Evaluating the achievement of sustainable ecological neighborhood indicators using the ENVI-MET simulation program

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Abstract

Climate change and the sharp rise in temperatures pose a significant challenge to urban settlements in arid regions, particularly in the absence of effective environmental planning standards. This study aims to evaluate thermal comfort as a planning indicator for sustainable ecological neighborhoods within the built and open environments of urban settlements. The methodology employed three-dimensional digital simulation using ENVI-met software, a three-dimensional simulation tool used to study and analyze microclimate in urban environments. The software allows for the evaluation of environmental interactions between buildings, vegetation, and surfaces to predict phenomena such as heat islands and improve outdoor thermal comfort. Key environmental indicators were modeled at peak solar radiation. These indicators included latent air temperature, mean radiant temperature (MRT), wind speed, sky view factor (SVF), and the predicted mean temperature (PMV). The simulation results revealed environmental degradation in the Abu Khalid neighborhood of Najaf, where temperatures jumped from 42.9°C at noon to approximately 48°C in the afternoon.

Keywords: Ecological neighborhood, thermal comfort, ENV-MET program, Najaf city

Introduction:

Urban sustainability is a comprehensive planning framework that seeks to strike a balance between environmental, social, and economic aspects in a way that ensures the sustainability of resources and improves the quality of life for residents (Farr, 2008, p. 12). A sustainable neighborhood is viewed as an integrated urban unit that aims to provide a highly efficient residential environment by integrating urban land uses with natural elements and strengthening the interconnections between various activities within the neighborhood (Wong & Yuen, 2011, p. 24). With the increasing impacts of climate change and rising temperatures in cities, thermal comfort has emerged as one of the key indicators for assessing the quality of the outdoor environment and the effectiveness of urban planning, as it reflects the state of thermal equilibrium between humans and surrounding climatic factors. Studies also confirm that improving the morphological characteristics of residential neighborhoods and incorporating shading elements and vegetation directly contribute to lowering temperatures and improving local climatic conditions (Shashua-Bar et al., 2009, p. 181). This research focuses on studying the impact of sustainable neighborhood principles—particularly compact urban structure and integration with nature—on enhancing thermal comfort within the residential environment. The Abu Khalid neighborhood in the city of Najaf al-Ashraf was selected as the study area because it is located in a hot, dry climate that requires specific planning and environmental measures to reduce heat stress and improve the quality of the outdoor environment. The research also relies on the ENVI-met software to simulate climatic interactions within the neighborhood and measure the impact of planning variables on the local climate, through the analysis of established scientific indicators such as the Predicted Mean Vote (PMV) and the Equivalent Physiological Temperature (EPT). The research aims to assess the extent to which the neighborhood's planning characteristics can achieve acceptable levels of thermal comfort in accordance with international standards, thereby contributing to a scientific framework that can be utilized in the planning of future residential neighborhoods in Iraq.

1. Sustainable Neighborhoods

Sustainable residential neighborhoods seek to meet the diverse needs of current and future residents, including their children and other users. These neighborhoods contribute to improving quality of life by providing opportunities and choices (Hagla, p. 2, 2008; Khalid). The residential neighborhood consists of a residential area comprising four blocks and up to 1,600 – 2,440 housing units, as shown in Figure 1. Residents can meet their daily needs within walking distance from their homes to public facilities such as education, shopping, social and cultural services, religious buildings, healthcare, recreation, sports, and other amenities, as well as public transportation stops (Chapter 4, Section 6—Urban and Rural Housing Standards for 2018). The average household size is 6 people, and the average residential neighborhood population ranges from 1,4400 to 9600 (2010 Urban Housing Standards Manual) Thus, the neighborhood's area consists primarily of the area of residential units, plots of land designated for public activities and open spaces at the neighborhood level, and pathways for pedestrians and vehicles, including parking spaces (Chapter 4, Section 12—Urban and Rural Housing Standards for 2018). A sustainable residential neighborhood is based on the integration of urban activities and nature, so that the relationship between people and the environment becomes complementary rather than competitive. Figure (2) in this study illustrates the evolution of the residential neighborhood concept from the traditional "Neighborhood Unit" proposed by Perry, through the principles of New Urbanism, to the concept of the sustainable neighborhood, which incorporates environmental, energy, and sense-of-place dimensions. (Ahlam, 2017, p. 134)

