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ORIGINAL PAPER
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STRATEGIES TO REDUCE THE URBAN HEAT ISLAND (UHI) IN CONTEMPORARY RESIDENTIAL PROJECTS IN BAGHDAD

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ABSTRACT

Motivation: The urban heat island (UHI) effect is one of the most significant challenges in contemporary urban environments, especially in hot, dry climates. In recent years, Baghdad has witnessed the development of 46 residential projects, highlighting the urgent need to examine the impact of (UHI) in modern residential projects and explore effective mitigation strategies. The research problem stems from the lack of local knowledge and studies in Iraq regarding (UHI) effect within modern residential projects.
Aim: The study aims to investigate the (UHI) phenomenon in Baghdad and explore strategies to mitigate its effect through implementation of afforestation, shading techniques, and the use of cool materials. The ENVI-MET simulation software was employed to assess the current situation and proposed development scenarios under the conditions of a hot summer day. A quantitative methodology was adopted. The findings showed that the scenario (C) led to a significant improvement in Potential Air Temperature values. Both scenarios (B and C) demonstrated a notable improvement in, Sky view factor (SVF) values, while the scenario (B) showed a considerable enhancement improvement in Physiological Equivalent Temperature (PET) values.
Results: The study highlights the importance of integrating design strategies in residential projects to effectively mitigate the (UHI) effect.

Keywords: The urban heat island (UHI), ENVI-MET, Potential Air Temperature, Sky view factor (SVF), Physiological Equivalent Temperature (PET)

INTRODUCTION

Urban Heat Island (UHI) Concept

The Urban Heat Island (UHI) phenomenon refers to the elevated temperatures observed in urban areas compared to their rural surroundings. It is recognized as one of the most significant anthropogenic impacts on the natural environment, causing increased energy consumption, elevated air pollution levels, and adverse effects on the health of residents (Abbas Abd-Elrady Hassan, 2016; AlTalebi & Al-Bazzaz, 2018; Khaza'al Hasson & Dhumad, 2018). The primary causes of (UHI) include the proliferation of high-density buildings within the city, with large thermal mass and heat-retaining properties, anthropogenic heat

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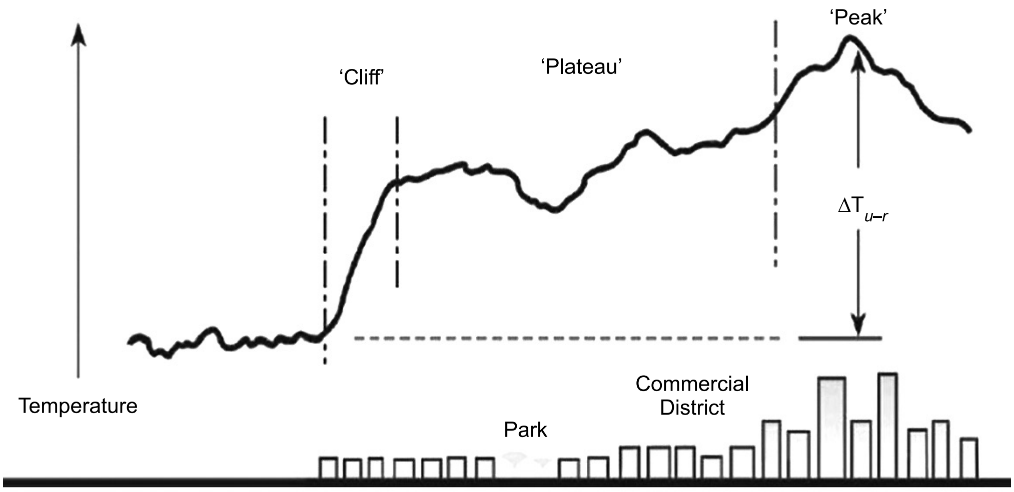

Fig. 1. (UHI) effects in the city and surrounding areas
Source: O'Malley et al. (2014).

emissions, air pollution, and high levels of energy consumption. Other contributing factors are the scarcity of green spaces, reduced wind flow caused by the built environment layouts, and the extensive use of materials that absorb solar radiation during the day and release it at night. The impact of (UHI) are mainly felt through alteration in the local microclimate and through the reduced thermal comfort and health of occupants (Al-Saffar & Al_Siliq, 2014; Husain et al., 2018; O'Malley et al., 2014). Fig. 1 shows (UHI) effects.

Types of Urban Heat Islands (UHI)

Urban heat islands (UHI) have various definitions based on their interaction with the atmosphere or the Earth's surface. Understanding this distinction is important to distinguish between the different types of urban heat islands and their relationship to urban structures and green spaces in Table 1.

