Impact of Urban Heat Island on Thermal Comfort in the Outdoor Spaces of Residential Complexes: Insights from the Durrat Karbala Residential Complex in Iraq

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Abstract

It is well known there is a significant global climate change, resulting in rising temperatures and the emergence of subsequent urban heat island phenomenon. Many researchers have examined the negative impact of these changes on people. However, how they affect those who take evening walks have not been particularly looked at.

This research examines this issue in order to propose solutions to the problem of discomfort experienced by the residents of residential complexes due to high temperatures during the evenings. This phenomenon is known as the urban heat island phenomenon. Therefore, this research addresses a specific problem related to the urban heat island phenomenon and provide potential solutions to mitigate its negative environmental impact on people. The research assumes the possibility of achieving thermal comfort in the outdoor spaces of residential complexes by reducing the effect of the urban heat island phenomenon.

To achieve this, the research follows an analytical approach taking a case study of a residential complex: the Durrah Residential Complex, in Baghdad. It is a residential project in one of the areas suffering from the urban heat island phenomenon in Karbala Governorate in Iraq. A simulation model program “envi-met" was used to ascertain this thermal comfort in this specific area.

The research proposes a model with treatments that help improve thermal comfort in order to reduce the urban heat island effect. The results of the reality model and the proposed model were compared by using graphs and heat maps to evaluate the effectiveness of the solutions. The paper concludes that planting a type of tree called Sophora japonica with wide areas of shading contributed to lowering the temperature, reducing the speed of hot air movement, and increasing thermal radiation. This helps in cooling hot surfaces and increasing the feeling of thermal comfort, thus reducing the urban heat island in the open spaces. The results may be generalized to the other open areas of Al-Durrah Residential Complex

Keywords: Thermal comfort, PMV, TMRT, air temperature, W.S, ENVI-met simulation, UHI.

Introduction

The goal in designing outdoor spaces of residential complexes in hot, dry climate areas is to reduce the effect of the urban heat island phenomenon by increasing the feeling of thermal comfort. Many studies have proved the significant impact of green solutions in urban planning for environmental cooling, energy savings, and enhancement of human thermal comfort (Musa, et al., 2022). According to Zhicheng et al. (2023), in the 1980s, the environmental movement made a marked progress in the field of sustainable design, by employing research and strategic approaches. This has marked a move towards emphasizing traditional planning concepts and principles for countries with less dependence on technology and energy (Rizko et al., 2017).

In this context, this research examines the status of the outdoor areas of the Aldurra residential complex in Baghdad, using a simulation model. The objective of the study is to contribute to enhance the perception of thermal comfort in the outdoor areas of residential complexes where the urban heat island phenomenon is noticed particularly during the early hours of the night when people gather in open spaces.

The study employed existing analytical studies related to thermal comfort, urban heat island, and the various climatic factors that affect them to gather basic information. It conducted a simulation of a complex model inserting the data into the ENVI-met programme and evaluated the results in order to find the best thermal zone. It also looked at design standards for urban housing and identified their main elements. Thus, this will establish the basis for the development of outdoor areas in local complexes overall, with a specific focus on the open spaces of the Aldurra complex.

Theoretical Framework

The Urban Heat Island Phenomenon

Urban Heat Island (UHI) is a phenomenon that arises from the atmospheric conditions above urban centers due to the characteristics in their surfaces, which affect the local climate (Caseo et al., 2014). It has been noted that urban areas have relatively higher temperatures compared to their surrounding areas due to the phenomenon of heat storage and release by buildings, roads, and paved surfaces. These man-made structures have the ability to absorb and retain heat during the day, then releasing it gradually during the night. A large number of people in these spaces thus experience increased discomfort, necessitating increased energy use for cooling.

This is compounded by thermal energy released by air conditioning systems and the burning of fossil fuels by vehicles and industrial processes collectively which contribute to the top layer of the earth and atmospheric temperatures inside urban areas. According to Lowe, (2016), Li et al. (2016) and Bhargava et al. (2017), UHI has been found to have negative impacts on different aspects including human comfort, human wellness, ecology, urban climate, quality of air, and consumption of energy. Further, they also increase smog production in urban areas.

The concept of UHI was introduced by Luke Howard in 1820. It was then characterized as a macro-climatic phenomenon. In the year 1993, Michael and Aniello have conducted a classification of the UHI phenomenon, identifying two primary categories. One of these is the phenomenon known as the 'macro UHI', which manifests at a significant spatial extent. The second type of UHI is known as 'Intra UHI', and it is associated with lower spatial scales (Ruddell et al., 2020).

The extent of the UHI is determined by many factors. The size of a city is directly correlated with the UHI. Urban geometry, a term denoting the collective arrangement of buildings and the interstitial spaces inside urban environments, have a notable influence on many environmental factors such as wind speed, thermal absorption, and shading. Reduction of vegetation in urban settings is also recognized as a significant contributing factor to the amplification of the UHI effect.

In fact, this phenomenon is especially evident in places characterized by wide pavements, non-permeable surfaces and heavy building coverage, which limit evaporation and lead to high surface temperatures. The cooling effect of trees and plants on air and surface temperature is attributed to the phenomenon of transpiration, and to their ability to offer shade.

Moreover, urban materials provide high thermal emission due to their reflective nature towards sunlight. They also show a higher heat-storage capacity compared to soil covered with green vegetation in some regions, having the potential to store twice as much thermal energy. Heat is caused additionally by human activities, including but not limited to transportation, heating and cooling systems, the functioning of various equipment, and industrial processes. According to Bhargava et al. (2017), geographical locations and weather are two other factors that contribute to the generation of heat.

Generally, heat absorbed has the potential to be released as long-wave radiation after a certain period of time. The degree of absorption and reflection is dependent on the basic physical characteristics of ground surfaces, as well as the facades and roofs of buildings. Moreover, as Ridha (2017) points out, vegetation has a critical role in relieving the impact of radiation on the environment by absorbing direct radiation.

Urban Heat Island (UHI) Mitigation Strategies

The UHI phenomenon refers to a city subject to higher temperatures compared to its neighboring spaces. The approach of mitigating this is to achieve thermal balance in urban centers by improving heat waste and minimizing heat absorption. Many field experiments have been carries out to examine the measurement of energy saving resulting from the rising of solar reflection from roofs. According to Akbari et al. (2005), roofs with solar-reflective properties have lower temperatures when exposed to sunlight compared to roofs that absorb solar energy. In fact, Oke et al. (1991) suggest that the light colours commonly observed in equatorial structures may contribute to a decrease in heat absorption due to its higher albedo.

According to Naikaet al. (2021), an important strategy for reducing air and radiative temperatures and boosting thermal comfort in urban areas is the increase of plant cover. This approach includes providing some form of shade and transpiration. A recent study published in the United Kingdom has detected that the use of a mitigation approach has shown evidence of inducing a cooling effect on urban water, even when outside temperatures were more than 20°C.