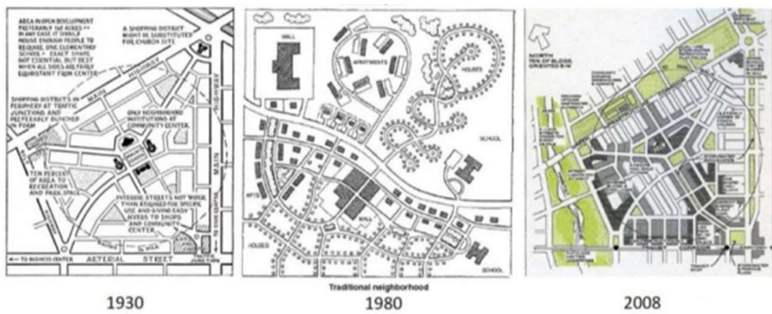


Figure 1 illustrates the evolution of the concept of the residential neighborhood within the traditional neighborhood unit

Source (Dinep & Schwab, 2010 Designing the Future of Communities .New York: John Wiley & Sons.p23)

2-1-Principles of a Sustainable Neighborhood :

The principles of a sustainable neighborhood are based on achieving a balance between environmental efficiency and the quality of urban life through the adoption of integrated ecological planning that relies on appropriate urban density and mixed-use development, thereby limiting urban sprawl and reducing the need for long-distance travel. (Cegielska et al., 2024, p. 7) A sustainable neighborhood is also based on the principle of integration with nature by incorporating green infrastructure into the urban fabric to enhance land-use efficiency and achieve environmental sustainability (Eco-City Alexandria Report, 2015, p. 12). Green infrastructure is a key component, providing interconnected networks of parks, green corridors, and green roofs, thereby supporting biodiversity and improving the local climate. Furthermore, a sustainable neighborhood prioritizes sustainable transportation by giving precedence to pedestrians and public transit and reducing reliance on cars, which helps lower emissions and create a healthier urban environment. It also relies on integrated resource management that includes the use of renewable energy and the recycling of water and waste, thereby promoting consumption efficiency and reducing environmental impact. (Cegielska et al., 2024, p. 7)

3-1-Thermal Comfort

Thermal comfort is defined as the mental state that expresses satisfaction with and acceptance of the thermal environment surrounding a person. It is a subjective state that varies from person to person based on physiological and personal factors, and it is achieved when thermal equilibrium is established between the human body and its surrounding environment, such that the body feels neither cold nor hot. (Abdel-Aal, 2018, p. 40) The human body possesses mechanisms that enable it to maintain thermal equilibrium with the external environment. It produces amounts of thermal energy through its vital functions, which correspond to the body's activity level and remain within the permissible thermal range that does not exceed the internal body temperature (37°C) whether the person is at rest or engaged in physical activity. The process of thermoregulation depends on the balance between heat gained and heat lost; any increase in one over the other places additional strain on the body's thermoregulatory system to maintain an appropriate temperature, and any change in this temperature poses a threat to the person's health and even their life. Therefore, the body must dissipate excess heat through processes such as evaporation from the skin or lungs, or through radiation or conduction, until it reaches a state of natural equilibrium. If, however, the body's thermal energy decreases relative to its surrounding environment, it performs these vital functions by providing the necessary energy. (Hong, T., 2024, p. 3). The human body's thermal equilibrium depends on two main groups of factors:

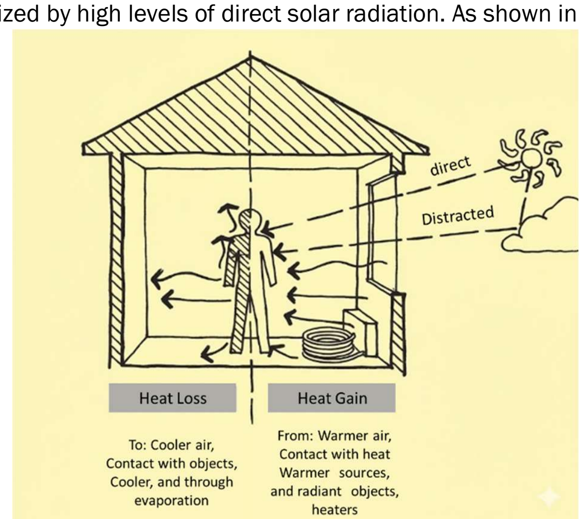
First: Climatic factors, which are factors related to the atmosphere surrounding a person and directly affect how they gain or lose heat. These include:
Temperature: The temperature of the surrounding air.
Radiation: Radiative heat exchange between the body and surrounding surfaces (such as sunlight or the coolness of walls).
Humidity: The amount of water vapor in the air, which affects the body's ability to dissipate heat through the evaporation of sweat.
Wind: The movement and speed of air, which plays a major role in cooling the body through convection.
Second: Intrinsic factors, which are biological and personal factors that determine the amount of heat the body produces or its ability to insulate itself and maintain its thermal balance:
Activity (level of exertion): The nature of the movement or work a person performs (whether at rest or exerting effort).
Clothing: The type of clothing worn and the level of thermal insulation it provides to the body.
Acclimatization: The body's ability to adapt to and become accustomed to a specific living environment over time.
Gender: Physiological differences between males and females in metabolism.
Health status: The efficiency of the body and its vital systems in managing thermal stress. (Ahmed Abdullah, 2008, pp. 88–92)