Table 1. Types of Urban Heat Islands

Urban canopy layer heat island	Below rooftops or treetops, air temperatures are measured at a height of 1.5 to 3 meters above the ground
Urban boundary layer	Above surface level, i.e. in the atmosphere, and this heat may extend for long distances with the winds
Surface temperature UHI	The surface temperature of the Earth's surface or buildings
Sub surface UHI	It is in the ground under the surface

Source: own elaboration based on (Hassan & Al-Kindy, 2023; Heisler & Brazel, 2010; Shalaby, 2011).

The research is concerned with the urban canopy layer heat island as it represents the actual thermal environment that affects occupants, typically measured at a height of 1.5–2m.

Reducing the Urban Heat Island (UHI) Effect

In general, two primary categories of mitigation strategies are employed to reduce the impact of UHI at the urban scale. The first focuses on increasing solar reflectivity through the use of "cool" or reflective materials on the exterior surfaces of the urban environments, and the second aims to enhance evaporation by increasing vegetation and water availability. Additional measures to mitigate the adverse effects of UHI include behavioral changings, improving building design, and reducing anthropogenic heat emissions in urban areas (Heaviside et al., 2017; Shaheen & Khalaf, 2009).

Therefore, the study adopts development scenarios related to the adoption of environmentally efficient materials with low heat storage capacity, and the afforestation strategies to reduce (UHI).

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MATERIALS AND METHODS

Study framework

This study adopts a quantitative methodological framework based on environmental simulation. A quantitative methodology was adopted by developing simulation models using ENVI-MET software (version X.X). The simulations accounted for the climatic conditions of a typical hot summer day (13 August 2023), with peak temperatures reaching 50°C. Materials and plant types were selected based on actual site observations. Additionally, three environmental development scenarios (A, B, and C) were formulated based on prior studies and academic trends, ensuring both scientific relevance and contextual applicability.

Study area

The case study selected for this research is Al-Wafi Residential City (Iraq Gate Residential Project), located in Baghdad, Iraq. The project represents a contemporary large-scale residential development that reflects recent trends in housing construction in the city. The study area consists of multi-story concrete buildings surrounded by asphalt roads and limited green spaces. It was chosen because it demonstrates typical design practices in Baghdad that often overlook climatic adaptation, making it an appropriate context for testing microclimate improvement strategies.

Methods

Four simulation models were developed in ENVI-MET to represent the existing situation and three alternative scenarios: Existing situation model: represents the current condition, with concrete façades, asphalt streets, and limited grass in internal gardens. Scenario A – Material modification: building façades were finished with reflective, low-absorptivity coatings, while basalt bricks replaced concrete walkways. Scenario B – Vegetation and shading: Sophora Japonica trees were introduced along pedestrian paths and between buildings, supplemented with pergola-type shading structures in communal spaces. Scenario C – Integrated approach: combined Scenarios A and B, applying reflective materials and basalt walkways together with vegetation and shading elements. Each scenario was simulated for a typical summer day to examine variations in microclimatic conditions.

Data

The boundary conditions for the simulations were based on meteorological data from the Iraqi Meteorological Organization and Seismology (IMOS), corresponding to 13 August 2023, a day representing peak summer conditions in Baghdad. The input parameters included air temperature, relative humidity, wind speed, and solar radiation. The analysis focused on three indicators: Potential Air Temperature (°C) – representing the near-surface air temperature. Sky View Factor (SVF) – the ratio of visible sky from ground level, indicating shading conditions. Predicted Mean Vote (PMV). These indicators allowed for a comparative assessment of thermal comfort improvements across the scenario.

LITERATURE REVIEW

Alobaydi et al. (2016) investigated the influence of urban form on the (UHI) by analyzing three different urban patterns in the city of Baghdad. The study excluded the effects of vegetation and materials in buildings and roofs by utilizing the ENVI-MET simulation.

Mohammed and Salman (2018) explored the relationship between urban form, green spaces and (UHI) formation. Using ENVI-MET, the study emphasized the importance of integrating urban design with environmental strategies to enhance local climate conditions.

Jasim et al. (2020) analyzed the effects of urban expansion on (UHI) using Landsat remote sensing techniques, focusing on surface temperature between 2003 and 2018. The results indicated a reduction in vegetation cover, leading to an increase in surface temperatures.

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Abdulateef and Al-Alwan (2020) addressed the surface urban heat islands (SUHI) phenomenon in Baghdad, using remote sensing to identify casual factors and trace temporal changes. The study highlighted the loss of cultivated land and the use of low-reflectivity materials as a major contributors.

Tawfeek et al. (2020) examined the canopy urban heat island (CUHI) effects Baghdad, relying on Landsat satellite image data and daily temperatures for three separate years. The study underscore the role of rapid urban growth and high population density in intensifying the CUHI phenomenon.

Salman and Saleem (2021) assessed the effectiveness of various (UHI) mitigation strategies such as (greening, reflective materials, urban tectonics), on human thermal comfort in Baghdad. These strategies were applied to three urban patterns using ENVI-MET.

