Evaluating Urban Thermal Comfort through a Holistic Micro-Climate Model: Baghdad as a Case Study

Baraa A.Ibraheem[1,b)], Zaynab Radi Abaas[2,b)]

[1]Department of Architecture- al-farabi university college.
[2]Department of Architecture- College of Engineering- University of Baghdad[2].

Corresponding E-mail: Baraa.abdulraheem@alfarabiuc.edu.iq [a)],
dr.zaynabr.a@coeng.uobaghdad.edu.iq [b)]

Abstract

Urbanization greatly affects the change in local climate conditions. To address this, urban vegetation needs to be expanded to help dissipate excess heat by promoting evaporation. This study aims to reconnect the urban corridors and spaces of the Al-Mustansiriya region in Baghdad city through a network of green infrastructure (GI), employing the ENVI-MET V4 simulation program, which is a comprehensive micro climate modeling system used to measure and enhance pedestrian comfort levels in an urban environment. The results of the analysis show the significant effect of urban intervention strategies in reducing pedestrian heat stress. Where the air temperature drops by 3-4℃. Furthermore, an association was detected between leaf area density and PET levels. In a broader sense, this research supports the use of ecological urbanization along with integrated urban micro-environment modeling as a catalyst for urban quality improvement.

Keywords: *Thermal Comfort, Green Infrastructure, ENVI-met V4, PET.*

1. INTRODUCTION

A huge shift in population towards urban regions has occurred during the last century, resulting in rapid urbanization around the world [1, 2]. As a result of the increased need for greater living space, today's cities face a slew of transformation issues, including urban sprawl and densification. Furthermore, considerable improvements in supporting infrastructure (e.g., transportation, heating/cooling systems, and water supply) are required. Environmental pollution increased anthropogenic waste heat, and poor outdoor thermal comfort are a few of the consequences of such developments, which significantly impact the urban quality of life. [3, 4] laimed that once the anthropogenic heat flux from the human activity exceeds 3 Wm-2, it may contribute to the expansion of the planetary boundary layer, causing a minor but considerable increase in the atmospheric residence period of particles released from places with high AHF levels. For example, the annual mean anthropogenic heat flow for the area of Austria in 2005 was in the range of 0.6 to 1.6 Wm-2, according to the Climate and Global Dynamics Laboratory (CGD), which is part of the National Center for Atmospheric Research (NCAR) [5]. Increasing vegetation areas, as well as utilizing high albedo materials and urban water bodies, are some of the solutions that may be put in place to assist alleviate the effects of the UHI phenomena [6, 7]. Even though a great number of recent researches have explored the effect of vegetation on urban climate, there is a shortage of knowledge of how different tree species' properties, such as size and layout, might ameliorate thermal comfort [8].

Green areas, on the other hand, are universally acknowledged as being useful for reducing air pollution, lowering daily temperatures, and even promoting mental well-being and facilitating social connections. [9] They discovered that vegetation can moderate summertime air temperatures and that this effect goes beyond the boundaries of green areas, particularly on the leeward side of the green area. Replacing vegetation with alternative tree species, on the other hand, did not appear to have a substantial impact.

Furthermore, [10] evaluated the impact of various urban design strategies on microclimate (e.g., tree planting, de-sealing of paved areas, extensive roof planting) and found that tree planting reduces both mean radiant temperature and air temperature. De-sealing impermeable surfaces can also help reduce the air temperature in highly populated metropolitan areas, particularly downwind of the prevailing wind direction. Roof gardening has a similar cooling impact when used downwind of the wind direction, especially on lower buildings.

This paper seeks to address this by investigating techniques for minimizing UHI impacts in Baghdad's peri-central regions.

The 3D microclimate simulation ENVI-MET V4 is used in the analysis [11]. Several objectives and simulated scenarios were used to test and evaluate the performance and effectiveness of the integrated green infrastructure (GI) concept. The goal was to improve the urban design interventions that were made.

2. GREEN INFRASTRUCTURE (GI) BACKGROUND

A planned network of natural and semi-natural features, such as gardens, trees, green roofs, and other planted areas, is referred to as “green infrastructure" [12] This infrastructure allows for movement between habitat nodes and is connected by suitably vegetated corridors. Through a variety of mechanisms, including direct shading, evapotranspiration, and the urban breeze cycle processes, green infrastructure can alter the city's energy balance [9]

Specifically, the evaporative cooling process that results from the transformation of sensible heat to latent heat combines the transpiration of water vapor from plant leaves into the atmosphere with the evaporation of water from moist surfaces to facilitate the disposal of trapped heat [8].