1-3-1 Climatic Factors Affecting Thermal Comfort

Climate has a direct impact on an individual's life and is considered one of the most important factors influencing human existence, behavior, and habits. (Abdullah S. Salman, 2023, p. 11) Although there are many factors—some internal and others external—that affect human activity and comfort either individually or collectively, humans continue to respond to changes in climatic conditions to varying degrees and in diverse ways, depending on age, gender, activity level, type of clothing, and diet on the one hand, and on the extent to which they are affected by and respond to these changes on the other. The physiological functions of the human body respond to changes in climatic factors to regulate body temperature and maintain a constant core body temperature. Therefore, it is essential to understand the climatic factors that influence thermal comfort, which are as follows:

1-Solar Insolation

Solar radiation is one of the most important factors in the climatic environment and has the greatest impact on the thermal behavior of objects and surfaces, thereby influencing the local climate, especially in hot, dry regions characterized by high levels of direct solar radiation. As shown in Figure (2)



source: / https://rercenter.uoanbar.edu.iq:Figure 2 illustrates the effects of solar radiation on humans

2- Temperature:

Air temperature affects the thermal equilibrium that occurs between the human body and its environment, as well as the extent to which the body reaches a state of thermal comfort (Abdullah S. Salman, 2023, p. 12).

3- Relative Humidity:

The range of humidity generally considered comfortable for humans is between 20% and 80%. If humidity falls below 20%, a person begins to experience constant thirst and severe skin dryness regardless of the temperature. Low humidity in the air also causes cracks in the nasal mucosa. If humidity exceeds 80%, evaporation becomes difficult for the human body because the air is saturated with water vapor.

4- Air Movement:
Air movement contributes to thermal comfort; although it does not result in a significant change in temperature, it increases heat loss through convection, especially when the air is cooler than the skin, This is because when the human body loses heat to the air in contact with it, the temperature of that air rises upon contact with the body. Air movement displaces the warm layer near the body and replaces it with cooler air, thereby creating a feeling of comfort. (Mahmoud A. Eissa, 2009, p. 34)

4-1-Indicators for Achieving Thermal Comfort in a Sustainable Ecological Neighborhood
There are several important indicators that help achieve thermal comfort in a sustainable ecological neighborhood, including :

Compact Urban Structure :
Urban Mass Density: By analyzing the urban mass density of the Abu Khalid neighborhood, we found it to be 51.2%, calculated using the urban mass ratio formula :

Urban Area Ratio = (Urban Area) / (Total Area) * 100%

When compared to the standard stipulating that density should be 40–60% (Neufert, E. 2012), it falls within the specified range.

Land-Use Diversity: This indicator refers to a mix of residential, commercial, educational, cultural, and administrative functions, which are integrated in a specific combination at a density appropriate for the urban area and varying from one location to another. This mix enables living, working, and shopping in a single location. Mixed-use areas are considered highly efficient in terms of infrastructure utilization and in meeting all the community's needs (Anderson, 1991, p. 53).

It can be calculated using the statistical formula for Simpson's coefficient as follows: $D = 1 - \sum (n/N)^2$ where D is the diversity coefficient.