Jameel and Hassan (2022) A study in Babylon, Iraq, examined the effect of urban adaptation elements – vegetation cover, water bodies, and shading patterns – on outdoor thermal comfort in educational complexes. Using ENVI-MET simulations, it showed that these elements could reduce air temperature by about 3°C and mean radiant temperature by 8°C. The sky view factor (SVF) was also decreased by 20%. The study highlights the importance of green infrastructure and urban design in mitigating UHI effects in hot-dry climates

Najah et al. (2023) evaluated the impact of green spaces and building configuration on urban temperature using the urban simulation tool ENVI-MET, confirming their significant influence on (UHI).

Alshammari et al. (2025) investigated (UHI) in Baghdad under the influence of rapid urban expansion and climate change. The study utilized Sentinel-3 satellite data and Open Street Map (OSM) infrastructure data to compare UHI patterns between 2016 and 2023.

Tareq and Al-kindy (2025) A study in Baghdad investigated strategies to improve thermal comfort in residential complexes, focusing on shading and environmentally efficient materials. The research applied a quantitative approach to the Budour Baghdad residential complex under typical summer conditions. Results showed that an integrated scenario significantly improved PMV and PET values, reducing heat stress areas. The study provides insights for developing sustainable design guidelines adapted to the local environment.

The literature review emphasized the critical role of urban form, vegetation and mitigation strategies in shaping thermal conditions in Baghdad. However, it also reveal the research problem of the lack of local knowledge and studies in Iraq regarding (UHI) effect within modern residential projects.

CASE STUDY

Iraq Gate Residential Project

Detailed Overview

The project is located in Baghdad, on the Karkh side, opposite Al-Zawraa Park Fig. 2. Currently under construction, portion of the residential units have been delivered to residents in phased stages. The project comprises (49) residential tower buildings of varying heights, (35) towers consist of (18) floors, (11) towers have (17) floors, two towers rise to (22) floors, and one tower reaches (25) floors (Al Sayyid & Ali, 2022).

Justifications for selecting the Iraq Gateway project:

The Iraq Gate Residential Project was selected as it exemplifies the contemporary residential urban expansion in Baghdad. Located in a central and strategically significant area of the city, the project features a multi-story residential building typology that reflects the prevailing pattern of modern housing developments in Iraq. Furthermore, its urban design serves as a potential model for mitigating the Urban Heat Island (UHI) effect.

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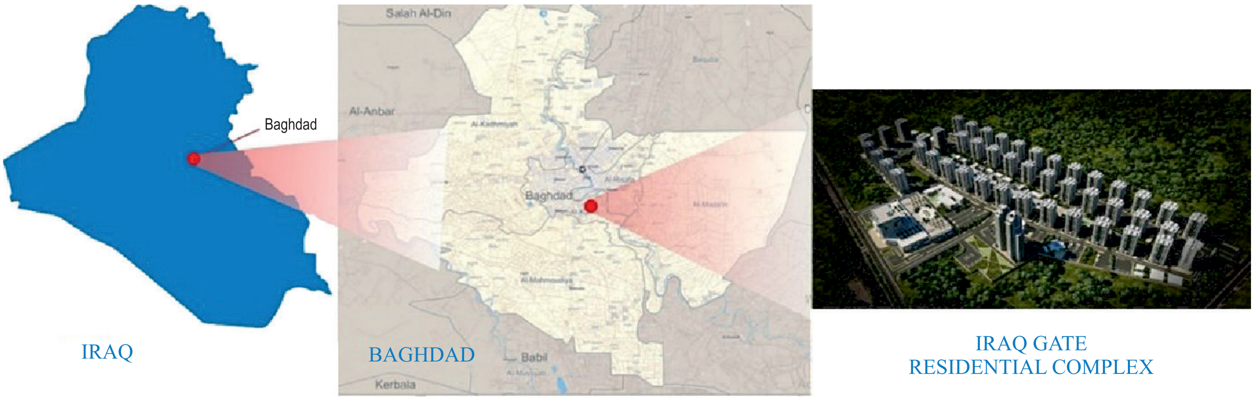

Fig. 2. Location of Iraq Gate Residential Complex
Source: own elaboration.

ENVI-MET ENVIRONMENTAL SIMULATION

Basic Simulation Settings

The input data for the simulation can be summarized as follows in Table 2.

Table 2. Data of the simulation input in ENVI-met

Baghdad city location (Lati.33°34′N, long. 44°40′E)	Model location
X-Grids = 175, Y-Grids = 67, ZGrids = 40	Boundary model
dx =2, dy = 2, dz = 2	Grids
0	Model rotation out of grid north
13th August 2023	Simulation date
00:00 AM	Simulation starting time
24 hours	Simulation duration
Min = 30 at 6:00 a.m. Max = 50 at 18:00 p.m.	The temperature of the atmosphere (°C)
Min = 6 at 2:00 a.m. Max = 26 at 12:00 p.m.	Relative humidity in 2m %
3.9	Wind speed
315 (0=from North …180=from South)	Wind direction

Source: own elaboration.