However, this increased effect of cooling can be significantly expanded by accurate planning of urban design. It has been clearly established that cooling is influenced notably by the configuration of the urban regions. According to Hathwayet al. (2012), the number of streets and roads positioned beside the river, along with the increased vegetation on the river banks, contribute to enhancing the cooling ability consistently maintained over a larger area.

Use of cool roofing as a reduction method for the UHI phenomenon is seen as a cost-effective approach to decrease the energy required for cooling of constructions and buildings. Wafa et al. (2022) have examined residential buildings where different selected passive cooling roof systems have been used under hot and dry climatic conditions. This technology, it is reported serves as an active cool roof solution for reducing the absorption air temperature of heat pump external units located on the rooftops. Therefore, it also aids in minimizing the difference in temperature between the origin and output air of the heat pump during cooling operations.

In this connection, Haider et al. (1992) have conducted an initial estimate of the influence of climate on the reflecting properties of surfaces. They have used three-dimensional climatic models to examine the potential effects of urban surface changes on the immediate climate. A comparative analysis has been done between the results of a base case simulation for the Los Angeles basin and alternative scenarios where either the urban albedo or the vegetal coverings are increased. The results of these simulations show a promising chance to mitigate urban energy consumption and atmospheric pollution by using surface alteration measures, resulting in a potential reduction ranging from 5% to 10%.

They also posit that the utilization of high-albedo materials resulted in a reduction of solar radiation absorption by building and urban structures, hence maintaining cooler surface temperatures and reducing the intensity of long-wave radiation. Jamei, et al. (2015) have also observed that there is a notable increase in the thermal conditions felt by pedestrians when there is a decrease in the predicted mean vote (PMV) and the mean radiant temperature.

The Role of Outdoor Thermal Comfort Indicator in UHI Mitigation Strategies

It is noticed that there is a decrease in the average daytime mean radiant temperature, air temperature, and PMV values after the achievement of a new plan in Melbourne. Salata et al. (2015) have examined the most effective mitigation technique establishing vegetation, whereas the application of high albedo materials have proved beneficial for improving the micro-climate on surfaces with a high sky view factor. The influence of tree shadowing on human thermal comfort has been found to be significant, as indicated by Ridha (2017) who has focused on the physiologically equivalent temperatures (PET).

Vegetation and its Impact on Improving Thermal Comfort

As mentioned, vegetation has an important role in improving thermal comfort. The existence of vegetation plays a significant role in improving human thermal comfort, even in cases where its influence on temperature of air is minimal. In spite of many academics focusing on the reduction of air temperature, it is typically the radiant exchange that produces the greatest influence on thermal comfort in an arid, hot region. Presence of vegetation has a significant role in enhancing outdoor thermal comfort. This is achieved through two primary mechanisms: direct shading of people and the reduction of long-wave emissions from surfaces. Additionally, vegetation helps to limit the quantity of solar radiation reflected from these surfaces Shashua-Bar, L., et al. (2011). Based on a research examination, it has been shown that the main benefit of vegetation in a hot climate is its ability to provide shading, that way can be reducing the impact of heavy solar radiation through surface radiation savings Ali-Toudert, F. (2005). The existence of tree shade as a common approach of mitigating the effect of temperature on pedestrians, particularly in similar situations during the hottest time of the day. As a result, the research findings indicate that outdoor thermal comfort is significantly impacted by the long-wave and short radiation emissions related to human activities Ridha, S. (2022)

The Effect of Vegetation on Temperature

Evapotranspiration, as identified by Bowler, et al. (2010) is an important mechanism in urban greening that effectively mitigates high temperatures. This process facilitates the cooling of both the leaf surface and the temperature of the air around it through the release of trapped heat. Additionally, it has been observed that trees have the ability to intercept solar radiation, so mitigating surface and air warming through the providing of shade Oke et al. (1991) Many research about urban vegetation and different parks consistently supports the idea that vegetated areas within cities generally show lower temperatures compared to non-vegetated regions. According to Bowler, et al. (2010)**,** the presence of green spaces, particularly in the form of large parks with trees, has been found to enhance the cooling effect on daytime temperatures.

According to the results of Qiu (2017), it is proposed that the presence of vegetation and urban agricultural evaporation lead to a decrease in urban temperature ranging from 0.5 to 4.0°C. Furthermore, the results of a simulation by Haider et al. (1992) indicate that the presence of additional vegetation in urban areas may lead to a decrease in air temperature by about 2°C. under certain weather conditions and the potential for evaporation of soil-vegetation systems, there is a possibility for a reduction of up to 4°C.

Sophora Japonica.

The Sophora japonica tree is widely regarded as a good choice for urban landscaping. The Sophora shows a vertical growth pattern ranging from 40 to 60 feet in height, with a horizontal spread of 30 to 45 feet. This growth pattern results in the formation of a well-defined, round shape, characterized by a fine texture, even during the early stages of tree development (Figure 1). The plant has a notable rate of growth and shows resilience to urban pollution, high temperatures, and arid environments. The tree has an advantage for a sunlit and hard environment, ideally situated on soil that is characterized by its low density and high permeability. The tree has beautiful, greenish-white to yellow blossoms that are bloomed during the mid to late summer season, contributing to a good environment for an extended period of time (Azad,2016)

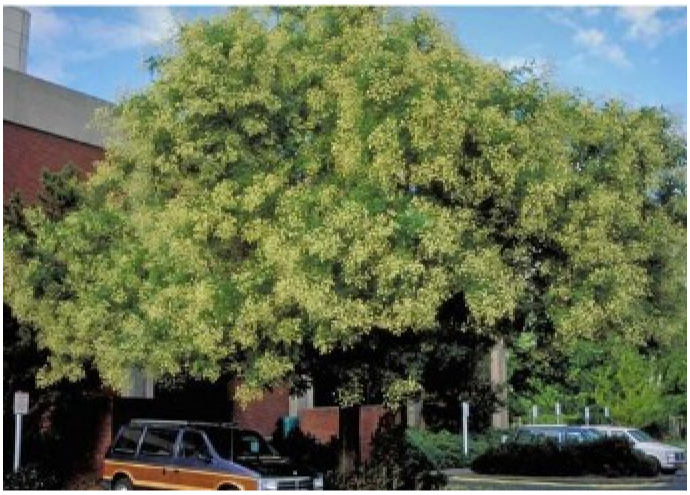


Fig. 1: Sophora japonica tree
Source: https://edis.ifas.ufl.edu/publication/ST592

Thermal Comfort

The concept of human thermal comfort refers to the psychological state in which persons experience relief with their thermal environment. According to Ridha (2017) the topic of thermal comfort has been a subject of discussion since the 1930s. Moreover, it is noted that there exist two different thermal comfort approaches, namely the model of steady-state and model of adaptive. The adaptive model is grounded in the theoretical framework for the ability of human body to naturalize to varying environmental conditions, both outdoors and indoors. According to Ghada (2016), thermal comfort can be understood as the result of the interplay between various factors including physical, physiological, cultural, and social dimensions. Thermal comfort is dependent on various factors such as architectural design, clothing choices, food choices, and climatic conditions. Discomfort can appear due to the difference in vertical air temperature between the lower limbs and the upper parts of the body, a dissimilar distribution of radiant heat, localized cooling by convection, or contact with a floor surface that is either very cold or hot (Peter,2022)

Thermal comfort is affected by numerous elements, which can be categorized into three different groups according to Auliciem, et al. (2007).

