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THE EFFECT OF SOLAR PANELS AND VEGETATION STRATEGY ON THE SUSTAINABILITY OF OPEN SPACES

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Abstract

Cities need to take serious steps to improve the living conditions of their citizens and their surrounding environment as the population of urban centers grows. Parking spaces have a clear potential to contribute to city sustainability. The research problem is that there is high energy consumption by residential buildings for multiple purposes and a significant increase in outdoor temperatures. Photovoltaic panels are a popular classification of sustainable rooftops adopted by cities around the world. This study aims to evaluate the impact of photovoltaic panels and trees in achieving sustainable development goals and combating climate change. In order to mitigate energy consumption and environmental issues related to fossil fuels and provide thermal comfort. The hypothesis of the research is that the use of renewable energy sources such as solar panels, in addition to vegetation can provide thermal comfort in addition to energy savings. The pilot study was conducted in residential complex in Iraq, Baghdad. Two different strategies and four separate scenarios were created using vegetation and photovoltaic panels. Envi-met 5.5.0 software was used to analyse and evaluate thermal comfort factors (PET, SVF) and simulated using ENVI-MET software on a summer day in July 2023. The results of the scenarios were then compared in terms of their impact on human thermal comfort. The results revealed a decrease in (PET) by (8.32) degrees Celsius, which achieved international standards for outdoor pedestrian comfort. As well as shading areas less exposed to sunlight with trees, in addition to providing shade to protect cars from weather factors, and finally providing electricity to homes.

Keywords:
Urban Environmental Simulation, Solar panels, parking space, vegetation, sustainability, thermal comfort, ENVI-MET.

1 Introduction

In Iraq, Baghdad is regarded as the biggest and densest inhabited city [1]. Moreover, Baghdad is among the world's hottest cities [worldweather.wmo.int]. According to the United Nations Population Fund (i.b.i.d.), the city is expanding extremely quickly and a lot of new urban areas are being built. There has been a global problem of climate change which has affected all the cities of the world. The city of Baghdad is one of the hot cities that witnessed a rise in temperature at a rate of 0.7 per decade [2]. In the hot, dry city of Bahrain, an investigation was done to examine how urbanization affects the thermal behaviour of recently established areas. It was discovered that the current urbanization process has resulted in an increase in urban temperature of two to five degrees Celsius. Due to urban activity such as ongoing construction operations and shrinking green spaces. The distribution of urban radiant heat islands is diverse and depends largely on the type of land cover and urban surface. Human comfort improves with green spaces. [3] A survey was conducted in Romania to make open spaces used for parking sustainable by installing solar panels on their extrovert rooftops. The model was simulated and the research demonstrated that including urban parking areas in a renewable energy production system through solar energy conversion proves to be a feasible and beneficial solution from two viewpoints many [4].

Sustainable construction strategies require creativity if low-carbon assignments are to mitigate the effects of climate change. From its inception to the present day, photovoltaic panels have dramatically boosted the amount of solar energy produced. Several advances in solar panel development and investigation have been made, such as the installation of photovoltaic panels on roofing as a more sustainable method to generate electricity. A photovoltaic roof is a building's roof that has solar radiation-converting photovoltaic cells installed to provide energy. Panels can be deployed as building-integrated photovoltaic (BIPV) or individually on a photovoltaic roof [5].

Because of its distinct multiple benefits, solar energy is regarded as one of the most significant renewable resources. Solar panels placed over spots for vehicles in urban areas are essential for safeguarding the space under and sheltering cars from environmental elements (wind, snow, heat), all of which contribute to driver comfort. This is an example of successful investment in responsible urbanization methods because it respects the environment and maintains itself through clean energy production and becomes profitable [4].

Research on how solar roofs could reduce the urban heat island effect (UHI) continues to be discussed; some studies contend that solar energy absorption can lower UHI, while others show opposing findings [7].

2 The benefits of installing solar panels

• It acts as a practical device for promoting understanding and speed the move to renewable energy

• it also shows nations, businesses, and people' commitment to lowering carbon emissions and participating in battling against global climate change.

• The use of solar panels achieves the net zero strategy.

• It provides environmental advantages and creates a more sustainable and efficient building environment.

• In order to achieve sustainability in the economy, society, and environment, solar panels are a major role, The financial incentive that a solar roof provides is one of its primary advantages. [8]. Australian PV families saved $252 million annually between 2010 and 2012, according to a study by Mountain and Szuster (2014). After considering installation expenses and government support, the cost of power produced by solar roofs can be as low as half that of commercial suppliers [7] Fig. 1

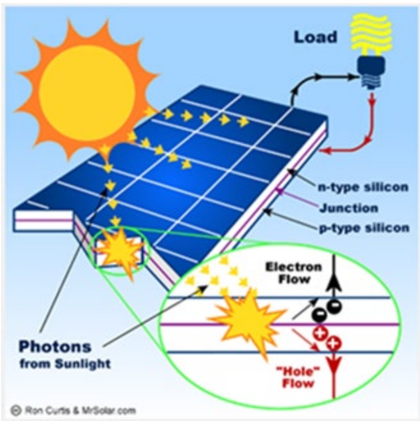

Fig1: The components of the human heat balance [6]

2.1 Solar panels efficiency

The efficiency of photovoltaic panels depends on various meteorological criteria, the most important of which are wind speed, temperature, and solar radiation values.