A sample from the Iraq Gate Residential Project Residential Complex, which is the part of the project that has been completed and occupied Fig. 3.

Simulation Models for the Iraq Gate Residential Project

A simulation of the existing situation was conducted for the selected sample of the Iraq Gate Residential Project. The selected scenarios are illustrated in Fig. 4.

1. The existing situation Model: This model represents on the current state of the project, featuring residential buildings contacted with concrete and heat-insulating glass. Street surfaces are paved with asphalt, while green strips surrounding each residential building are covered with grass.
2. Scenario A: In this scenario, the finishing materials of the residential buildings were modified to incorporate green façade. Additionally basalt bricks were used for the street surfaces instead of asphalt.
3. Scenario B: This scenario introduced shading through the planting of Sophora Japonica trees and installing other shading devices the areas between the residential buildings, aiming to reduce surface temperature and improve microclimatic conditions.
4. Scenario C: This comprehensive scenario combined scenarios A and B. It includes the application of green façade to the residential buildings, the use of basalt bricks for street surfaces, and the addition of shading through planting Sophora Japonica trees and installing other shading devices the areas between residential buildings.

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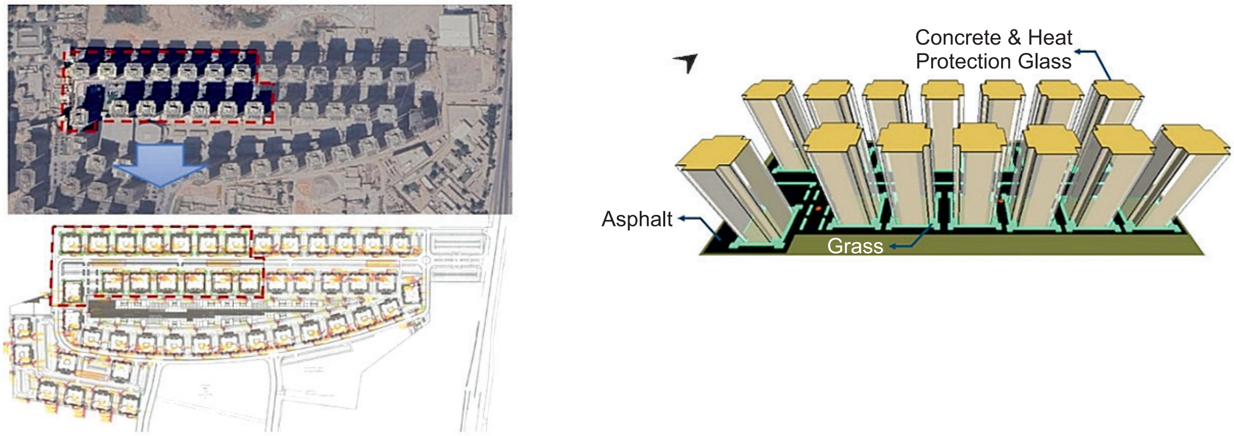

Fig. 3. The selected sample of the Iraq Gate Project
Source: own elaboration.