Under ideal circumstances, evapotranspiration around green spaces and nearby places can reduce air temperatures by 2–8°C [13]. Shading trees also reduce radiation by limiting the amount of heat absorbed and retained. [14] Investigated the impact of Cairo's urban development on the radiant temperature variation in the semi-arid climate of Cairo.

Despite data supporting the usefulness of green infrastructure as a tool for environmental control [15], several biophysical and sociopolitical factors could have an impact on how well it is implemented [16].

This is mainly because there isn't enough room inside the compact urban structure and there isn't enough precise, quantitative information to utilize in demonstrating and quantifying its potential advantages to the right decision makers.

3. STUDY METHODOLOGY

3.1 Study Area

This research is being carried out in Baghdad, the capital of the Iraqi region of almustansiriya, which is located on the eastern bank of the Tigris River at latitude N33.19'32.70' and longitude E44.26'31.2. Residential usage predominates in this area, which accounts for 60% of the total 2636.36 hectares of the study area. The layout of the area is a grid; the area features long striped green spaces between the residential neighborhoods, and the area is encircled by four bridges. The reason for selecting this region is the existence of four notable monuments, the most important of which is Al-Mustansiriya University, one of the oldest Iraqi universities. The second is the presence of Palestine Street, one of the most prominent streets in Iraq. On the southern boundary, there is the "Al-bab Al-Wastani" which is the oldest gate in Baghdad's rounded walls. The fourth is Beirut Square, one of the capital's important medical centers. Figure (1) illustrates the region's land uses.

3.2 Urban Microclimate Modelling

Depending on several meteorological parameters, researchers can determine the level of heat stress on the human body using a PET (Physiological Equivalent Temperature) parameter.