One of the most important criteria for solar energy generation is the annual solar radiation values. For example, Germany has annual radiation values of 3.35-2.75 kWh/m2, and with an installed solar energy capacity of 58,728 megawatts, it produced 50,000 megawatt hours of energy in 2021[9]. Compared to Iraq, the city of Baghdad, temperatures at the peak of summer reach above 50 degrees Celsius when the average maximum temperature in summer reaches 45 degrees Celsius, and the average temperature exceeds 30 degrees Celsius for 5 months in Baghdad [10]. Given the country's geographical location, the city of Baghdad enjoys abundant sunlight throughout the year, making it ideal for installing photovoltaic solar panels. It promotes the transition towards clean energy in Baghdad (Researcher) Fig. 2.

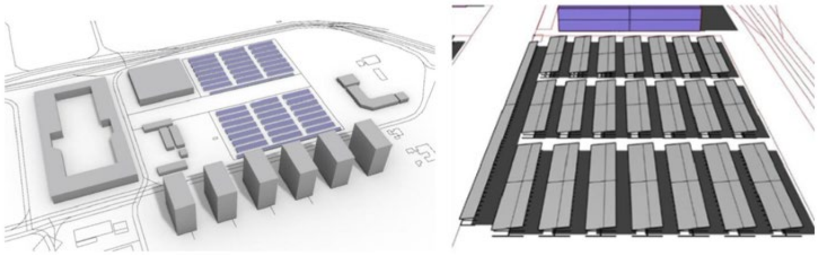

Fig 2. Model of the parking lot and surrounding buildings [9]

A study was conducted in Turkey, Izmir 2023, to apply a photovoltaic panel system to two equal parking lots with dimensions of 24,000 square meters in an urban area. The energy produced in the summer was more than in the winter, and through the process of simulating power generation, it was determined that 8,084 megawatts per hour of electricity could be generated through 7,006 A unit of photovoltaic panels with a capacity of 660 watts installed on roofs [9].

Solar panels installed above parking spaces play an important role in protecting the area below, protecting vehicles from climatic factors (wind, snow, exposure to high temperatures) and also providing modern comfort for drivers. This is an example of a successful investment in responsible urbanization methods because it respects the environment, sustains itself by producing clean energy and becomes profitable [11].

3 ENVI-met and Leonardo

Fundamental aspects of the ecological model:

ENVI-met is a 3D non-hydrostatic microclimate model capable of calculating and simulating urban climate between 0.5 and 10 meters in area and ten seconds in time, as is the usual grid resolution. Using the fundamentals of fluid dynamics and thermodynamics, it computes the dynamics of the local climate during the course of the diurnal cycle, which lasts from 24 to 48 hours. Wind direction and speed, air temperature and humidity, turbulence, radiative fluxes, bio climatology, and gas and particle dispersion are the primary prognostic factors in the program [12].

Accordingly, this study aims to evaluate the effect of environmental treatments in providing human thermal comfort for open spaces in a residential complex in the city of Baghdad. The findings of this research will contribute to a deeper comprehension of how environmental interventions contribute to human comfort in extremely hot environments. This will help architects, planners, and landscape engineers. The gardens are designed in open spaces with an environmental design suitable for the hot, dry climate.

4 Urban environmental simulations

ENVI-met is simulating the interactions between atmosphere, vegetation ,soil, and buildings on a microscale level. Every single plant and every urban structure can explicitly be simulated, making ENVI-met the perfect tool for urban planners, architects and urban climatologists who want to simulate the meteorological components of the urban environment [13].

5 Human thermal comfort

Though clearly described, thermal comfort is a fairly complicated notion. This is a result of the requirement to consider many environmental and individual elements. The International Standard ISO 7730 defines human thermal comfort as "that condition of mind in which satisfaction is expressed with the thermal environment." Both environmental and individual variables are among the six that influence thermal comfort. Even though they may not be related to one another, these elements work together to support human thermal comfort.

- Environmental variables like humidity, air velocity, radiant temperature, and air temperature.
- Individual variables: Clothes Insulation and Metabolic heat [14].

5.1. The Physiological Equivalent Temperature (PET)

Is a useful measure for analyzing how solar and wind speed affect thermal comfort and heat storage in urban areas.

Recent research suggests that the PET, rather than indoor-based thermal indices, might be utilized to quantify thermal comfort levels in outdoor situations. Makaremi et al. concluded from their findings that thermal comfort for humans in outdoor spaces of Malaysia's hot and humid environment might be included into design standards to improve outdoor human comfort in tropical places. The PET index is used to determine thermal comfort levels. Table1 describes the ranges of physiological equivalent temperature (PET) for various levels of heat awareness by humans and physiological stress on humans [14].