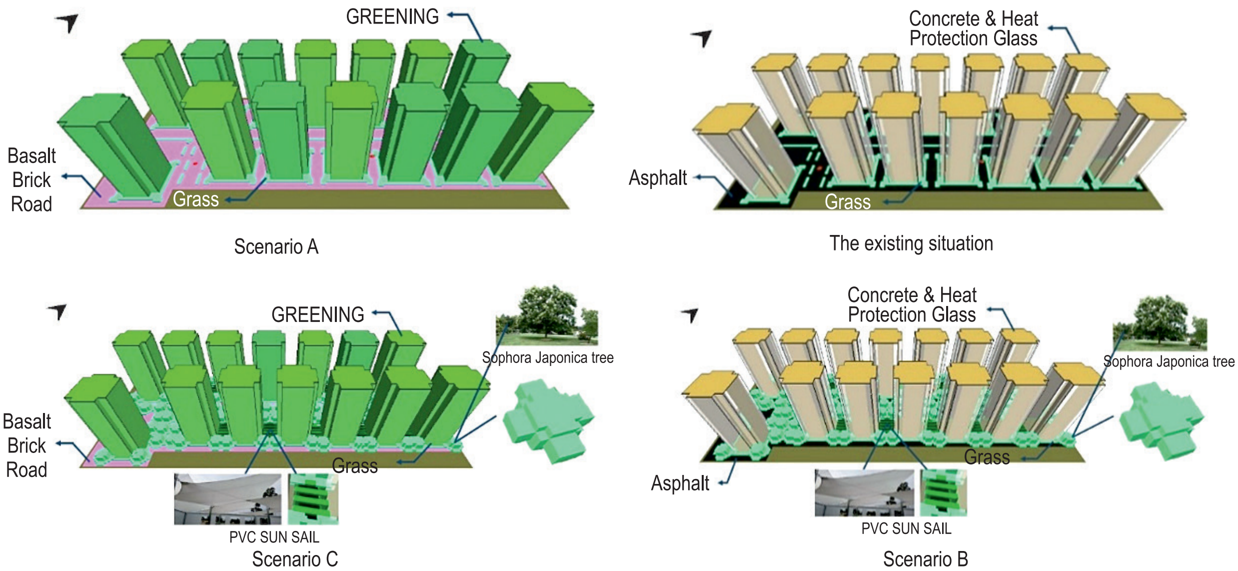

Fig. 4. The Iraq Gate Residential Complex simulation scenarios
Source: own elaboration.

RESULTS

Potential Air Temperature

The results infescate that scenario C recorded the lowest values for both maximum and minimum temperatures (Fig. 5). Although the variations maximum and minimum temperatures for the selected scenarios were relatively modest, the overall temperature distribution across the site demonstrated a noticeable improvement. These simulation results are summarized as in Fig. 6, which compares the percentages distribution of temperatures zones across the site, in the simulation the existing situation 73% of the site area exhibited temperature of X>40 C, In scenario A this percentage decreased to 32.60%, In scenario B it dropped to 49%, and in scenario C the percetage reached its lowest value of 24.30%.

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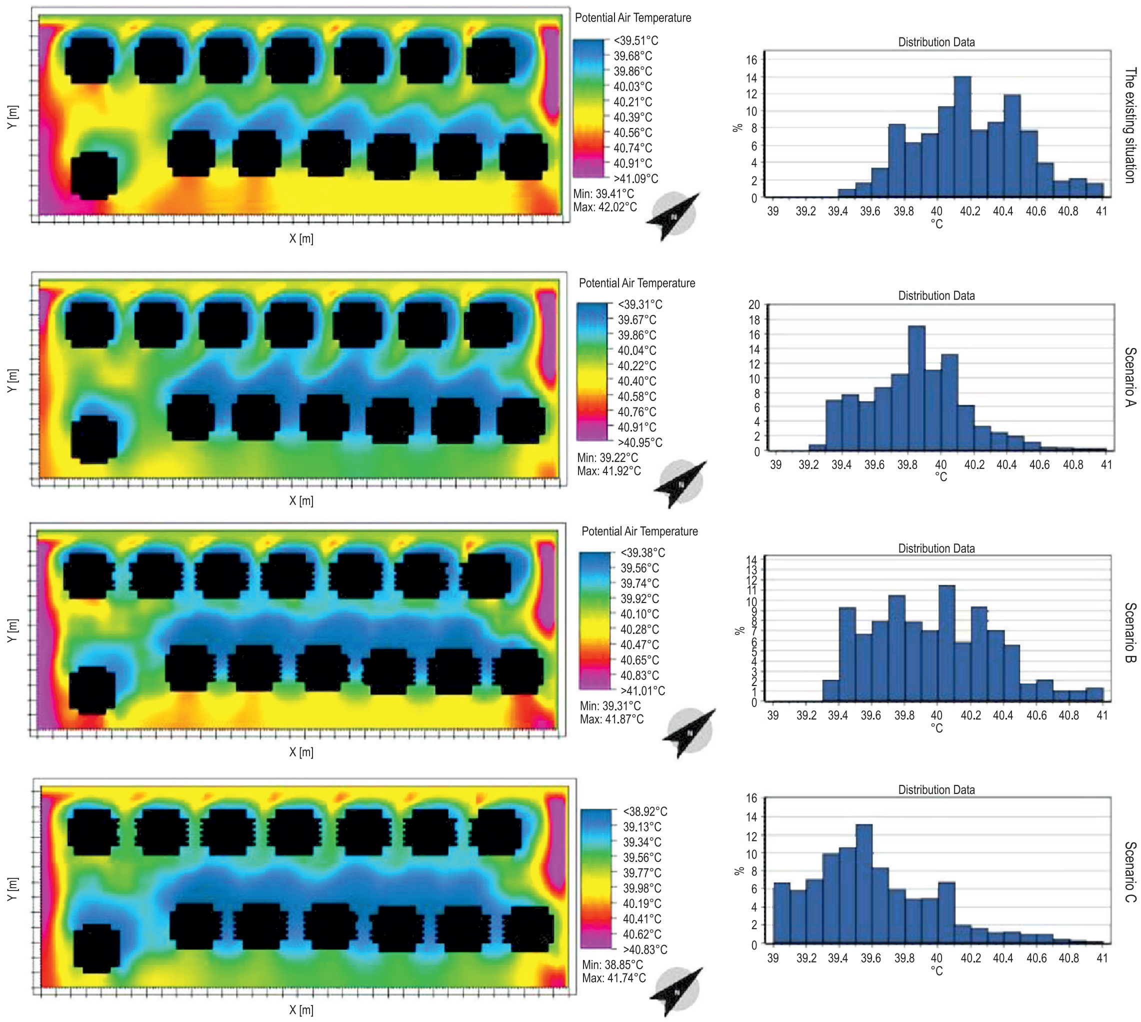
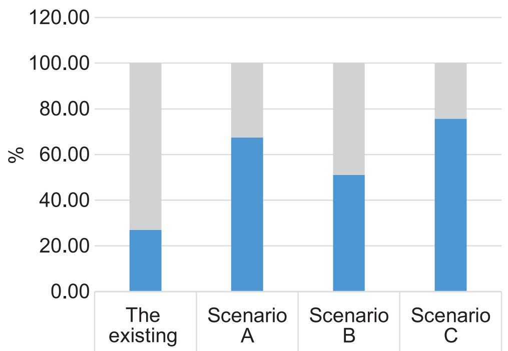


