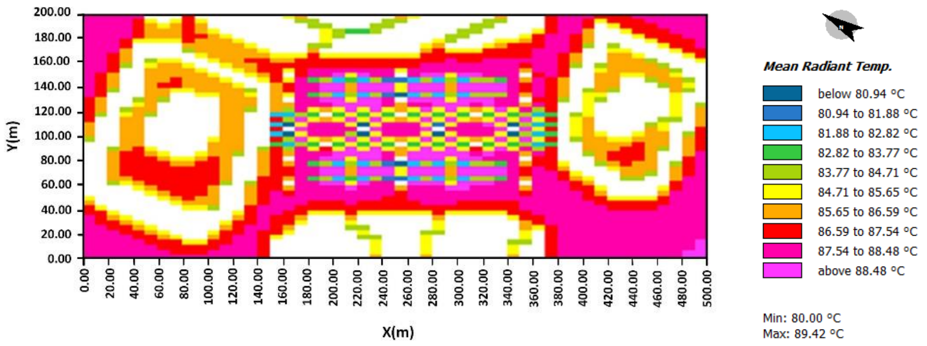


Figure 21. Mean radiant temperature (MRT) at midday for the proposed urban design (Model III)

As seen in Figures 22 and 23, the percentage of thermal comfort for the second model is higher than the first model. That is to say, the central yard's new finishing materials and paving contributed to an increase in the thermal comfort feeling. On the other hand, in comparison to the other models, the proposed model (Model III) showed an increase in the feeling of thermal comfort, which was a result of adding shades and trees (see Figure 24). The proposed model has the highest percentage of thermal comfort index of 18.53%, as compared with the other models (with values of 17.14% and 15.76%). Thus, the proposed model has an acceptable thermal comfort index.