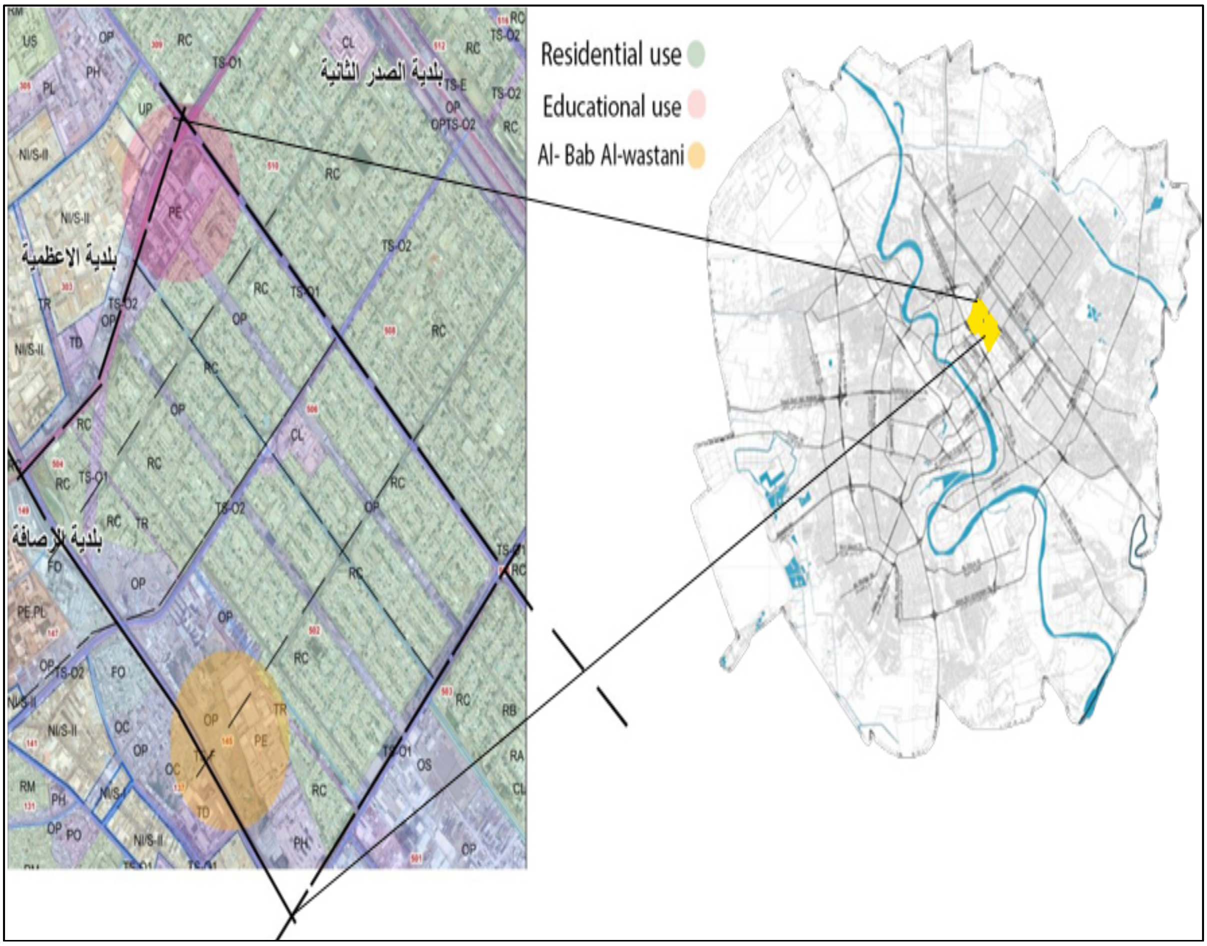


Figure 1. Shows a bitmap of the research area that depicts the region's land use.

PET is defined as the air temperature in a typical indoor environment in which human energy stores are maintained at the same skin temperature and perspiration rate as those under the
Conditions to be evaluated [17]. Taking into account its suitability for measuring the outdoor temperature of the areas.
In addition, Thermal comfort is usually characterized as a state of mind that provides satisfaction with the surrounding temperature. You may feel uncomfortable if the body is too warm or cold, or an unwanted rise in temperature or cooling occurs in a particular part of the body.
Thus, reaching the level of human thermal satisfaction is fundamental to the continuity of urban space. Previous studies have indicated that the comfort zone or neutral level of PET in cold regions ranges from 18

to 23°C, 8-18°C is considered slightly cool, while 23 to 35°C is considered hot [18]. However, studies have shown that people can react differently to heat stress under different climatic and cultural conditions. While comfortable PET results can be as high as 30°C in hot climates, comfort at 23°C can be achieved in colder climates, which may apply to Baghdad [19].
By ISO 7730 (W), the inputs to the model adopted a human work change process, doing light work of 80 W, weighing 75 kg, walking speed of 1.21 m/s, and clothing insulation (Clo) of 0.90 kg in summer as used in the studies [19].

3.3 ENVI-MET V4

ENVI-Met is a 3D urban design simulation model, developed in 1993 by Michael Bruse, in microclimates that can revitalize surface-plant air within an urban environment [20]. The ENVI-Met software is among the main modeling devices used to predict microclimatic conditions during urban design and development.
This program calculates climatic conditions, such as air temperature, relative humidity, wind speed, radiant temperature, and surface temperature, taking into account the different reflections from the surfaces and green properties [21]These outputs are represented with different visualizations in LEONARDO, (which is included in ENVI-Met 4.4). ENVI-Met inputs were obtained during summer 2018 at the peak heat hour of 3:00 PM. The summer solstice, which falls on June 21, is the longest day of the year.
This date was chosen as a simulated date due to the high sun exposure and maximum heat stress available on that day. The duration of the overall simulation of atmospheric parameters spanned hours 24 starting at 6:00 AM. All microclimatic parameters were obtained from the Abu Ghraib meteorological station in Baghdad. Table (1) shows the input simulation data.
According to the ASHRAE 2017 Climatic Design Terms, Baghdad's climate is classified as an extremely hot climate with the highest average temperatures (34.2 °C to 36.3 °C) in June, July, and August. July is the hottest month, with an average annual temperature of 24.2°C with a maximum of 50.9°C based on data collected by Baghdad over the past 50 years.

3.4 Simulation and scenarios of urban changes

The research adapted seven chosen points in two scenarios. Each point represents a different position and different urban structure. As shown in Figure (2). The first scenario (base scenario) represents the current status of the district before any intervention, and the second scenario incorporates green infrastructure as a solution to the existing problem in the selected area.
This scenario as shown in Figure (3) involves connecting the area to a network of green infrastructure; green hubs connecting to the three existing nodes in the area; providing waterways; and replacing the entire surface of the site area with locally available paving materials. The main objectives are to increase the material's LAD and increase its efficiency. The scenario includes the establishment of an environmentally friendly garden at point A, activating the neglected space surrounding Al-bab Al-wasting, and reconnecting the area with heritage, which enhances the feeling of cohesion and belonging to the spaces due to their connection with a historical value.