Sustainable Mobility
A. Accessibility: The concept of accessibility is one of the characteristics of a well-functioning city or urban area, and it is considered one of the fundamental pillars that enhance a place's vitality. This concept provides a framework for understanding the interrelationship between transportation and land use, and it includes a measure of opportunities—or the ease with which people can access goods, activities, services, and destinations. Accessibility is considered one of the key metrics in this regard and reflects how close a specific location is to various destinations (Litman, 2017, p. 6) and how to reach those destinations. The multiplicity of destinations individuals seek, depending on their varying needs, creates a certain degree of travel confusion for users; ease of access to various services helps reduce the confusion people experience, Furthermore, accessibility as a mobility indicator is linked to land-use indicators in that environment, as it addresses the proximity of residential areas to other destinations within a distance that is acceptable for pedestrians and cyclists (Rode & Floater, 2014, p. 4).

B. Connectivity: This is expressed by dividing the number of intersections by the area of the region in hectares. It is a measure of the extent of connectivity within the transportation network and the ease of travel from one place to another. High connectivity in street and road networks increases direct links and shortens distances between trip origins—which are typically residences—and destinations for various uses (work, shopping, and recreation), thereby enhancing interconnectivity and functional integration among them (Sallis et al., 2004, p. 252)

Integration with Nature
This refers to the incorporation of natural elements into people's daily environment to enhance their psychological and physiological well-being. This includes the use of green roofs and walls, providing direct views of natural landscapes, and using local and sustainable building materials. (Kellert et al., 2011, p. 12)

Integration with nature is achieved through :

Orientation
Orientation is the determination of a building's angle or the alignment of urban spaces and streets relative to the cardinal directions (north, south, east, west) to maximize the benefits of natural conditions (sunlight and prevailing winds). (Al-Obaidi, 2018, p. 66)

A. Orientation to Reduce Solar Heat Gain:
In hot and dry regions (such as the climate of Iraq), it is preferable to orient the longitudinal axis of buildings and streets from east to west. This orientation reduces the exposure of long facades to the scorching sun in the early morning (east) and afternoon (west), while facilitating the shading of south- and north-facing facades. As shown in Table 1

B. Orientation to Take Advantage of Winds:
Planning integrates with nature by orienting streets and open spaces at an angle ranging from (20 to 45 degrees) with the desired prevailing wind direction (such as the northwesterly winds in Iraq) to allow air to penetrate the urban fabric and cool outdoor spaces through natural ventilation, while avoiding orientations that face directly into dusty or dry winds. (Al-Obaidi, 2018, p. 67)

Shading

Shading is the intelligent management of blocking direct sunlight from urban surfaces (facades, streets, walkways) during the hottest hours of the day, while allowing natural light to penetrate. It is divided into two complementary types, including natural shading such as trees and vegetation: the use of dense shade trees and green corridors to shade street surfaces and pedestrian walkways. Trees play a dual role; they block solar radiation and lower the temperature of the surrounding air through transpiration and evaporation, as shown in Table 1. (Lechner, 2014, p. 44)

-4Reducing Energy Consumption

This is achieved through thermal shading, a preventive planning tool designed to block direct solar radiation from urban surfaces and spaces. This indicator reduces the heat gain of built-up areas, thereby effectively contributing to the mitigation of the local climate and lowering surface temperatures in hot and dry regions. Shading in a sustainable environment is achieved through a compact urban structure and green infrastructure that provides natural shade for walkways. The effectiveness of this indicator is measured in the study by analyzing shading using the ENVI-met simulation software to ensure the protection of pedestrian spaces. Thus, shading serves as the cornerstone for reducing the heat island effect and improving the quality of the neighborhood's outdoor environment. Thermal comfort is achieved. Thermal comfort refers to a state of thermal equilibrium between the human body and its surrounding environment, in which the individual feels no thermal discomfort. This state is achieved when the body's thermoregulatory mechanisms cease to exert additional effort to maintain its internal temperature at a constant 37 degrees Celsius. This comfort depends on a combination of climatic factors—such as temperature, humidity, and air movement—and subjective factors—such as the type of activity and clothing. It is assessed in the study using precise scientific metrics, such as average temperature

PMV (Predicted Mean Vote) is one of the most important thermal comfort indices used in the ENVI-met software to assess the expected thermal sensation of humans in the outdoor environment; it is based on a set of climatic variables, including air temperature, relative humidity, wind speed, and mean radiant temperature. (Cherchi et al., 2025, p. 5) The Sky View Factor (SVF) (Sky View Factor) is one of the key indicators in the ENVI-met program; it expresses the proportion of the sky visible from a specific point within the urban fabric, and its values range from 0 to 1, where low values indicate increased shading caused by buildings and trees, while high values indicate greater exposure to the sky. The SVF directly influences solar radiation, mean radiant temperature (MRT), and thermal comfort levels in urban spaces (Yao et al., 2025, p. 3). A sustainable neighborhood aims to enhance this comfort through ecological planning that balances the energy gained and lost by humans. As shown in Table 1