Table 1. Classification of PET values in terms of the thermal perception and heat stress [15].

PET	Thermal perception	Grade physiological stress
4 c	Very cold	Extreme cold stress
8 c	Cold	Strong cold stress
13 c	Cool	Moderate cold stress
18 c	Slightly cool	Slight cold stress
23 c	Comfortable	No thermal stress
29 c	Slightly warm	Slight heat stress
35 c	Hot	Moderate heat stress
41 c	Very hot	Strong heat stress
>41 c	Very hot	Extreme heat stress

6 Methods and data

This study employs the ENVI-met model to evaluate the influence of solar cells for parking lots and open space vegetation on outdoor thermal comfort characteristics. Simulations need two sets of provided data: the configuration file (.cf) provides the simulation's essential settings and climatic parameters, and the area input file (.in) contains the case study's morphological aspects. The sky irradiance factor describes how much solar radiation the Earth gains (SVF), while the expected mean rating (PET) determines the external physiological temperature. Using 4 scenarios to achieve appropriate thermal comfort

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6.1 Climate of Iraq

The urban microclimate is greatly impacted by architectural elements such as the kind of residential structures and open space between buildings, which affect wind patterns and increase exposure to solar radiation. The study focuses on the physical structure of the built environment and how it influences the thermal comfort of residents in open areas. A residential complex was chosen in the city of Baghdad, and Baghdad was chosen as a model city for the hot, dry climate region. Central region of Iraq.

Iraq is positioned between 29 and 37 degrees north. Baghdad, the capital, is located at 33°19′N, 44°25E and is part of the Middle East and North Africa region. Summers are hot and dry, while winters are chilly and damp. As for Baghdad. Peak summer temperatures surpass 50°C when the average maximum summer temperature is 45°C, and the average temperature exceeds 30°C for 5 months in

Baghdad [10]. Therefore, weather data for the hottest month of the year was chosen on (July 21, 2023) in Baghdad Fig 3.

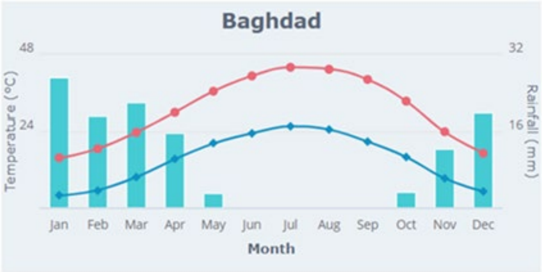


Fig 3. Temperatures during the year in Baghdad [16]

6.2. Study area

According to the objectives and purpose of the study to know the impact of environmental treatments within residential complexes, and their impact on the sustainability of open spaces and environmental performance, The practical study was conducted in a residential complex in Baghdad (Bismaya City Residential Complex) which is distinguished by its modern design as it includes (8) residential sectors. It has an almost identical design in all sectors in terms of the height of the buildings, the choice of the type of trees, and the parking space. Each sector contains residential units ranging from (9,000 - 15,000) units. Each level has (12). Apartment. The case study was conducted in sector B, locality B1. As in the Fig4,5,6,7.

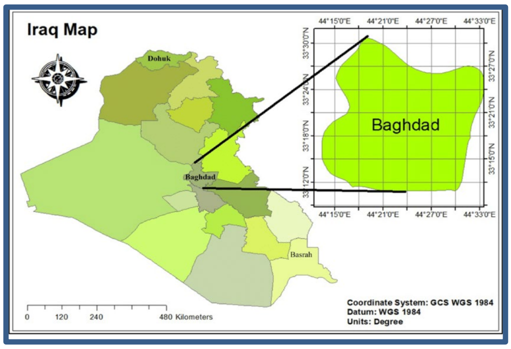


Fig 4. The location of the case study site [17].

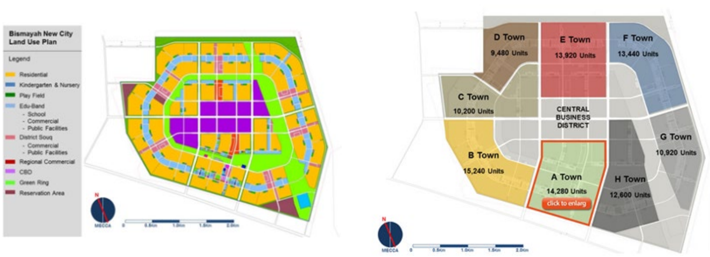


Fig 5: The town plan and developed land use of plan of Complex Residential Basmaya [18].