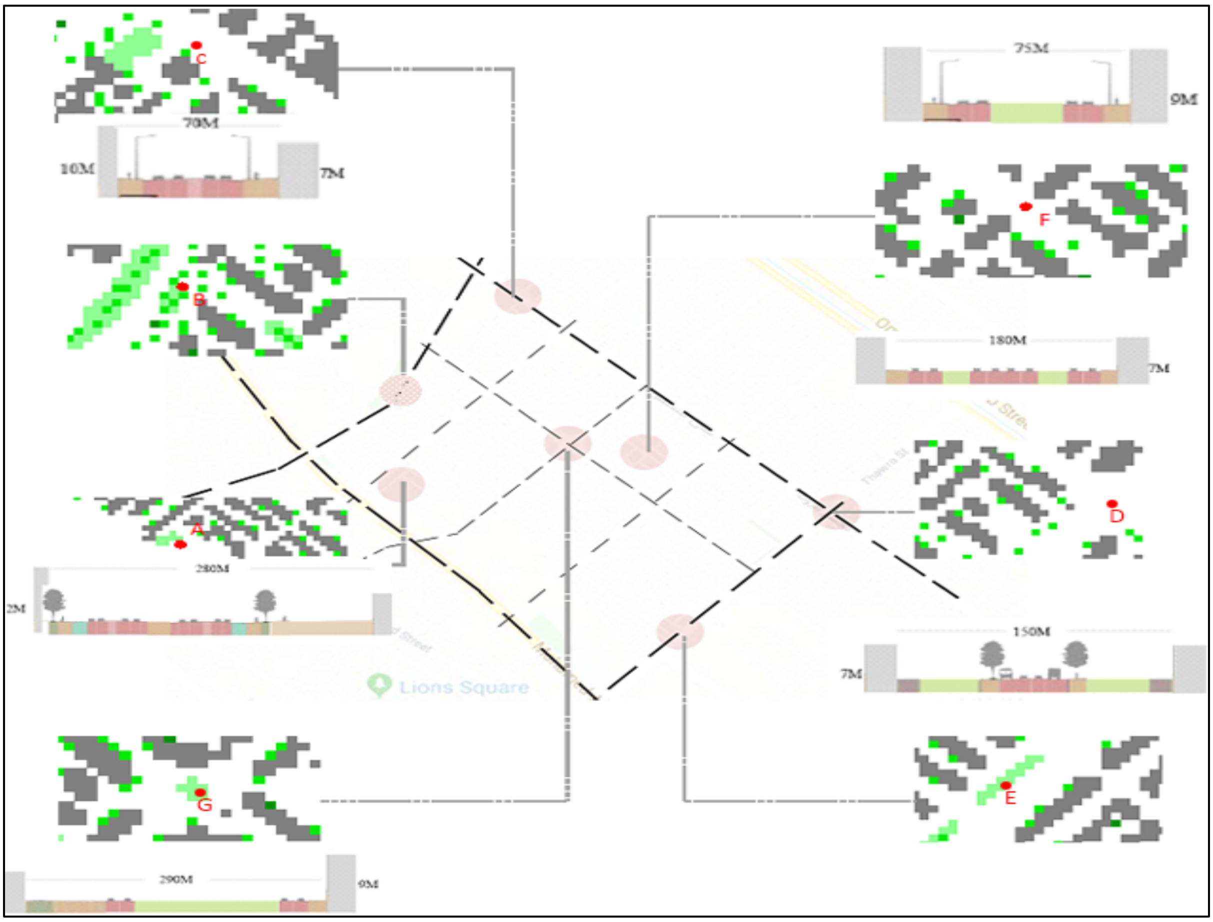


Figure 2. The seven selected points are shown in the ENVI-Met software interface of the study region.

Table 1. Simulation data.