Fig. 5. Potential Air Temperature simulation results
Source: own elaboration.



	The existing	Scenario A	Scenario B	Scenario C
X>40	73.00	32.60	49	24.30
X<40	27.00	67.40	51	75.70

Fig. 6. The percentages of (Potential Air Temperature)
Source: own elaboration.

These findings suggest that the integrated scenario C that combined shading through afforestation and environmentally efficient materials was the most effective in reducing site temperature, achieving noticeable thermal improvement.

Sky View Factor

The results are presented in Fig. 7, which illustrate the existing situation and the proposed scenarios for 12 noon and at an altitude of 1.5 meters above ground level. The analysis categorized to three main classifications of sky view factor (SVF) adopted in the research:

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– Low SFV (0.4–0.1): represents areas with high building density or dense vegetation cover.
– Medium SFV (0.6–0.4): represents areas with moderate building density or vegetation cover.
– High SFV (0.9–0.6): represents open areas with high level of direct sky exposure.

A detailed summary of the results is provided in Table 3.

The results indicate that the SFV values are similar for both (The existing situation and scenario A) as neither includes external shading elements. Likewise (scenarios B and C) show similar SFV values, as both incorporate the same degree of shading provided by trees and canopies in open spaces.

Table 3. Sky View Factor simulation results (in %)

Simulation	Low SFV (0.4–0.1)	Medium SFV (0.4–0.6)	High SFV (0.9–0.6)
The existing situation	32.75	28.0	39.25
Scenario A	32.75	28.0	39.25
Scenario B	43.00	20.4	36.50
Scenario C	43.00	20.0	36.50

Source: own elaboration.

The percentage of areas with high SFV (0.9–0.6) for both (The existing situation and scenario A) was 39.25%. In contrast, this percentage decreased in (scenarios B and C) to 36.5%, reflecting reduction