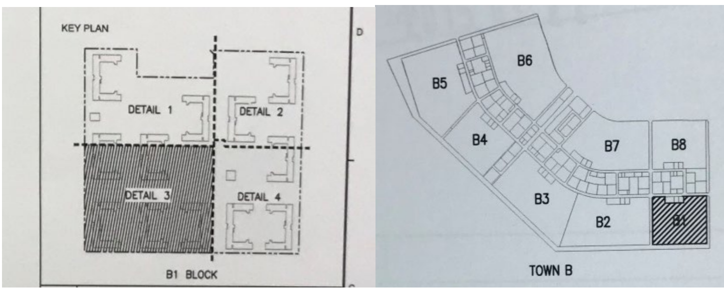


Fig 6: Location of the study area (B1 Block) [19]

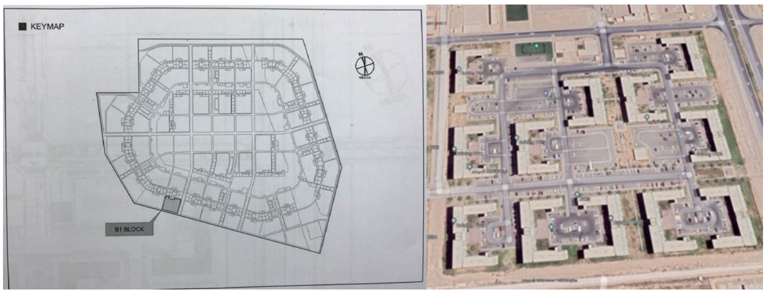


Figure 7: The location of the case study site (researcher use Program Google Earth)

The building style is the same, Design of residential units in the shape of the letter (U). These places include broad roadways and walkways (pedestrian pathways), with street widths ranging from 18 m to 10, and the sidewalks are 2 meters wide.

Asphalt is the main material used in streets, and the interlocking material in sidewalks is 6 mm thick. The buildings are distributed in different directions in each sector, or they are opposite each other in one area. The number of floors is fixed in the entire complex, 10 floors with a height of 30 meters. The trees actually planted in the study area are palm trees as shown in Fig 8. [18].

Fig 8: Bismayah Complex: Photographed by the researcher on 7/21/2023 at 10;00 am

A parking space has been allocated for each residential apartment, as there are two parking spaces in the city of Bismaya, a central parking lot for the city located in the middle, and another parking space for each sector. The number of parking spaces in the study area (Block B1) is 1090, i.e. 0.76% of their need, and the rest of the parking spaces are in the central parking lot [18] fig9.

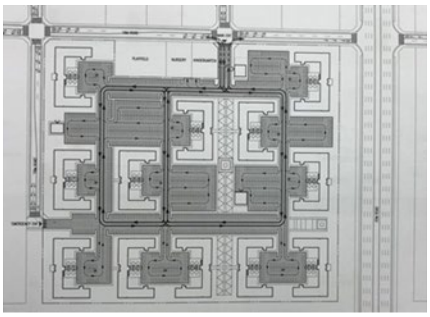


Fig 9: the parking spaces in block B1 in the study area [19].

6.3 Scenarios

Different scenarios (4) were simulated as follows:

- Model(A): represents the current conditions as a diagram of a current reality.
- Model (B): A drawing according to the company’s plan

- Model (C): Design of solar panels for car parks
- Model (D) According to the company's plan, in addition to two types of trees (Albiza) and the Japanese Sophora fig10.

Fig 10: trees (Albiza) and the Japanese Sophora [20]

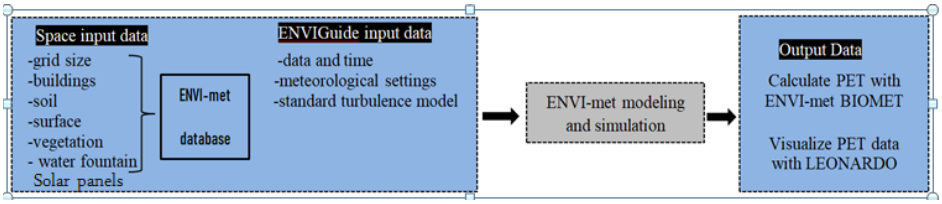
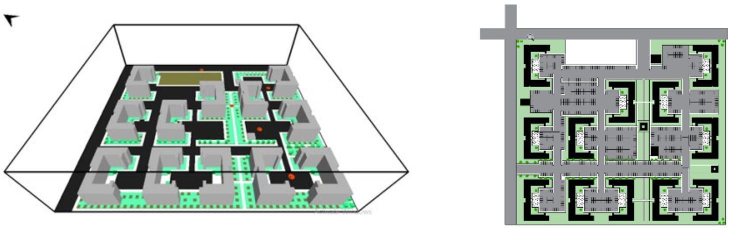


Fig (11): Simulation process for ENVI-met software (researcher).