- Climatic parameters, including air temperature, relative humidity, radiation, and air speed, have an impact.
- Personal characteristics including metabolism (the chemical reactions in the body's cells that change food into energy) and clothes.
- 3-There are several elements that lead to this phenomenon, such as the influence of acclimation with the age and environment.

Mean Radiant Temperature (TMRT) is identified as the primary determinant influencing human thermal comfort within an outdoor urban environment Musa, H., et al. (2023). Moreover, TMRT is defined as the total quantity of long-wave and short-wave radiation fluxes that are absorbed by the body, so influencing the energy balance and the level of thermal comfort experienced by persons (Wang et al., 2014).

PMV index

The Predicted Mean Vote (PMV) is an indicator used for thermal comfort evaluating of outdoor environments by considering the heat balance and the actual temperature. Table 1 presents the PMV index, which is a representation of the average response of a big population, as expected by the thermal sensation scale adopted by Peter (2022). The PMV metric is utilized to evaluate the average thermal feeling of a general group of people inside an identified environment. According to Ridha (2017), the presence of gardens, trees, and vegetation in urban areas can lead to a reduction in the PMV index by around 0.5 units due to the capacity of multiple reflections occurring within buildings.

Table 1: PMV index
Source: Ridha, S., (2017)

Cold	-3
Cool	-2
Slightly cool	-1
Neutral	0
Slightly warm	+1
Warm	+2
Hot	+3

The PMV, or Predicted Mean Vote, is a mathematical function that relates to the local climate. In many cases, the PMV can exceed the range of [-4] to [+4], which is outside the limits of the original scale of experimental data. More information about the PMV can be found at http://www.model.envi-met.com/. Table 1 depict the distribution of (PMV) at midday. The PMV values show a significant elevation, surpassing +4 and reaching levels of +8 and beyond. Although this outcome is accurate in terms of numerical values (Ridha,2017) (http://www.model.envi-met.com/).

The PMV values are operationally defined as -4, representing a state of being very cool, and +4, representing a state of being very warm. A thermal comfort rating of 0 indicates a state of neutrality, as depicted in Figure 2. The utilization of the Predicted Mean Vote (PMV) equation for estimating outdoor thermal needs during periods of elevated midsummer temperatures can produce PMV values of +8 and above with considerable efficiency. From a mathematical standpoint, the results are considered to be accurate, even when they exceed the range of the actual Predicted Mean Vote (PMV) (Ridha,2017).

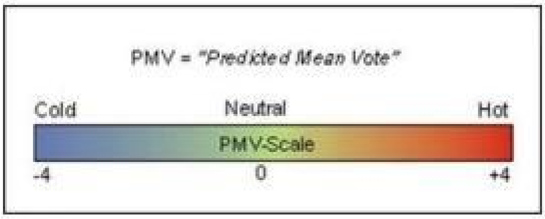


Fig. 2: The standard scale of PMV
Source: www.ENVI-met.com

Design Standards for Outdoor Spaces in Residential complexes

Since the early 2000s, there has been a significant increase in the development of residential cities on a global scale. The rapid growth of this emerging phenomenon can be primarily attributed to the expansion of urban populations and the occurrence of manmade problems. The World Health Organization (WHO) warrants that conditions of living in urban areas must be conducive to the health and well-being of their population Abdullah, et al. (2019) This requirement comes from the realization of a fundamental connection between the availability of outdoor spaces surrounding residential units within a district and the level of physical activity among inhabitants, basically aiming to enhance the quality of life within a healthful environment

The Concept of Urban Outdoor Space

According to Najah et al. (2022), urban open space refers to the land area that basically unblock, 'soft' surfaces such as soil, grass, shrubs, and trees" refers to all regions, regardless of public accessibility or general management, that are characterized by these specific features. The urban area includes many components such as parks, children's playgrounds, and other green spaces that are explicitly designed for recreational purposes. Moreover, it includes additional facilities such as automobile parking facilities and streets (Adolphe,2001).

The neighborhood, as a fundamental urban structure, serves as the social framework within which persons gain achievement and establish. The impact of neighborhood characteristics on citizens' quality of life has been examined in multiple research (Batty,2013).

Moreover, it is suggested that the level of satisfaction with one's neighborhood serves as an arrange factor in the overall state of personal welfare, so serving as a foundational element in understanding the overall standard of living. The authors also often highlight that numerous aspects related to the living environment play a role in determining population contentment, and these factors can be categorized as physical and social characteristics. Within the field of housing, the term housing extends beyond just shelter. It includes the availability of social infrastructure that enhance various sides of residing in individual habitations, including access to facilities such as shops, schools, and open spaces. Moreover, it encompasses the provision of physical infrastructure, such as roads, electricity, water, security, waste disposal, and communications (Lee, et al. 2020). Therefore, when it comes to the design or occupancy of a residential unit with the goal of maximizing happiness, it is important to maintain a harmonious balance between environmental quality and various necessary factors that contribute to well-being. One such factor is the maintenance of environmental balance (March, 1975).

The concept of sustainability has developed as a notable term in the field of environmental enhancement, in addition to the concept of a new planning model. The term in question is mainly linked to the concept of sustainable development, which include the harmonious coexistence and interplay between humans and their surrounding environment. In the field of housing, sustainable development refers to the harmonious progress of social, economic, and environmental objectives. This consists of integrating infrastructure technologies and facilities development with the long-term vision of eliminating poverty and achieving local economic development goals (Costanza, et al.1997). From a general perspective, environmental quality can be got in the field of urban planning. Residential satisfaction refers to the subjective evaluation of the overall quality of life experienced by those residing in a particular housing unit. Authorities of urban planning typically include open areas, green spaces, and playgrounds as essential components for necessary infrastructure of the development for new urban districts. This is done to ensure the well-being and overall health of the population residing in these districts. The insufficient availability of open spaces inside urban neighborhoods, along with their substandard quality, can significantly block the overall well-being of the people. This limitation prevents the care of healthy lifestyles, such as engaging in outdoor activities, walking, and recreational pursuits.

Design Standards for Urban Housing in Iraq

The locating of the Sun's position relative to any given place on the Earth's surface is established through the utilization of the azimuth and elevation angles. These parameters are influenced by various elements including the specific date, time, and latitude.

Both angles are significant factors in determining the orientation of a building, with a preferred orientation of 35 degrees towards the north being generally seen suitable for buildings in Iraq.

In Iraq, the sun's largest and smallest angles of rising occur at noon on June 22nd, measuring 78 degrees. On December 22nd, at noon, the temperature reached 31 degrees.

According to the Iraqi Urban Standards, optimal orientation for structures in the dry hot zone is recommended at 35° East South. Conversely, for buildings located in the humid hot zone, specifically the southern part, the most suitable orientation is advised to be at 15° East South (Nibras et al.,2019).