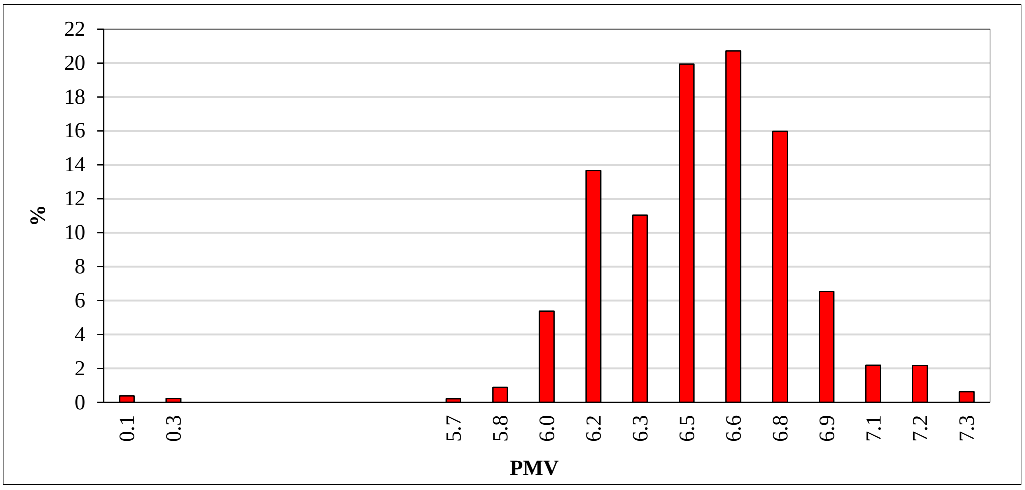


Figure 22. The percentage of thermal comfort indicator (PMV) for Model I

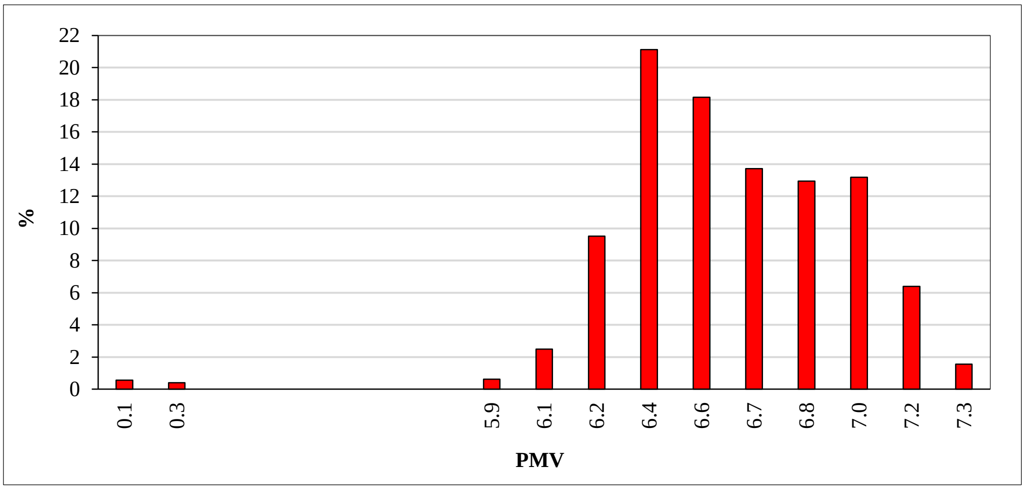


Figure 23. The percentage of thermal comfort indicator (PMV) for Model II

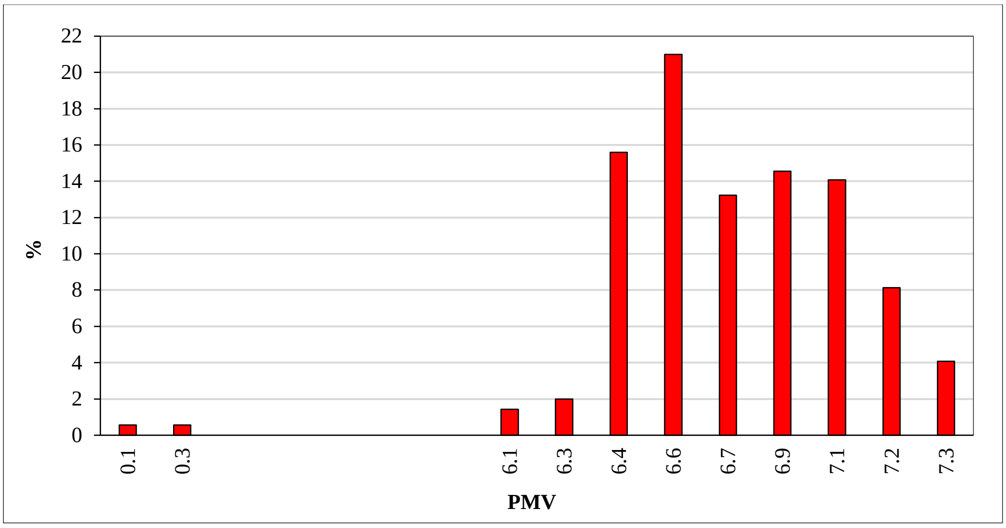


Figure 24. The percentage of thermal comfort indicator (PMV) for Model III

5. Conclusions

This paper improves the thermal comfort area by proposing adding several layers (e.g., trees and roofs) to the study area due to the high temperatures in this region. Therefore, the following points might be used to summarize the most important conclusions:

- The proposed models were utilized to provide an impression of the urban climate and identify the zones that need to be modified in the study area, with the goal of finding solutions to reduce the entropic impacts and improve the quality of life.
- In the proposed models, the temperature and wind speed for the chosen study area were simulated by using climate factors.
- Adding shade and trees to the middle path of Model III resulted in a decrease in the wind speed, Sky View Factor (SVF), and thermal radiation. However, an escalation was observed in the thermal comfort area.
- Using a white marble floor in the center of the THS and ATHS contributed significantly to reducing the temperature of the study area, since the input temperature was 51.8°C, while the temperature measured in the three models ranged between 38–40°C, i.e. a decrease of approximately 12°C.
- The highest average temperatures were recorded in Model I, and the temperatures were lower in Model II and Model III.
- Model I and Model II had the same average airspeed, while Model III had a lower average airspeed, indicating that adding shade and trees in the middle of the pedestrian movement path helped reduce airspeed.
- The average thermal comfort area was reduced in Model I since it covers a small area of the yard paths, while the same thermal comfort area was increased in Model II and Model III.
- Changing the type of paving concrete to marble and adding roofing helped in reducing the temperature by 2ºC and increasing the area of thermal comfort in the yard.
- The Sky View Factor (SVF) values were decreased in Model III compared to the previous models, particularly in the interior areas of the central yard due to the planting of Sephora trees and the addition of the shades.
- Since Karbala city is of great importance as it gathers millions of people throughout the year, especially during religious seasons, it is suggested to investigate the urban heat island values for the region.