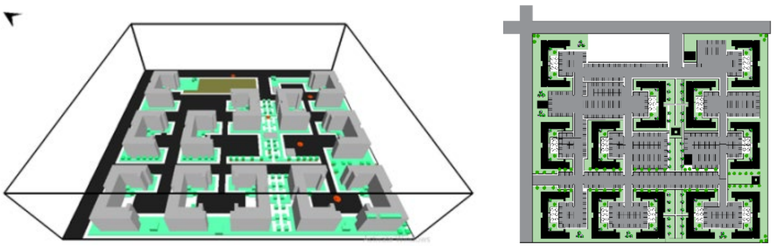
Calculating vital meteorological indicators such as air temperature, relative humidity, wind speed, etc., and urban thermal comfort indicators such as (UTCI, PET ‹PPD or PMV) by (Bio-Met) [21]

All of them is represented at a scale of 90 m 80 m 30 m and a resolution of 4 m 4 m 3 m per unit, yielding a total model area of 360 m 320 m 90 m. Four alternative scenarios were developed. The simulation lasted 24 hours. In addition, eight were positioned in the research area to better assess thermal comfort characteristics. Table 1 displays all of the situations utilized in this study, as well as the number and kind of trees in each one.

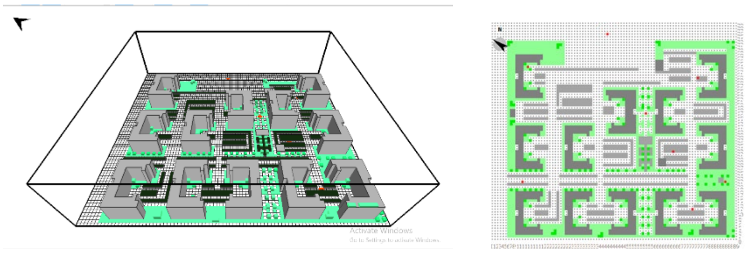
3D Mode (ENVI-met) 2D Mode (ENVI-met)



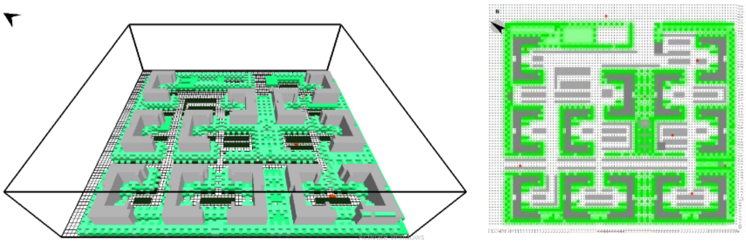
Model (A): represents a simulation of the study area according to the reality of the situation, and we note that the area lacks vegetation cover and represents the highest temperatures in the parking lot.



Model (B): Simulation of the study area according to the plan of the Korean Hanwha Company. We note the addition of vegetation cover and a number of trees in separate areas.



Model (C): Simulation of the study area after adding solar panels to the parking lots. As shown in the design above



Model (D) based on Model (C) and adding two types of trees (Pisa) and Japanese Sophora that are suitable for the hot, dry climate and the climate of Iraq.

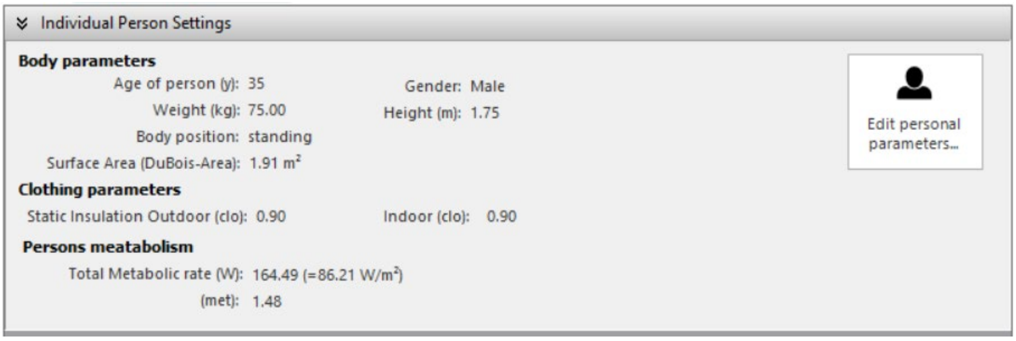


Fig 12: Individual person settings on program envi-met [Researcher]

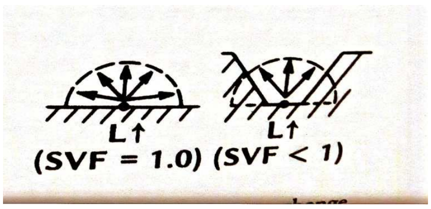


Fig.13: Global limits for the sky width factor range from (0.0-1.0). [15].

Its value ranges from (0 to 1), meaning that the closer it is to (0), the greater the shading, and thus provides thermal comfort fig14.

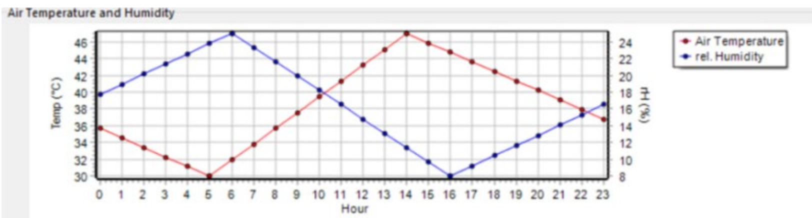


Fig 14: Meteorological data table for the city of Baghdad on July 21, 2023 Source: Researcher, based on the ENVI-MET and program.