Orientation indicators and climatic treatments are factors that play a major role in architectural design. The angular position of the sun relative to any given place on the surface of Earth is commonly referred to as either the azimuth angle or the zenith angle. The consideration of date and time is a crucial factor in building orientation standards. In Iraq, the azimuth angle factor is seen to be 35 degrees in the direction of the north. The determination of the highest and smallest angle of the year is derived from a calculation that takes into account certain factors.

1. The sun's position at noon on June 22 is seen to have an elevation angle of 30 to 78 degrees
2. The optimal orientation for buildings within this region is determined to be at an azimuth angle of 35 degrees eastward from the southern direction.

Fig. 3: Climatic zones in Iraq
Source: The Urban Housing Standards

The orientation of buildings in the hot and humid southern region, characterized by high temperatures and humidity levels, is a critical consideration.

1. The solar azimuth angle at the noon hour on December 22nd is 31.30 degrees.
2. The optimal orientation for buildings is achieved when they are positioned at a 15-degree angle eastward from the southern direction.

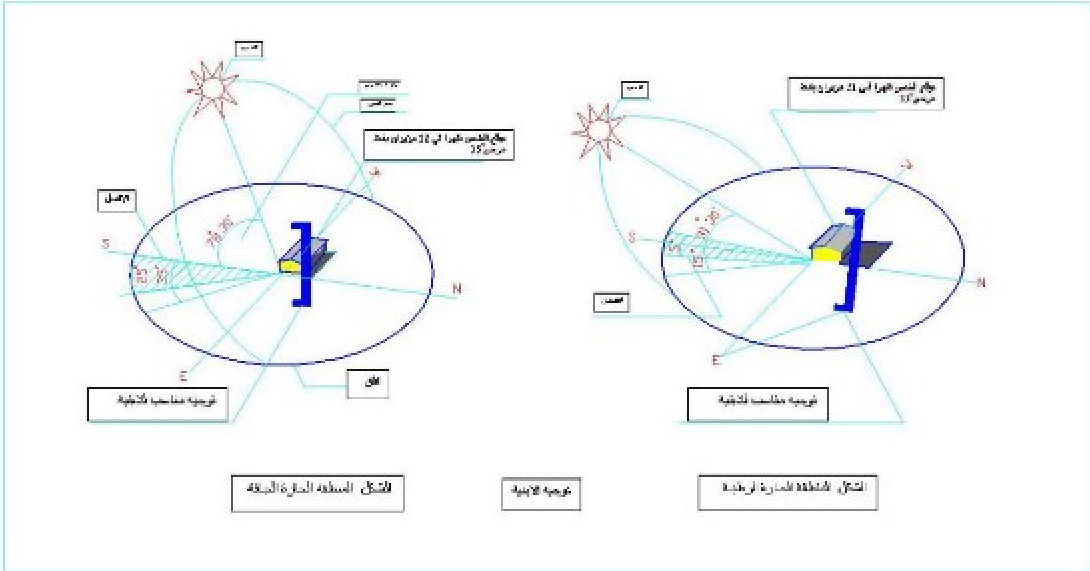


Fig. 4: Orientation of the building according to zoning
Source: The Urban Housing Standards

The Urban Housing Standards publication of October 2010 includes a report by the state commission of the Housing/ Studies Section, which highlights the significance of outdoor spaces as follow:

1. Playgrounds specific for youngsters aged 6 to 11 years old.
2. Sport squares are specific areas intended for teenagers between the ages of 12 and 18 to engage in physical activities.
3. The founding of community parks to take care of the needs of all residents.

Each category of these open spaces or facilities should be strategically planned, accurately developed, and good classification based on age groups. The consideration of the highest distance between blocks and various types of activities is also accounted for, as outlined in the Table 2.

Table 2: Planning indication for open spaces in new project of housing undertaken in Iraq
Source: The Urban Housing Standards

Type of public Service buildings	Age of the users	Area (Meters square / person)	Land area square meters)		Maximum distance from residential Units (meters)	Access way
			Stadium area	Total area		
field to play	Children (6-11) years	0.75	600-900	400-600	200-300	intersection with sub streets allowed
Sports area	Youth (12-18) years	0.50	900-1500	600-1000	500-800	intersection with main streets allowed
Parks. Car parking. Sports area	All residents	5.00	-	-	800	intersection with main streets allowed

The primary objective of this study is to find out whether the new projects of residence fit with the criteria of open spaces outlined in the regulations of Iraq. Moreover, the study aims to evaluate the validity of the suggesting assumption for the notable reduction of compliance with these criteria in the new residential projects. It is important to note that places within the design were identified; nevertheless, they were determined to be inaccessible due to their considerable distance from the residence, rendering them impractical for usage by the families. Moreover, certain spaces were designated exclusively for garden purposes, further limiting their accessibility.

Literature Review

During the past decades, urbanization and the dramatic increase in urban populations have increased the urban heat island effect. As a result, researchers have paid more attention to the causes of the urban heat island effect. Many studies have dealt with the problem of the urban heat island and its relationship to the feeling of thermal comfort at different levels. However, there are only few studies on the effects of urban heat island on specific spaces.

Some of them considered this phenomenon as a tool that helps the urban designers to accomplish the task of designing urban spaces, as Mohammad et al. (2023) have outlined. They have conducted systematic evaluations and thematic analysis of published papers and scientific research show that according to the studies, climatic elements and city-building factors influence urban heat island. Sunlight, wind speed and direction, cloud cover, soil and air humidity, precipitation, latitude, seasonal change, topography, and nearness to rivers and the sea have been identified as climate influencers. Although these elements are almost uncontrollable in existing cities, they are critical in locating new cities and defining their developments. However, the second element category is controllable and is associated primarily with city planning and construction. Indeed, recognizing the significance of these factors can explain the importance of urban planning and design in reducing the effect of urban heat island.

In contrast, Zhengtong, et al. (2023) have examined the urban heat island phenomenon and its effect on the feeling of thermal comfort. They look at the variation patterns and location distribution characteristics of UHI in New York, and summarize the seasonal temperature distribution characteristics, employing a formula to calculate a thermal discomfort index. They also measure the effect of UHI on human sensory thermal comfort. The results show that the surface temperature in the study area has generally shown a slow upward trend over the last 20 years. In July, for example, maximum and minimum temperatures had risen by 3.2 and 4.1 degrees Celsius, respectively. At the location scale, majority of the heat island areas in the study area were concentrated in the New York City cluster, particularly between May and October, when the effect was especially noticeable. The temperature map has sdisplayed clearly high temperatures. Between June and August 2020, the human discomfort index (DI) has increased in comparison to 2001. Land use map shows that as the city grows, people's DI indexes rise, and the proportion of people who are disturbed by heat rises to 50%. Except for the New York City cluster, the rest of the state was comparatively thermic-free. This finding indicates that too much urban development concentration has a negative impact on residents' quality of life.

Thus, the combined impact of climate change and urban heat islands on the human discomfort index, must be considered while adjusting the local high temperature and thermal field area through meaningful planning, increased greening, and the use of building technology to make cities more livable.