Table (1) Indicators of Thermal Comfort in a Sustainable Neighborhood

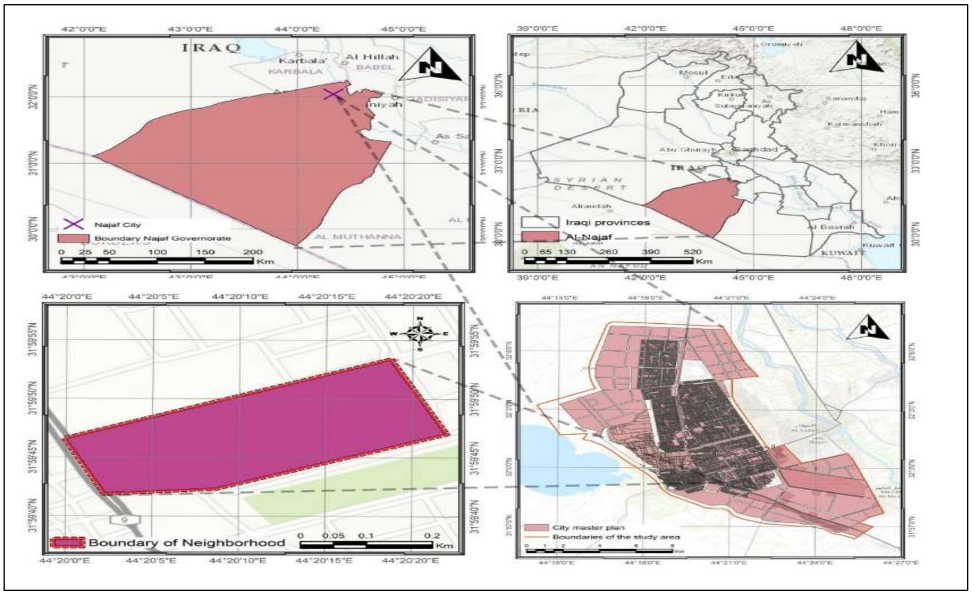
Main Indicators	Secondary Indicators	Criterion	Measurement
Compact Urban Structure	Urban Mass Density	Density	40–60% Source: (Neufert, E., 2012)
	Diversity	Diversity Index	0–1
	Ratio of Built-up Mass to Open Space	Mass-to-Space Ratio	Calculated as the ratio of built-up area to open space
Sustainable Mobility	Accessibility	Connectivity Ratio	100% accessibility of the population within a walking distance of 400–800 m
	Connectivity	Intersection Density	Number of intersections divided by the area of the region
	Spatial Analysis Tools	GIS-based Analysis	Spatial analysis tools such as GIS
Integration with Nature	Orientation	Population Served	Percentage of population served × per capita share
	Open Spaces	Green Space Ratio	Percentage of green spaces
Reducing Energy Consumption	Shading	Thermal Comfort	Shading analysis using ENV software
	Thermal Comfort	PMV, MET, and SVF Indicators	Measured using PMV, MET, and SVF indices

Source: The Researcher

Study Area: Abu Khalid Neighborhood – Najaf

The Abu Khalid neighborhood is a residential area in Najaf, located within the urban boundaries of the city, which is considered one of the most important religious and urban centers in Iraq. The neighborhood is situated in the northeastern part of downtown Najaf, as shown in Figure 5, and is characterized by its relative proximity to the main roads connecting the city to its regional surroundings, making it part of the city's modern urban expansion. (Ministry of Municipalities and Public Works, 2010)

Najaf is located in the southwestern part of the country, placing the neighborhood within a hot, dry climate that directly affects thermal comfort levels. The neighborhood covers an area of approximately 11 hectares and features a mixed-use urban fabric that combines residential units with basic services. It reflects a pattern of modern urban development linked to increased demand for housing, making it a suitable case study for examining the factors influencing thermal comfort within residential neighborhoods in hot cities. Furthermore, its planning characteristics—such as building density, the street network, and the proportion of green spaces—contribute to defining local environmental conditions, which reinforces its importance as a study area in urban sustainability research.