Table (2): Temperatures and humidity within 24 hours on July 17, 2023 (researcher based on the ENVI-MET program)

Temperature (C)	Relative Humidity (g/kg)	Time p.m.	Temperature (C)	Relative Humidity (g/kg)	Time a.m.
43.22	14.80	12.00	35.67	17.71	00.00
45.11	13.10	13.00	34.53	18.93	01.00
47.00	11.40	14.00	33.40	20.14	02.00
45.87	9.70	15.00	32.27	21.36	03.00
44.73	8.00	16.00	31.13	22.57	04.00
43.60	9.21	17.00	30.00	23.79	05.00
42.47	10.43	18.00	31.89	25.00	06.00
41.33	11.64	19.00	33.78	23.30	07.00
40.20	12.86	20.00	35.67	21.60	08.00
39.07	14.07	21.00	37.56	19.90	09.00
37.93	15.29	22.00	39.00	18.20	10.00
36.80	16.50	23.00	41.33	16.50	11.00

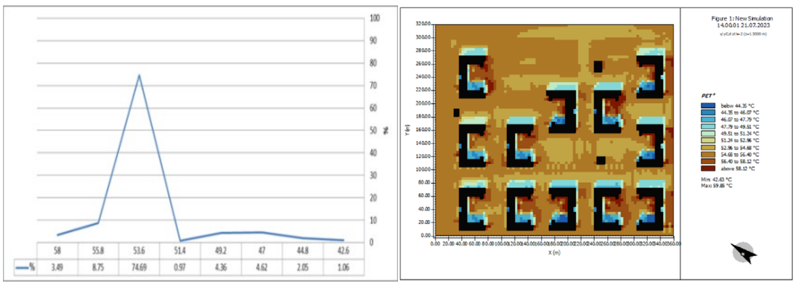
7 Results and Discussion

7.1 Physiological equivalent temperature (PET)

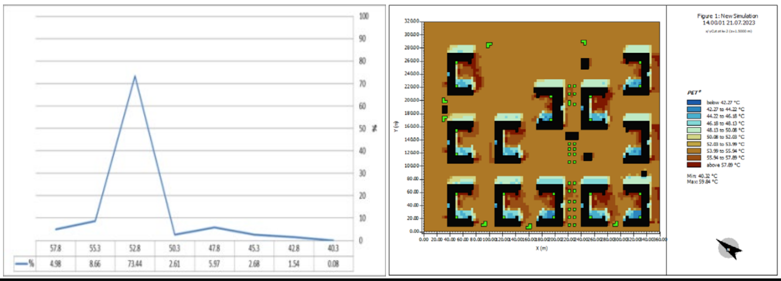
Figure 3 demonstrates the difference between the maps of the thermal comfort index (PET) for the four scenarios in the residential complex at 14:00 noon, and we notice a decrease in temperatures down to the global standard for (PET). For example, the PE index at 14:00 noon.:

- Scenario (A) min temperature 42.63C, max temperature 59.85C, The highest rate 74.69% temperature 53.6C.
- Scenario (B) min temperature 40.32C, max temperature 59.84C, The highest rate 73.44 % temperature 52.8C.
- Scenario (C) min temperature 38.30C, max temperature 59.84C, The highest rate 52.93% temperature 54.5 C.
- Scenario (D) min temperature 34.31Co max temperature 58.50Co The highest rate 35.49% temperature 52.3Co.

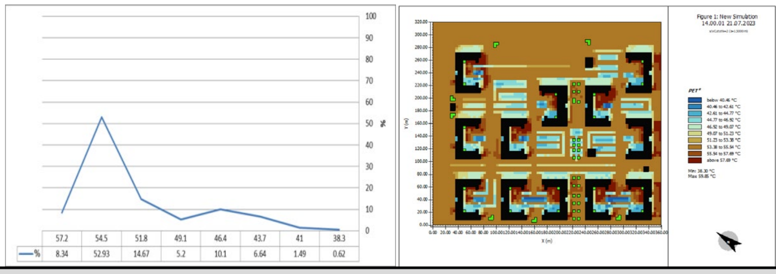
Scenario (A) results at 14.00 pm. at a height of 1.5 meters



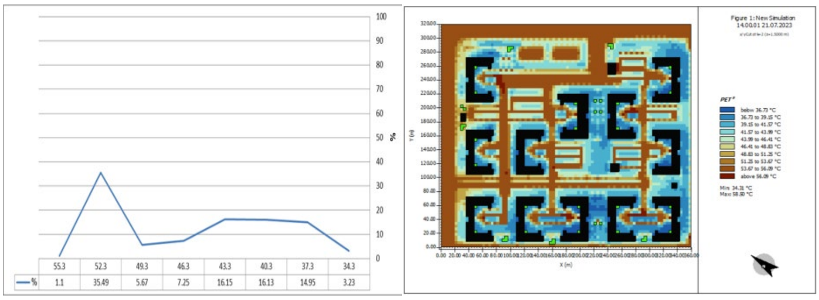
Scenario (B) results at 14.00 pm. at a height of 1.5 meters