On the other hand, Nida et al. (2023) have discussed how to use urban landscaping to reduce the urban heat island effect. They have conducted a review of literature to define the significance of urban gardening for heat island mitigation. They have also conducted a spatial analysis to measure the land surface temperature in order to better understand the benefits of urban gardens in densely populated areas. According to previous research, enhancing urban gardening to citizens can be an effective strategy for increasing the proportion of green space required for a healthy urban environment. It is clear that urban gardens help reduce the heat island effect by providing thermal comfort, lowering flood risk, and saving energy for building architects. They suggest policymakers to develop strategic plans to achieve practical urban gardening as an urban heat source.

At the same time, Kubilay et al. (2021), mitigation measures for urban heat islands and their impact on pedestrian thermal comfort are presented, beside a multiscale coupled model that enables detailed analysis of the local impact of urban heat island mitigation measures. To account for dynamic heat and moisture storage in the built environment, the model employs coupled computational fluid dynamics (CFD) simulations with unsteady heat and moisture transport (HAM) in spongy urban materials. During a heat wave, an actual case study is conducted for a public urban square in Zurich. The effects of two different mitigation strategies, namely adding artificial moistening to pavements and adding vegetation, on pedestrian thermal comfort are evaluated and compared. In both conditions, the results show an improvement in thermal comfort. The improvement caused by the addition of trees is larger and lasts longer due to the shadow effects, despite the fact that trees reduce ventilation and increase relative humidity, which has an adverse effect on thermal comfort.

Notably, some studies have dealt with the effect of street tree diversity and urban heat island effect too. For example, Rendon, et al. (2023) have looked at the possibility that higher diversity within street trees may offer greater cooling benefits than less diverse urban forests. In this connection, it is claimed that the urban forests of California are among the most diverse in the world and offer an opportunity to test the relationship between diversity and cooling at a large scale. For 136 urban ZIP codes, they connected the most comprehensive data to date on California's urban forests to both local station and satellite weather data for the period 2010–2018. They have tested whether biodiversity, measured by the Shannon-Wiener index and the new Top Diversity 50 index, is correlated with extreme heat in summer. After controlling for local averages in weather and tree canopy cover, it has been found that urban forest biodiversity is associated with lower maximum and higher minimum temperatures from June to September. Their specifications make it unlikely that reverse causality drives the result. Instead, they suggest that greater tree species diversity may boost daytime cooling through several pathways, including mutualism and greater aboveground biomass, a mechanical relationship where greater biodiversity implies a greater likelihood of having species with excellent shade, and cooling benefits from structural diversity in urban settings.

It is argued that the effect of the urban heat island phenomenon on the feeling of thermal comfort in the outdoor spaces of residential complexes is critical to the functional performance of those spaces. However, from the foregoing research, it is clear that this has not been addressed as a mitigation strategy. This study is thus conducted in an effort to shed light on this type of space and identify appropriate environmental treatments to improve the feeling of thermal comfort in them by reducing the effect of urban heat island phenomenon.

Research Methodology

A lot of research has been undertaken about urban heat island effect and its relationship with thermal comfort from different points of view. However, the effect of the urban heat island phenomenon has not been addressed on the feeling of thermal comfort in the outdoor spaces of residential complexes. This is despite the importance of them for comfort and as gathering areas for the residents of residential complexes and in which many recreational and social activities are practiced.

In this research, the analytical approach is used. A simulation was done for one of the selected residential complexes in the hot, dry region in Karbala, Iraq by creating two models: the first one represents the reality of the situation, while the second is a proposed model with environmental treatments. Data inserted to these two models were gained by field visits to the Aldurra residential complex as well as from the National Investment Commission. Climate data was obtained from the Iraqi Meteorological Organization and Seismology (IMOS), where the hottest days within the last ten years are identified to perform the simulation. An analysis of the results is made to show the efficiency of the treatments in reducing the urban heat island phenomenon to improve the feeling of thermal comfort. A flipchart depicted in the Figure 5 provides an illustration of the study framework.

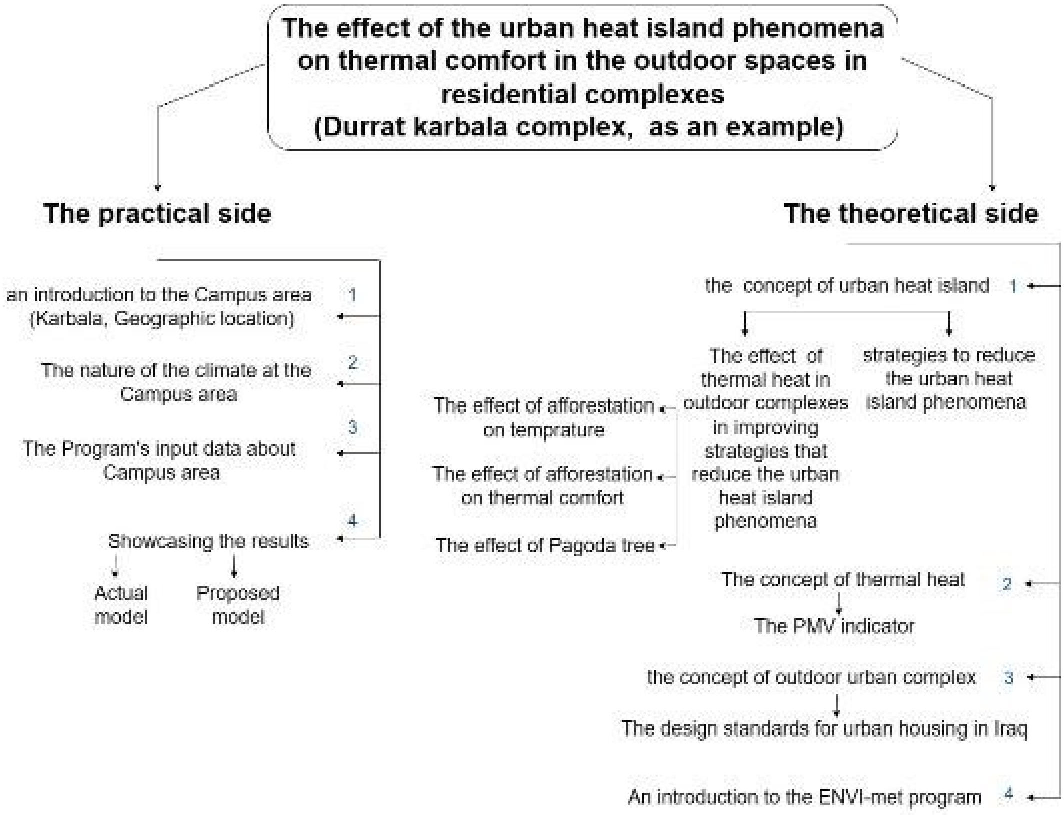


Fig. 5: Representation of the methodological approach followed using the ENVI-met program.
Source: Authors

Karbala: The Geographical Location

Karbala is situated in close proximity to the transitional boundary separating stable and unstable geological platforms. The city is situated around 92 kilometers Southwest of Baghdad, the capital of Iraq, within the geographical coordinates of Longitude 44.03700-44.03200 to the East and latitude 32.61800-32.61560 to the North Al-Khateeb, (1988), as depicted in the Figure 6. The climatic conditions in the region closely look like those of a western desert climate, as indicated by the analysis of climatological factors. The climate of Iraq is characterized by hot and arid summers, as well as cold and rainy winters (Awadh, et al. 2012).