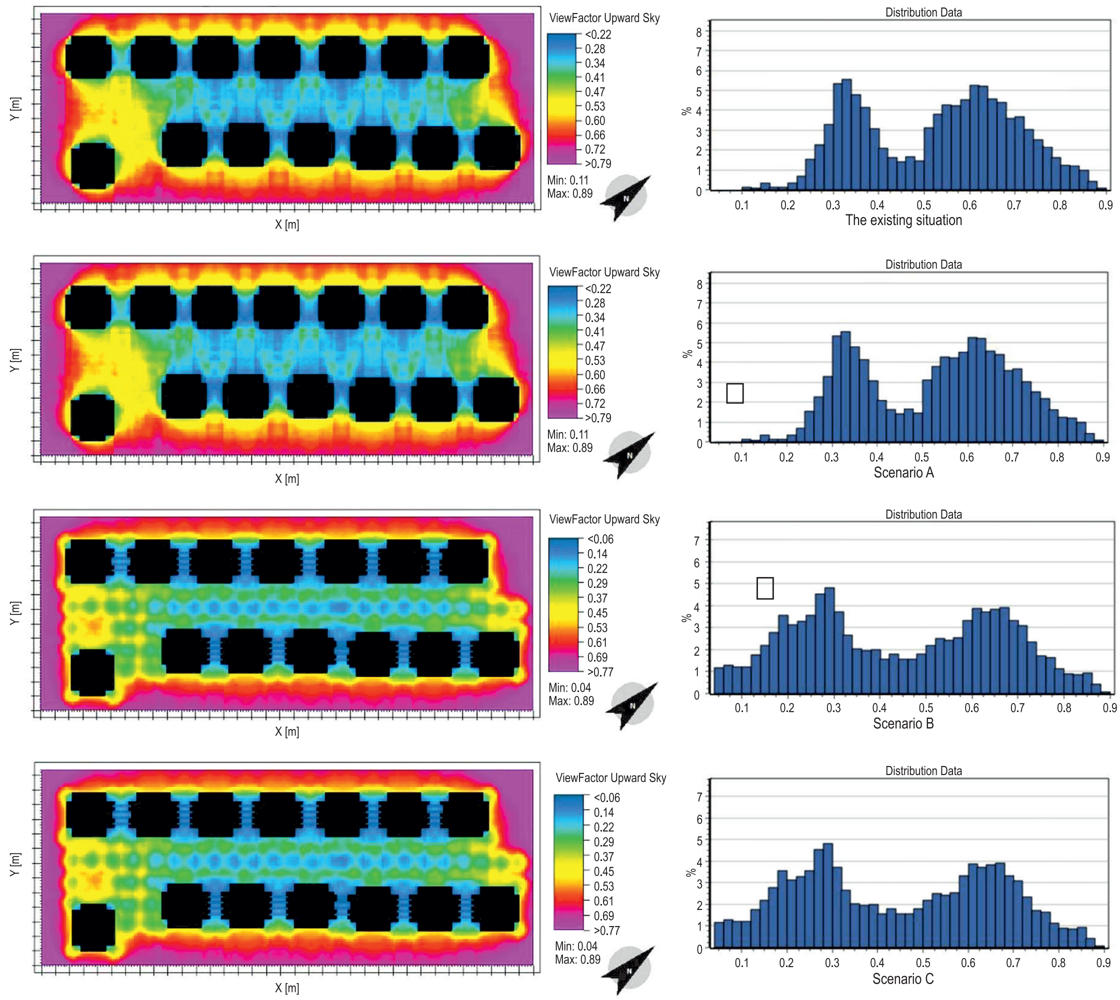

Fig. 7. Sky View Factor simulation results
Source: own elaboration.

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in sky exposure due to added shading. For medium SFV (0.6–0.4) the percentage was 28%, in both (The existing situation and scenario A), dropping to 20.4% in (scenarios B and C). As for low SFV (0.4–0.1) the percentage was 32.75% in the (the current situation and scenario A). This percentage increased significantly in (scenarios B and C) reaching 43%.

These results reveal that high SFV (0.9–0.6) was most prominent in (The existing situation and scenario A), indicating a higher exposure to direct sky. Conversely low SFV (0.4–0.1) was most prominent in (scenarios B and C), highlighting the effectiveness of dense shading elements. This clearly underscores the importance of efficient shading to enhance the environmental performance.

Physiological Equivalent Temperature (PET)

The results reveal variation in the maximum and minimum PET values of the selected scenarios compared to the existing situation (Fig. 8). Scenario A