Scenario (C) results at 14.00 pm at a height of 1.5 meters



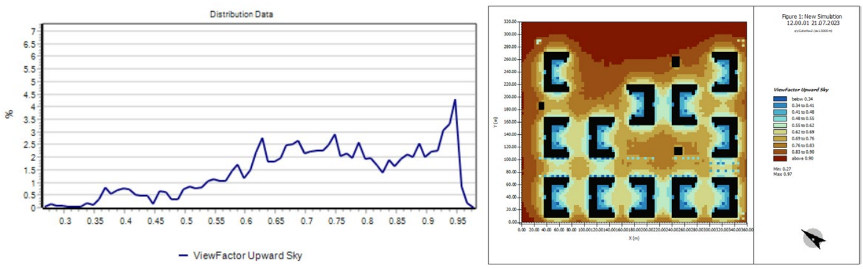
Scenario (D) results at 14.00 pm at a height of 1.5 meters



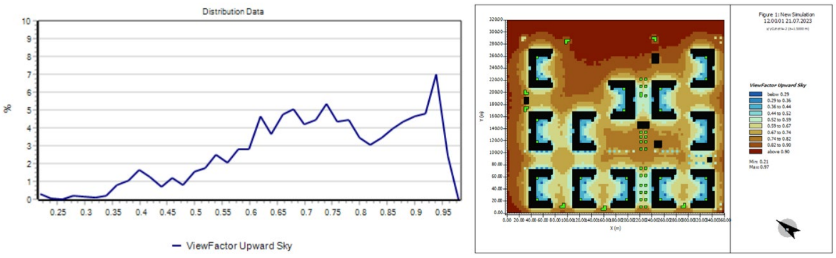
7.2. The sky view factor (SVF)

- Scenario (A): A value of (SVF) less than 0.5 represents a percentage 14.48%.
- Scenario (B): A value of (SVF) less than 0.5 represents a percentage 15.25%.
- Scenario (C): A value of (SVF) less than 0.5 represents a percentage 22.89%.
- Scenario (D): A value of (SVF) less than 0.5 represents a percentage 64.41%

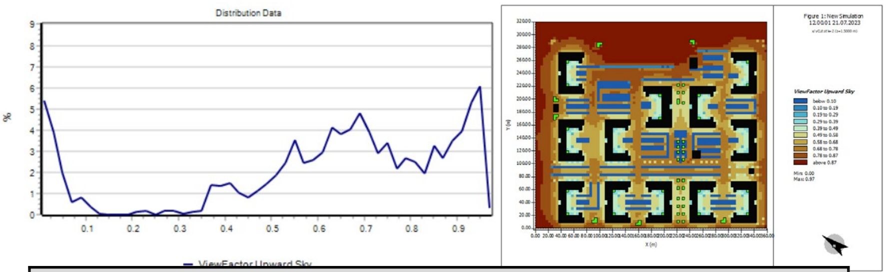
Scenario (A)



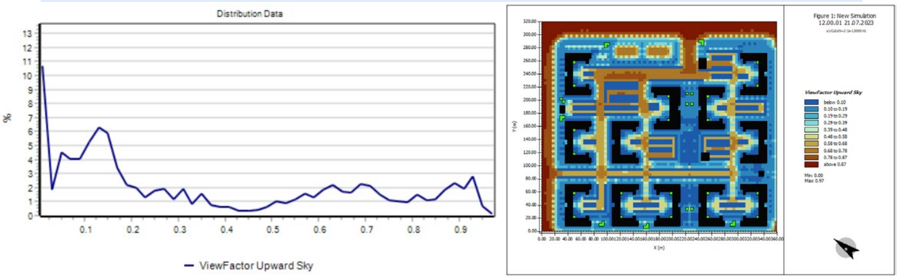
Scenario (B)



Scenario (C)



Scenario (D)



8 Conclusions

This study examined the impact of solar panels and vegetation on the sustainability of open spaces of a residential complex Baghdad's climate is particularly hot and dry. Four alternate scenarios were examined and addressed based on their influence on thermal comfort. The highest temperatures were recorded at 14:00 noon. The conclusions are as follows:

The second scenario: The simulation results showed a difference in temperature from the first scenario due to the addition of a small percentage of trees and vegetation, by a difference of 2.31 degrees Celsius.

The third scenario: The simulation results showed significant differences in temperatures compared to the second scenario after adding the solar panels, with a difference of 2.02 degrees Celsius.

Fourth scenario: The simulation results showed significant differences in temperatures compared to the third scenario after adding two types of trees in open spaces, with a difference of 3.99 degrees Celsius.

As for the minimum temperatures, the results showed that (PET) decreased by 8.32 degrees Celsius, as the lowest temperature in the residential complex was (42.63 degrees Celsius) and became (34.31 degrees Celsius) after using environmental treatments, solar panels, and vegetation.