Analysis of the Study Area Based on Indicators Derived from the Theoretical Framework:

The study area will be analyzed based on indicators derived from the theoretical framework, which are:

Compact Urban Structure:

When measuring the urban mass ratio, the ratio of urban mass (51.2%) to open spaces (48.8%) indicates a relative balance in the urban fabric, which is considered one of the principles of a sustainable neighborhood. This balance contributes to improved thermal comfort by providing partial shade and reducing direct solar radiation. Open spaces also support natural ventilation within the neighborhood. Thus, this ratio helps reduce the heat island effect and improve urban climate conditions .

Table 2 illustrates the application of the entropy equation in the Abu Khalid neighborhood

No.	Land Use	Area (%)	Proportion (Pi)	In(Pi)	Pi × In(Pi)	Entropy Index
1	Residential	45.64	0.4564	-0.78	-0.36	
2	Green Area	18.11	0.1811	-1.709	-0.309	0.868088
3	Commercial	29.90	0.2990	-1.21	-0.36	
4	Public Services	6.35	0.0635	-2.76	-0.18	
Total	—	**100.00**	**1.0000**	**-6.457**	**-1.203**	**0.868088**

Source: The researcher, based on Simpson's equation

The table shows a notable diversity in land uses within the Abu Khalid neighborhood, which has a total area of approximately 6.94 hectares. Residential use accounts for the largest share at about 45.64%, followed by commercial use at 29.90%. In contrast, green spaces and public services account for the smallest shares, at 18.11% and 6.35%, respectively, reflecting the neighborhood's need to enhance these essential services. The final value of the entropy index was 0.868088, which is very high and close to one (1). Statistically and in terms of urban planning, this result indicates a homogeneous, balanced, and highly efficient distribution among the various urban functions and land uses within the study area.

Sustainable Mobility:

Accessibility: As shown in the figure below, the Abu Khalid neighborhood is characterized by an urban layout that achieves high efficiency in terms of accessibility. The neighborhood measures 500 m by 223 m and is based on a centralized system that places essential services and green spaces at its heart. Access to educational institutions is approximately 400–800 m, to health services approximately 500–1,000 m, to commercial activities within a 400-meter walking distance, and to other community facilities approximately 400–800 m, allowing residents to reach them on foot in just a few minutes. This design is further supported by a well-organized road network that connects the neighborhood directly to a major arterial road, facilitating smooth vehicle traffic to and from the area. Functionally, commercial areas have been distributed along the periphery to facilitate service to visitors from outside while maintaining a quiet and smooth flow of traffic within the residential sectors, making the neighborhood an integrated model that combines ease of mobility with quality of life.

Integration with Nature

Nature is typically associated with green spaces, which represent the proportion of the total area in the study area. The ratio of green spaces in the area is 1.25, as shown in Figure 9.

Reducing Energy Consumption:

We observe here, based on the indicators above, that a notable balance has been achieved in the study area through the application of the equations outlined in Table 1, However, this did not help achieve thermal comfort for humans; therefore, we turned to the two most important indicators in the study—orientation and shading—by planting Albizia trees using the ENVI-MET simulation software, which helps reduce energy consumption .

ENVI-MET Software:

Studying the urban environment at the ecological level is a complex process that requires field measurements, experimental analyses, and other methods that are time-consuming and labor-intensive (Wang et al., 2019), therefore, computer modeling using software such as ENVI-MET is an important tool for investigating the potential and limitations of environmental changes in both existing urban structures and their future developments (2023, 66 (Eingriber et al. The software was developed by Michael Bruce and his team in 1993, according to Bruce (1998), ENVI-MET is a three-dimensional model capable of simulating microscopic interactions between urban surfaces, vegetation, and the atmosphere, and it allows for the analysis of the effects of small-scale changes in urban design (such as trees and building configurations) on the local climate under various conditions on a mesoscale (Bruce and Fleer, 2009, p. 373)

ENVI-MET indicators within the scope of this research:

The program provides an analysis of environmental indicators by assigning them specific values represented by mathematical values and color gradients on thermal maps. Blue represents the lowest value and violet the highest. The most important indicators to be adopted in the practical phase will be identified later

1- Temperature: Represents the potential air temperature at a specific point on the Earth's surface.

2- Sky Exposure Coefficient (r): A measure of the proportion of the sky visible from a specific point on the Earth's surface, with values ranging from 0 (completely obscured sky) to 1 (completely unobstructed sky).

3- Thermal comfort: Thermal comfort is an integral part of urban design studies; it can be defined as the psychological state expressing satisfaction with the environment (Teshneidel et al., 2020.1).