Fig. 6: Location of the Karbala Governorate in Iraq
Source: Awadh et al., 2012

Durrat Karbala Residential Compound

Durrat Karbala's residential investment project is located in the neighborhood adjacent to the Saif Saad neighborhood (Southeast of the city) and is considered the closest investment project to the heart of the city (National Investment Commission, Iraq).

- The project consists of 1,260 housing units (houses) in an integrated complex with services on a land area of (660,000) square meters.
- It is distinguished by the fact that it is built on the latest international models, where the single house consists of a raft foundation, columns, bridges, and concrete ceilings to give the housing unit durability and a long building life, and it is characterized by being finished with good architectural finishes.
- It is characterized by containing (135,000) square meters of green spaces, which makes the project an environment-friendly project
- The work is carried out by the Turkish Marmara Company.
- Cost of the project is (180) million US dollars.
- The project contains residential units with an area of 200 square meters, with a land area of (10*20), two floors, and a building area of 170 square meters. The house contains a hall, kitchen, living room, three bedrooms, and four bathrooms.
- A house with an area of 220 square meters has a land area of (20x11). It is of two floors, and a building area of 190 square meters. Each house consists of a hall, a kitchen, a living room, three bedrooms, and four bathrooms.
- A house with an area of 300 square meters has a land area (12 x25). It is of two floors, and a building area of 260 square meters. Each house contains a hall, a kitchen, a living room, four bedrooms, and four bathrooms.
- A house with an area of 400 square meters has a land area of (20x20). It is of two floors and a building area of 350 square meters. Each houses contains a hall, a kitchen, a living room, five bedrooms, and six bathrooms.
- In addition to the above, the project also consists of a number of service buildings, such as Mosques, primary and middle schools, kindergartens, daily shopping centers, swimming pools, and public parks

Fig. 6: Location of Karbala Governorate in Iraq
and Location of Durrat Karbala in the Governorate
Source: Authors.

Climate in the Study Area: Karbala, Iraq

Karbala shows a hot desert environment characterized by extremely high temperatures and arid conditions throughout the summer months, but winters are quite good. While there is no specific month that can be considered widely wet, the period from November to April accounts for the majority of the total yearly heavy rain. The average weather conditions in Karbala have been determined by an analysis in statistical way of past weather hourly data and model simulations spanning from January 1980 to December 2016 (Alisawi,2020)

The city of Karbala experiences a long summer characterized by high temperatures, high heat and dry conditions with absence of cloud cover. Conversely, the Winter season is marked by low temperatures, minimal humidity, and generally cloudless sky. The yearly temperature shows a range of 6°C to 44°C, with infrequent appearance of temperatures below 2°C or above 47°C. According to Figure 7, the optimal periods to engage in warm-weather activities in Karbala are during the months of April, May, September, and October. The average of daily maximum temperatures over the cool and hot seasons are greater than 38°C and lower than 21°C, respectively. The duration of the hot and cool seasons spans around 3 to 9 months, specifically from May 25th to September 23rd, and 3 to 4 months, specifically from November 23rd to March 3rd. The months of July and January are characterized as having the highest and lowest temperatures of the year, respectively. During the hot season, the average high temperature is 44°C, while the average low temperature is 30°C. Conversely, during the cool season, the average low temperature is 6°C, while the average high temperature is 16°C. It is noteworthy to indicate that 51.80ºC was employed for the purpose of simulating the proposed models. The temperature measured on July 28, 2020, as documented by the Iraqi Meteorological Organization and Seismology (IMOS), denoted the highest temperature observed on that day.

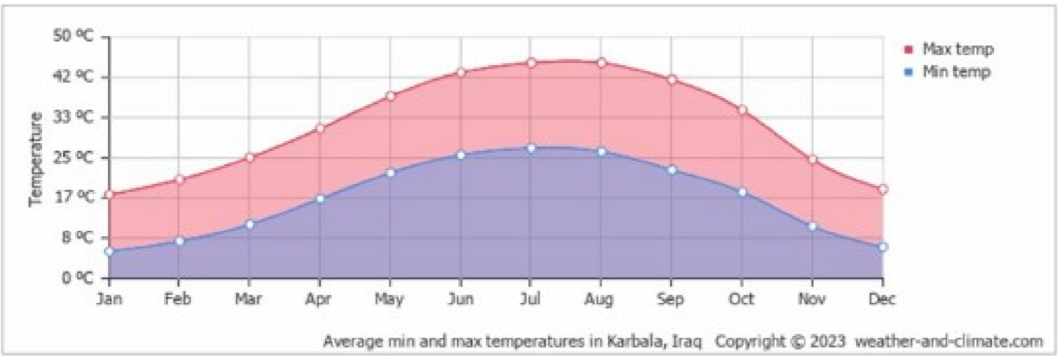


Fig. 7: Climate summary of the study area,
Source: www.weather-and-climate.com, (2022).

Envi-Met Model

ENVI-met is a microclimate simulation software especially useful for studying open areas and how they are affected by wind turbulence, vegetation, adjacent urban structures. And how these factors end up affecting the area's microclimatic features such as pollutant dispersion, impact upon the ecosystem, and bioclimatology in general, these calculations are done with the accordance of a list of factors (including structures, clouds, and humidity for example). This data is inputted sequentially as an hourly, daily, or weekly time series. To lobe later processed in accordance with the program's internal logic.

The Trustworthiness and reliability of the ENVI-met program for simulating outdoor spaces has been shown in many studies, showing that the results of the simulations have matched locally extracted meteorological data (Ridha, 2022). Other studies such as Alitoudert & Mayer have also validated the simulation by studying several streetscapes with a focus on PET (physiologically equivalent temperature) and human thermal comfort. Although they also found that the result to be somewhat overstated, the error seeming to be a product of higher-than-expected radiation fluxes and focused on wind speeds, the simulation has been cross validated through air temperature comparisons, in which ENVI-met showed to produce accurate results accurate average air temperatures and diurnal amplitude. ENVI-met were shown to be accurate in measuring the effect of aspect ratio and symmetrical distribution on urban design in Baghdad city, and how greenery strategies affect the general thermal comfort of the city.

Data Entered into the Program

The data utilized in the simulation of the proposed model was provided by the Integrated Marine Observing System (IMOS). As previously stated, the temperatures selected to simulate the suggested models were 51.80ºC at 4 pm as the maximum temperature and 24.8ºC at 6 am as the minimum temperature. According to the IMOS, the temperature recorded on 28 July 2020 at Karbala represented the highest recorded for that day. Therefore, the primary parameters characterizing the climate conditions were a wind direction of 315º and a wind speed of 3.90 m/s. The relative humidity ranged from a minimum of 24% at 4 pm to a maximum of 36% at 6 am. The simulation was conducted over a duration of 24 hours. Before the beginning of the work in ENVI-met, a step of pre-processing was conducted in AutoCAD.