6. Declarations

6.1. Author Contributions

Conceptualization, H.H.M. and A.N.H.; methodology, A.N.H.; software, H.H.M.; validation, H.H.M., A.N.H. and A.A.A.; formal analysis, H.H.M.; investigation; resources, A.M.H.; data curation, H.H.M.; writing—original draft preparation, A.N.H. and A.M.H.; writing—review and editing, M.M.H.; visualization, A.N.H.; supervision, A.N.H. and A.A.A.; project administration, H.H.M.; funding acquisition, A.M.H.. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Acknowledgements

The authors wish to thank the University of Baghdad for their help and encouragement.

6.5. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Taleghani, M., Tenpierik, M., & Van den Dobbelsteen, A. (2012). Environmental impact of courtyards-a review and comparison of residential courtyard buildings in different climates. Journal of Green Building, 7(2), 113–136. doi:10.3992/jgb.7.2.113.

[2] Ramadan, M. F. A. (2010). Interactive urban form design of local climate scale in hot semi-arid zone. Ph.D. Thesis, School of Architecture, University of Sheffield, Sheffield, United Kingdom.

[3] Brown, R. D. (2012). Book Review: Urban Microclimate: Designing the Spaces between Buildings. Urban Studies, 49(5), 1157–1159. doi:10.1177/0042098011435914.

[4] Md Meftaul, I., Venkateswarlu, K., Dharmarajan, R., Annamalai, P., & Megharaj, M. (2020). Pesticides in the urban environment: A potential threat that knocks at the door. Science of The Total Environment, 711, 134612. doi:10.1016/j.scitotenv.2019.134612

[5] Fahmy, M., & Sharples, S. (2009). On the development of an urban passive thermal comfort system in Cairo, Egypt. Building and Environment, 44(9), 1907–1916. doi:10.1016/j.buildenv.2009.01.010.

[6] Liu, N., & Morawska, L. (2020). Modeling the urban heat island mitigation effect of cool coatings in realistic urban morphology. Journal of Cleaner Production, 264, 121560. doi:10.1016/j.jclepro.2020.121560

[7] Farhan, S. L., Abdelmonem, M. G., & Nasar, Z. A. (2018). The urban transformation of traditional city centres: Holy Karbala as a case study. Archnet-IJAR, 12(3), 53–67. doi:10.26687/archnet-ijar.v12i3.1625.

[8] Hassan, A. K., & Yassin, S. M. Updating the urban plan of the status holy city center of Karbala. Iraqi Journal of Mechanical and Material Engineering, Special Issue (B), 321-333. (In Arabic).

[9] Alobaydi, D., Mohamed, H., & Attya, H. (2015). The Impact of Urban Structure Changes on the Airflow Speed Circulation in Historic Karbala, Iraq. Procedia Engineering, 118, 670–674. doi:10.1016/j.proeng.2015.08.501.

[10] Al-Khateeb, A. A. (1988). Geomorphology of Karbala hill. Doctoral Dissertation, Collage of science, University of Baghdad, Baghdad, Iraq. (In Arabic).

[11] Awadh, S. M., & Ahmad, L. M. R. (2012). Climatic prediction of the terrestrial and coastal areas of Iraq. Arabian Journal of Geosciences, 5(3), 465–469. doi:10.1007/s12517-010-0257-4.