The results showed that (SVF) had a clear decrease in rate of 0.21. Shading using solar panels and vegetation provides better thermal comfort and lowers the value (SVF) to reach international standards that achieve the best outdoor thermal comfort. Thus, making the residential complexes sustainable.

The results confirmed that using solar panels to shade from the sun's rays provides improved thermal comfort for pedestrians, as well as saves energy for the residential complex and reduces thermal stress at noon. The use of vegetation contributes to proposing an appropriate design to confront climate change in the city of Baghdad, specifically in the summer. Therefore, the results obtained from this study can be considered as a guide for designers regarding urban design studies and thermal requirements in a hot, dry climate.

References

[1] IRAQ POPULATION SITUATION ANALYSIS REPORT: Iraq National Population Commission (INPC) Supported by United Nations Population Fund, 2012, p. 105.
[2] ABRAHEM, S. A. - HASSAN, S. A. - KHAMEES, W.: Impact of Facade Material of Mass Housing on Outdoor Thermal Comfort in Hot-arid Climate, IOP Conf. Ser. Mater. Sci. Eng., vol. 881, no. 1, 2020, doi: 10.1088/1757-899X/881/1/012006.
[3] RADHI, H. - FIKRY, F. - SHARPLES, S.: Impacts of urbanisation on the thermal behaviour of new built up environments: A scoping study of the urban heat island in Bahrain, Landsc. Urban Plan., vol. 113, pp. 47–61, 2013, doi: 10.1016/j.landurbplan.2013.01.013.
[4] AXINTE, E. - VASIE, G. - TELEMAN, E.-C. - RO.CA.V.-E. - AXINTE, A.-O.: Including Solar Panels on Parking Areas in the Sustainable Development Concept. Wind Effects, Environ. Eng. Manag. J., vol. 14, no. 9, pp. 2255–2262, 2018, doi: 10.30638/eemj.2015.240.
[5] ALONSO-MARROQUIN, F. - QADIR, G.: Synergy between Photovoltaic Panels and Green Roofs, Energies, vol. 16, no. 13, p. 5184, Jul. 2023, doi: 10.3390/en16135184.
[6] TOUDERT, F. A.: Dependence of Outdoor Thermal Comfort on Street Design in Hot and Dry Climate, Berichte des Meteorol. Institutes der Univ. Freibg., no. 15, 2005, [Online]. Available: http://www.freidok.uni-freiburg.de/volltexte/2005/2078/.
[7] WU, A. N. - BILJECKI, F.: Roofpedia: Automatic mapping of green and solar roofs for an open roofscape registry and evaluation of urban sustainability, Landsc. Urban Plan., vol. 214, no. May, p. 104167, 2021, doi: 10.1016/j.landurbplan.2021.104167.
[8] BANIBAQASH, A. - HUNAITI, Z. - ABBOD, M.: Assessing the Potential of Qatari House Roofs for Solar Panel Installations: A Feasibility Survey, Solar, vol. 3, no. 4, pp. 650–662, 2023, doi: 10.3390/solar3040035.
[9] ELTEZ, E. B. - ULGEN, K.: The Parametric Design of a Photovoltaic Power System over a Parking Lot, Gazi Üniversitesi Fen Bilim. Derg. Part C Tasarım ve Teknol., vol. 11, no. 1, pp. 55–67, 2023, doi: 10.29109/gujsc.1171126.
[10] HASSAN, S. A.: The impact of residential building's design on the energy consumption in hot desert climate (Baghdad city as an example), no. June 2018, 2019, doi: 10.4090/juee. 2018.v12n1.088092.
[11] XINTE, E. - VASIE, G. - TELEMAN, E.-C. - RO.CA.V.-E. - AXINTE, A.-O.: Including Solar Panels on Parking Areas in the Sustainable Development Concept. Wind Effects, Environ. Eng. Manag. J., vol. 14, no. 9, pp. 2255–2262, 2018, doi: 10.30638/eemj.2015.240.
[12] LOGINOV, D. S.: 31st International Cartographic Conference, Geod. i Kartogr., vol. 999, no. 8, pp. 52–63, 2023, doi: 10.22389/0016-7126-2023-999-9-52-63.
[13] ARAPAKIS, P.: The use of 3D digital models in microclimatic studies: First steps in coupling CityGML with ENVI-met, 2019.
[14] HASAN, A. T.: Human Thermal Comfort Evaluation in Open Spaces of Two Multi-Story Residential Complexes Having Different Design Settings, Duhok-Iraq, Eng. Technol. J., vol. 34, no. 8, pp. 1700–1715, 2016, doi: 10.30684/etj.34.8a.19.
[15] RIDHA, S.: Urban Heat Island mitigation strategies in an arid climate. Is outdoor thermal comfort reachable, no. Lmdc, p. 141, 2017.
[16] Worldweather.com.
[17] Google.com.
[18] Bismayaha.org.
[19] The National Center for Engineering Consultations in Baghdad, Iraq.
[20] Wikipedia.com.
[21] Envi-met.info/doku.php.