The software successfully achieved the reconstruction of the district by using an image with bitmap destination as the foundational reference, alongside the AutoCAD data. The dimensions of the grid used to calculate the model area were x = 50, y = 50, and z = 40. The grid size is represented by a grid cell with dimensions of 2 m in the x-direction (dx), 2 m in the y-direction (dy), and 2 m in the z-direction (dz). The model has undergone a rotation of 35º, taking into account building changes and the characteristics of typical streets in a dry climate.

Model Configuration

The research site in Karbala was based on its suitability as a model for the common climate conditions in Iraq. Karbala is located in the central Euphrates region, serving as a geographical tie that connects the climatic characteristics of the western, northern, and southern regions within the country. The area under study proves a significant density of residential units and is distinguished by its large green areas. A section of the apartment complex that is distinguished by its streets, homes and green areas was chosen as the study's model see fig (8,9). The difference between the two models is planting a type of trees that is characterized by providing wide areas of shading is called Sophora japonica instead of grasses in the green area of chosen site. The following table illustrates the finishing materials utilized in both of the reality and the proposed model.

Table 3: Finishing Materials
Source: Authors.

Description	Model I	Model II
walls	Brick walls	Brick walls
roofs	Concrete tiles	Concrete tiles
Streets	Asphalt pavement	Asphalt pavement
greening	grasses	Sophora japonica

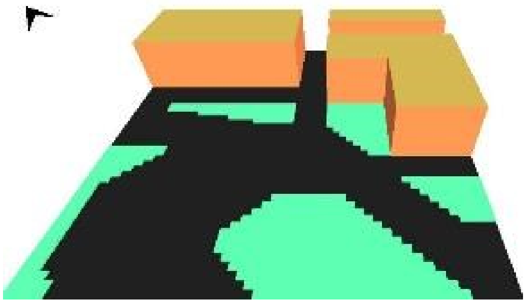


Fig. 6: Reality model drawing by ENVI-MET
Source: Authors.

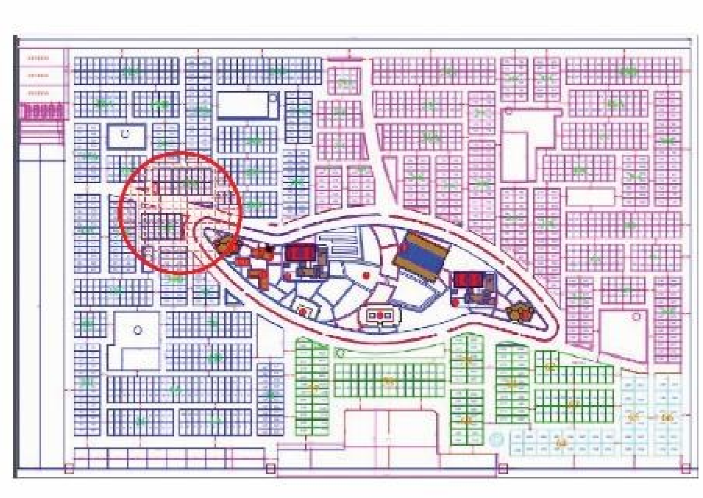


Fig. 7: Site Plan of Durrat Karbala and the zone representing the study area
Source: Authors.

Review Results of the Reality Model

The assessment of indicators related to the urban heat island phenomenon is often performed after 9:00 PM. The primary factors impacting this phenomenon include temperature, radiant heat, wind speed, and thermal comfort factor. Within the context of the reality model framework, the factors indicated before can be delineated as follows.

Table 4: the results of the reality model
Source: Authors.

indicator	min	max
Air temperature	40.5	41
TMRT	33	36
Wind speed	0.4	4
PMV	3	4

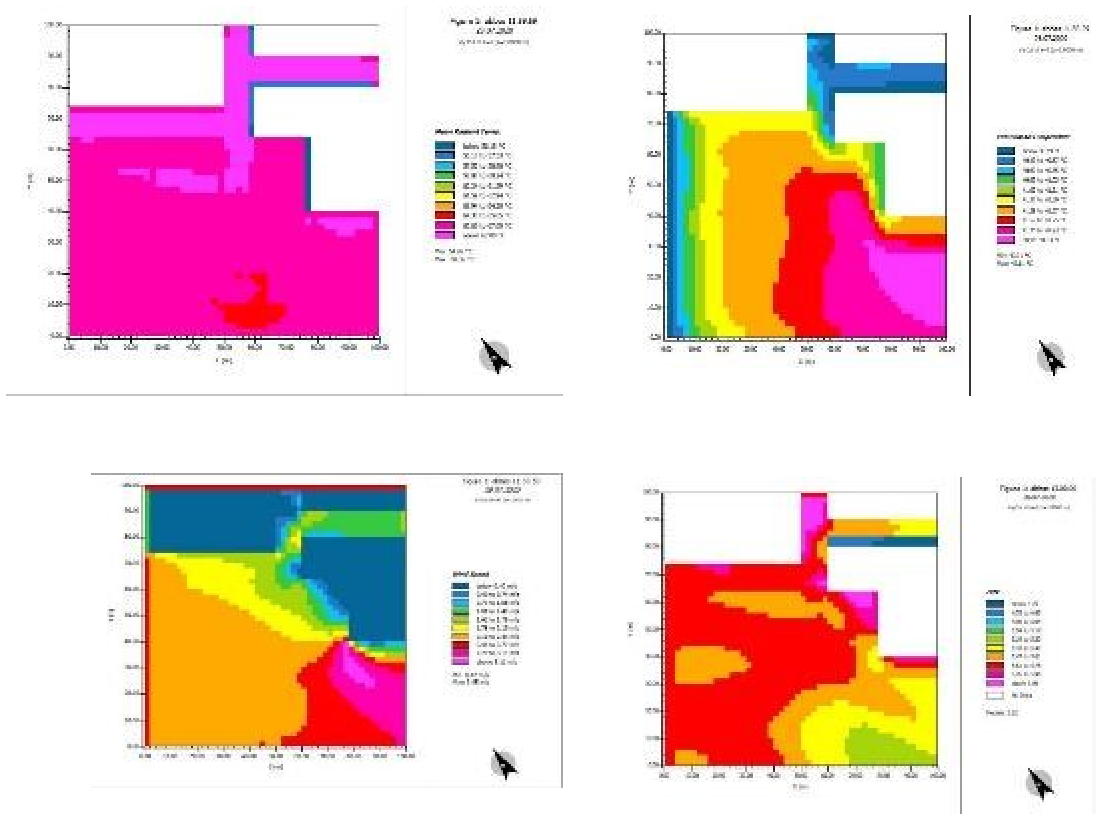


Fig. 8: Results charts of simulation of the reality model.
Source: Authors.