Table 3 shows the ENVI-MET program inputs for the selected sample

Parameter	Value
Location	Najaf City
Simulation Period	1–17 July 2025
Total Simulation Time	24 Hours
Maximum Temperature	49°C at 3:00 PM
Minimum Temperature	29°C at 4:00 AM
Maximum Relative Humidity	65% at 6:00 AM
Minimum Relative Humidity	5% at 3:00 PM
Wind Speed	1.5–3.5 m/s
Sample Location	Abu Khalid Neighborhood, Najaf (31.006545, 44.336957)

Source: The Researcher

The Abu Khalid neighborhood was selected for simulation in the ENVI-MET program. The location selected for the simulation is illustrated in the following figure:

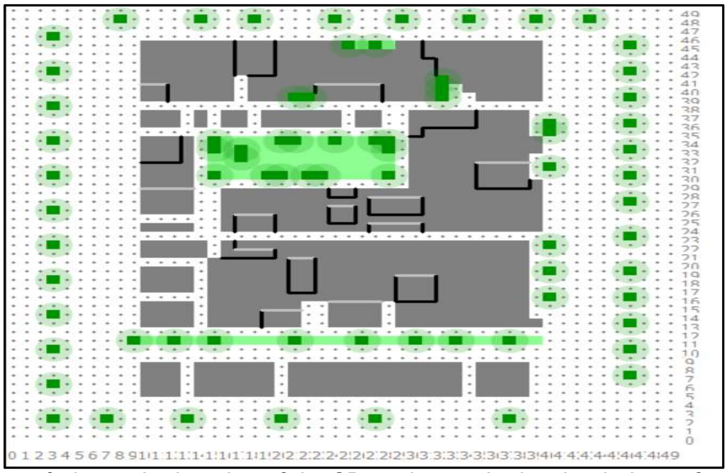


Figure 4 shows the location of the 2D study area in the simulation software

Analysis of the Current State of Thermal Comfort in the Study Area:

Analyzing the current state of thermal comfort is an essential step toward understanding the prevailing climatic conditions within the Abu Khalid neighborhood in the city of Najaf, as well as the extent to which urban characteristics affect the outdoor environment. The ENVI-met software was used to simulate microclimatic variables and assess the distribution of temperature and relative humidity, with the aim of diagnosing thermal comfort conditions in the study area and identifying areas of thermal stress. The following were examined :

Average Temperature (PMV):

The simulation maps generated by the ENVI-met program at 12:00 p.m. illustrate the spatial distribution of air temperature at a height of 1.8 m within the study area. As shown in Figure 5, warm colors (yellow, orange, pink, and purple) indicate areas with higher temperatures, which are concentrated in streets and open spaces directly exposed to solar radiation. In contrast, cool colors (blue and dark blue) represent cooler and more temperate areas, and their presence is often associated with shaded areas or proximity to building complexes that limit direct exposure to sunlight. The relative humidity map also shows spatial variation between areas, with light colors indicating relatively higher humidity values, while dark colors indicate lower humidity and increased dryness. This variation reflects the impact of urban characteristics and the distribution of open spaces on the local climate and the level of thermal comfort within the neighborhood.

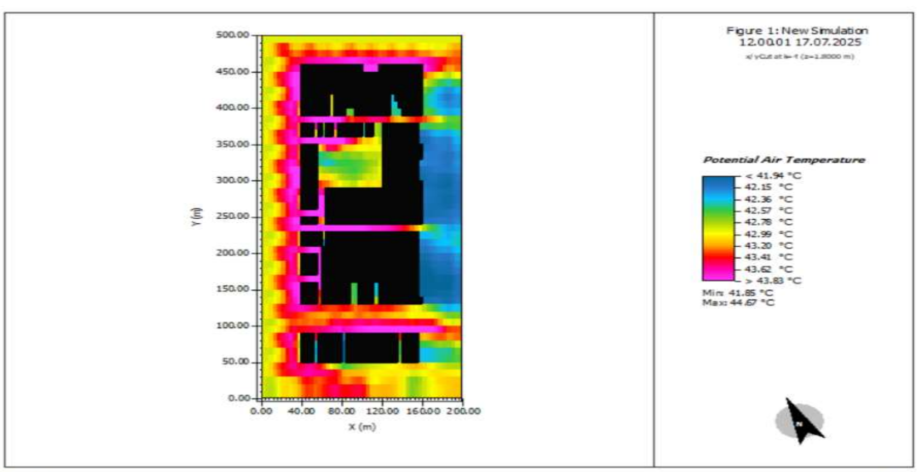


Figure 5 shows the distribution of temperatures at 12:00 p.m. for the study area, as generated by the ENVI-.MET simulation program