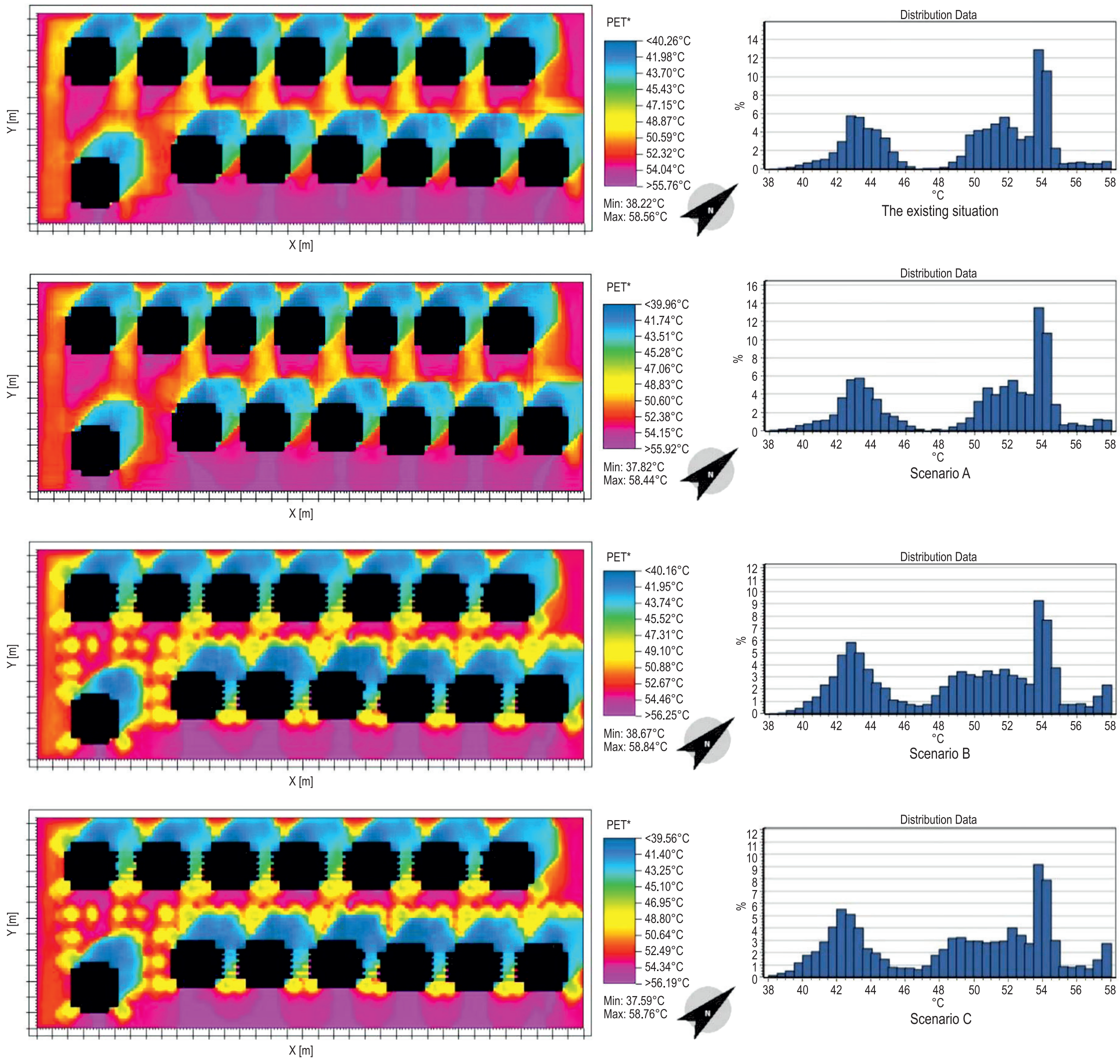

Fig. 8. PET simulation results
Source: own elaboration.

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recorded the lowest maximum value, while Scenario C exhibited the lowest minimum value. The simulation outcomes are summarized in Fig. 9, which compare the distribution percentages of PET values across the entire site. For analytical purpose, the results were categorized into two main groups as adopted in the study:
– PET X <50
– PET X >50

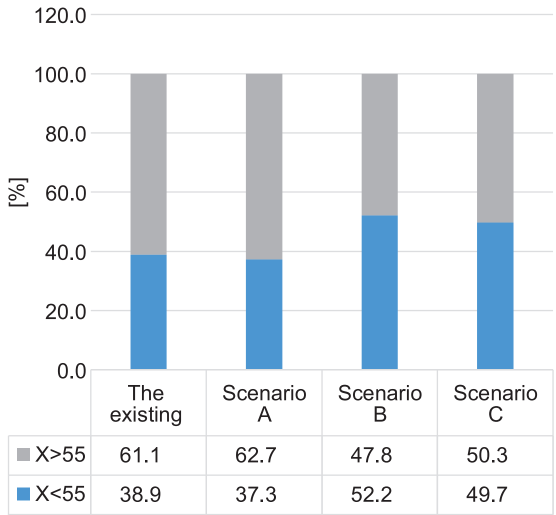

Fig. 9. The percentages of PET values
Source: own elaboration.

In the existing situation, PET X >50 accounted 61.1% of the site. In Scenario A, this percentage increased to 62.7%, in Scenario B, it decreased to 47.8%, and in Scenario C, it reached 50.3%. Accordingly, Scenario B demonstrated the best performance in terms of reducing the PET values, highlighting the effectiveness of enhance shading strategies.

CONCLUSIONS

The study aimed to evaluate the urban heat island (UHI) phenomenon in new residential projects in Baghdad through the analysis of potential air temp., sky view factor (SVF), and Physiological Equivalent Temperature (PET). It also assessed and compared the selected scenarios (A, B, and C) with the existing situation scenario of the selected project. The findings indicate that scenario C was the most effective in improving potential air temp. values, Both scenarios (B and C) showed better performance in reducing SVF values, as shown in table 4, thereby decreasing sky openness. Scenario B proved to be the most effective in enhancing Physiological Equivalent Temperature (PET) under typical daylight conditions, emphasizing the critical role of effective shading strategies and the use of appropriate materials in mitigating the UHI effects. The evaluation indicators developed in this research offer valuable tool for planners and designers of residential project, forming a strong basis for developing local policies aimed to assess and enhance the environmental performance of new residential projects in Baghdad. The findings of the current research highlight the need for relevant authorities to develop planning and design regulations for contemporary residential projects in Baghdad that incorporate environmental strategies aimed at mitigating negative environmental impacts. Such regulations may include requirements for the use of environmentally efficient materials and the integration of vegetation for shading, which may significantly contribute to reducing the effects of rising temperatures in urban environments.

Table 4. Summary of simulation results

Simulation	Potential air temp.	Sky View Factor	PET
Scenario A			
Scenario B	✓	✓	✓
Scenario C		✓	

Source: own elaboration.

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