Review Results of the Proposed Model

Thermal comfort values recorded a noticeable improvement, ranging from (1.2-3) in addition to an increase in thermal radiation, which reached to (40) and a decrease in wind speed (0.1-3.4) as shown in the attached table and figures.

Table 5: The results of the proposed model
Source: Authors.

indicator	min	max
Air temperature	40	41
TMRT	33	40
Wind speed	0.1	3.4
PMV	1.2	3

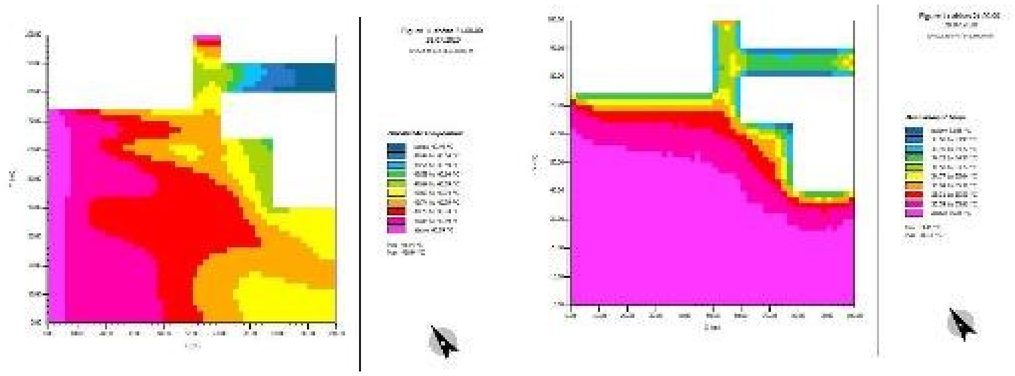
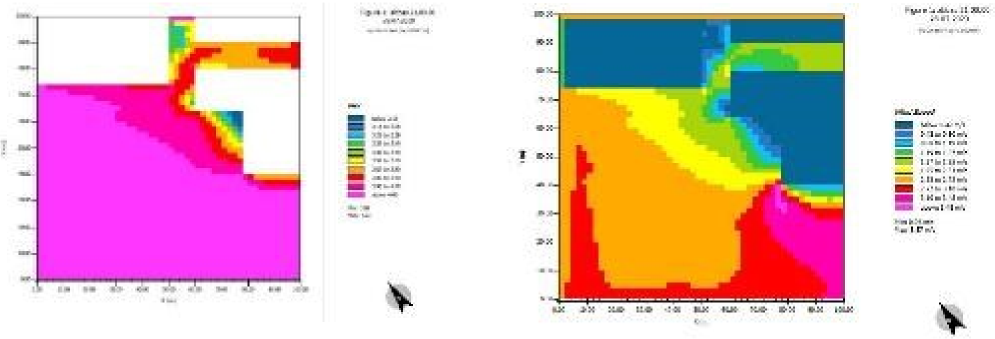


Fig. 9: Results of the simulation - the proposed model.
Source: Authors.

Comparison and Conclusion

From the review of the results of reality and proposed models, the following can be noted (Fig. 10):

- Lower temperatures are acquired in the study area in the proposed model compared to the reality model.
- An increase in the radiant temperature is recorded in the proposed model in comparison with the reality model, which means an increase in the ability to get rid of latent heat gained throughout the hot hours of the day



- A decrease in wind speed in the proposed model is noticed due to the presence of trees, that act as windbreaks which reduces the feeling of hot air as in the reality model.
- A noticeable decrease in the thermal comfort index can be observed in the proposed model compared to the reality model.

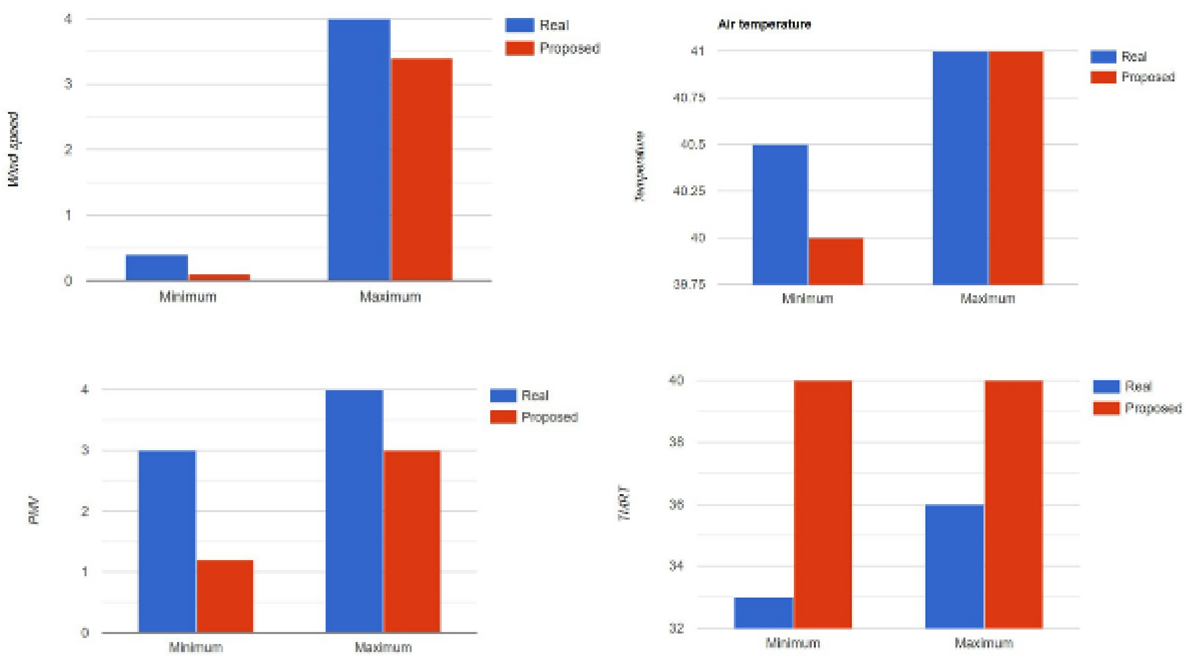


Fig. 10: Results of the comparison between the simulation of real and proposed models
Source: Authors

From these results, it can be concluded that the using of an umbrella tree such as Sophora japonica in the proposed model helps in the reduction of the urban heat island phenomenon. It improves the sense of thermal comfort in the study area which comprise the open spaces in the Al-Durrah Residential Complex. These results can be generalized to the rest of the open spaces in the complex and to all residential complexes in the governorate.

Recommendations

The most important design factors based on the study result, which can be used for reducing the effect of the urban heat island in the outer spaces of the residential complexes in a hot dry climate are as follows:

- The use of shaders, mainly on the busy roads.
- Increasing green spaces and the use of short, green, and umbrella plants instead of palms, which are tall and give little shade.
- Becoming aware of all of the above and caring for the outside spaces ranging from crowded roadways to residential gathering places actively contributing to the functional performance of the residential complex.

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