Sky View Factor (SVF):

The Sky View Factor (SVF) map shown in Figure 6 illustrates the spatial variation in the extent to which parts of the neighborhood are exposed to the sky at pedestrian level. Pink and purple colors indicate high SVF values (close to 1), signifying open, unobstructed areas that are more exposed to direct solar radiation. Green and yellow colors represent moderate values, reflecting a partial impact from built-up areas or shading elements. Meanwhile, blue and dark blue colors indicate low Sky Visibility Factor (SVF) values and are associated with areas surrounded by buildings or located in the shade, which reduce direct exposure to the sun. The results confirm that high SVF values in most parts of the neighborhood contribute to increased heat gain during daylight hours, which calls for enhancing shading and green elements to improve outdoor thermal comfort.

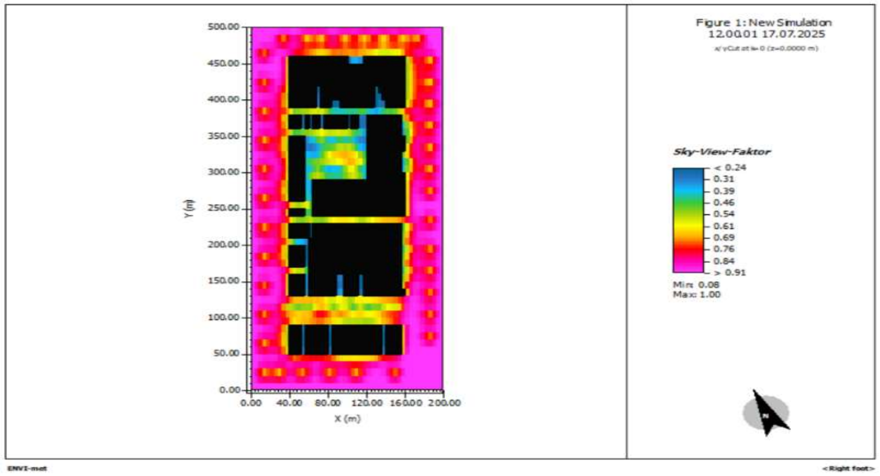


Figure 6 shows the sky visibility coefficient at 12:00 p.m. in the study area, as calculated using the ENVI-MET software

Conclusions:

1. The study's results showed that the current planning and urban characteristics of the Abu Khalid neighborhood do not achieve acceptable levels of thermal comfort during the peak summer period, despite the presence of some indicators of urban sustainability within the urban fabric .
2. The high Sky View Factor (SVF) values contributed to increased exposure of streets and open spaces to direct solar radiation, leading to higher radiant temperatures and increased thermal stress on users .
3. Simulation results showed that the relative balance between built-up areas and open spaces alone is insufficient to achieve thermal comfort unless it is combined with natural shading elements and effective green infrastructure .
4. The neighborhood achieved a good level of functional diversity and ease of access to services, which enhances the efficiency of urban use and brings it closer to the principles of a sustainable eco-neighborhood .
5. The ENVI-met software demonstrated high efficiency in analyzing the local climate, diagnosing areas of thermal stress, and determining the impact of urban characteristics on thermal comfort indicators within the urban environment .
6. It was found that the limited green spaces and insufficient shading in outdoor areas are among the main causes leading to the deterioration of local climatic conditions and the rise of the PMV index to uncomfortable levels.

Recommendations

1. Increase the proportion of vegetation cover within the neighborhood by planting shade trees along streets, sidewalks, and public squares to improve local climate conditions .
2. Adopt sustainable urban shading strategies through green canopies and shading architectural elements to reduce direct exposure to solar radiation .
3. Re-examine the orientation of buildings and streets in future development projects to align with prevailing wind directions and contribute to enhanced natural ventilation .
4. Enhance green infrastructure by creating interconnected green corridors and linking open spaces to parks and natural features within the neighborhood .
5. Adopt thermal comfort indicators such as PMV and SVF as part of the evaluation and design criteria for new residential neighborhoods in hot, arid Iraqi cities .
6. Encourage the use of building materials with low thermal absorption and heat-reflective surfaces to limit the rise in temperatures of roofs and outdoor spaces.

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