[12] Alisawi, H. A. O. (2020). A sewer overflow mitigation during festival and rainfall periods: case study of Karbala. Applied Water Science, 10(12), 241. doi:10.1007/s13201-020-01323-y.

[13] Toudert, A. F. (2005). Dependence of outdoor thermal comfort on street design in hot and dry climate. Ph.D. Thesis, dissertation, Freiburg University, Freiburg, Germany.

[14] Ghaffarianhoseini, A., Berardi, U., & Ghaffarianhoseini, A. (2015). Thermal performance characteristics of unshaded courtyards in hot and humid climates. Building and Environment, 87, 154–168. doi:10.1016/j.buildenv.2015.02.001.

[15] Monam, A., & Rückert, K. (2013). The Dependence of Outdoor Thermal Comfort on Urban Layouts. In Young Cities – Developing Urban Energy Efficiency. Universitätsverlag der TU, berlin, Germany. doi:10.14279/depositonce-3701.

[16] Ozkeresteci, I., Crewe, K., Brazel, A. J., & Bruse, M. (2003). Use and evaluation of the ENVI-met model for environmental design and planning: an experiment on linear parks. Proceedings of the 21st International Cartographic Conference (ICC), Durban, South Africa, 10-16 August 2003, 402-409.

[17] Okpalike, C., Okeke, F. O., Ezema, E. C., Oforji, P. I., & Igwe, A. E. (2022). Effects of Renovation on Ventilation and Energy Saving in Residential Building. Civil Engineering Journal, 7, 124–134. doi:10.28991/cej-sp2021-07-09

[18] Eslamirad, N., De Luca, F., & Lylykangas, K. S. (2021). The role of building morphology on pedestrian level comfort in Northern climate. Journal of Physics: Conference Series, 2042(1), 12053. doi:10.1088/1742-6596/2042/1/012053.

[19] Tan, X., Liao, J., Bedra, K. B., & Li, J. (2022). Evaluating the 3D cooling performances of different vegetation combinations in the urban area. Journal of Asian Architecture and Building Engineering, 21(3), 1124–1136. doi:10.1080/13467581.2021.1903905.

[20] Li, G., Ren, Z., & Zhan, C. (2020). Sky View Factor-based correlation of landscape morphology and the thermal environment of street canyons: A case study of Harbin, China. Building and Environment, 169, 106587. doi:10.1016/j.buildenv.2019.106587.

[21] Chen, Y., Wang, Y., & Zhou, D. (2021). Knowledge map of urban morphology and thermal comfort: A bibliometric analysis based on citespace. Buildings, 11(10), 427. doi:10.3390/buildings11100427.

[22] Ridha, S. J. (2018). Effect of Aspect Ratio and Symmetrical Distribution on Urban Design in Baghdad City, and the Impact of Greenery Strategies on improving Outdoor Thermal Comfort. IOP Conference Series: Earth and Environmental Science, 151(1), 12035. doi:10.1088/1755-1315/151/1/012035.

[23] Pourshaghaghy, A., & Omidvari, M. (2012). Examination of thermal comfort in a hospital using PMV-PPD model. Applied Ergonomics, 43(6), 1089–1095. doi:10.1016/j.apergo.2012.03.010.

[24] Ridha, S. (2017). Urban heat Island mitigation strategies in an arid climate. In outdoor thermal comfort reachable, Ph.D. Thesis, Civil engineering, national Institute of Applied Science of Toulose (INSA de Toulouse), Toulouse, France.

[25] Zheng, S., Guldmann, J. M., Wang, Z., Qiu, Z., He, C., & Wang, K. (2021). Experimental and theoretical study of urban tree instantaneous and hourly transpiration rates and their cooling effect in hot and humid area. Sustainable Cities and Society, 68, 102808. doi:10.1016/j.scs.2021.102808.

[26] Gherri, B., Maiullari, D., Finizza, C., Maretto, M., & Naboni, E. (2021). On the thermal resilience of venetian open spaces. Heritage, 4(4), 4286–4303. doi:10.3390/heritage4040236.