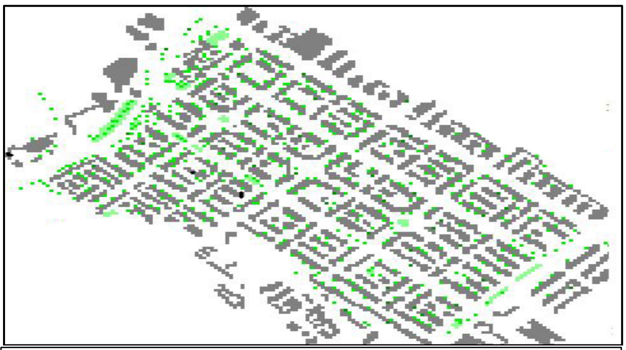
Simulation start time	**06:00:00am**
Simulation duration	24h
Wind speed	2.50
Wind direction	270
Grid cell dimensions	Dx=14, dy=12, dx=2
Model dimensions	X=160,Y=140, Z=30
Total area dimension	2240*1960m

The first main axis of the GI is the axis of the connection between the three activities and urban spaces as the GI's primary network. The linear spaces serve as a secondary network that feeds the primary network to make it an integrated network that incorporates urban spaces and provides free access to green spaces that improve community relations, revitalize vital activities, encourage walking, and provide green parks for residents to mix and communicate within. The park serves as a lung for the community by providing the ideal climate to increase the flow of people and improve the health and wellbeing of the locals. The use of both Albizia and palm trees is appropriate for Iraqi weather, as these trees grow quickly and are resistant to severe conditions. Using high whiteness paving materials as mentioned in Table (2).

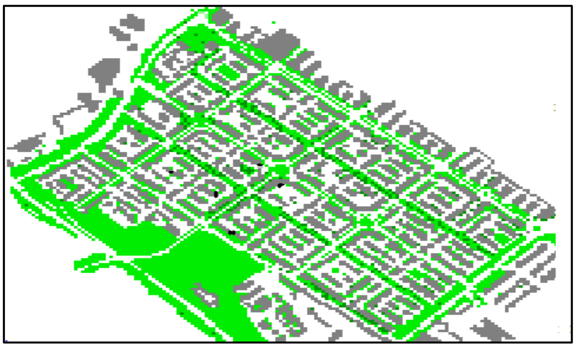
Table 2. Material and pavement type and albedo.

point	Current materials	albedo	Baveme nt	albedo		Suggested material	albedo	Suggested bavement	albedo
(A) (25.51)	Xx Grass 50cm aver. Dense	0.2	00 Soil	0.2		AJ Albizia Julibrissin 12 m crown, width 11 m	0.6	TB Terre pattue (Smashed Brick(	0.8
						PW Palm Washingtonia	0.2	DR Test Lane	
						H2 Hedge 2 m	0.2		
(B) (35.87)	H2 Hedge 2 m	0.2	ST Asphalt road	0.225		AJ Albizia Julibrissin 12 m crown, width 11 m	0.6	TB Terre pattue (Smashed Brick)	0.8
						PW Palm Washingtonia	0.2	DR Test Lane	
(C) (61.125)	XY Grass 50 cm aver. Dense	0.2	ST Asphalt road	0.225		GG Grass aver,dense 50 cm	0.2	PP Pavement concrete used dirty	0.4
						AJ Albizia Julibrissin 12 m crown, width 11 m	0.6	DR Test Lane	
(D) (155.47)	XY Grass 50 cm aver. Dense	0.2	ST Asphalt road	0.225		01PDISD Dense small 5 m	0.2	PL Concrete pavement light	0.8
(E) (135.30)	XY Grass 50 cm aver. Dense	0.2	00 Soil	0.2		PW Palm Washingtonia	0.2		
)G((80.72)	Xx Grass 50cm aver. Dense	0.2	ST Asphalt road	0.225		AJ Albizia Julibrissin 12 m crown, width 11 m	0.6	PP Pavement concrete used dirty	0.4
(F) (103.6)	GG Grass aver, dense 50 cm	0.2	00Soil	0.2		AJ Albizia Julibrissin 12 m crowns, width 11 m	0.6	TB Terre pattue (Smashed Brick(	0.8
								Test Lane DR	

A-Base scenario



B- GI scenario



- The second scenario represents the activation of urban spaces in the region.
- The use of palm trees and trees Albizias and Short Shrubs, which are of high whiteness.
- The use of water-permeable paving material to collect rainwater.

- The first scenario represents the current state of the region
- The presence of grass and short shrubs
- And palm trees and trees
- Use of asphalt for paving

Figure 3. Framework details for the two scenarios.

4. SIMULATION RESULTS

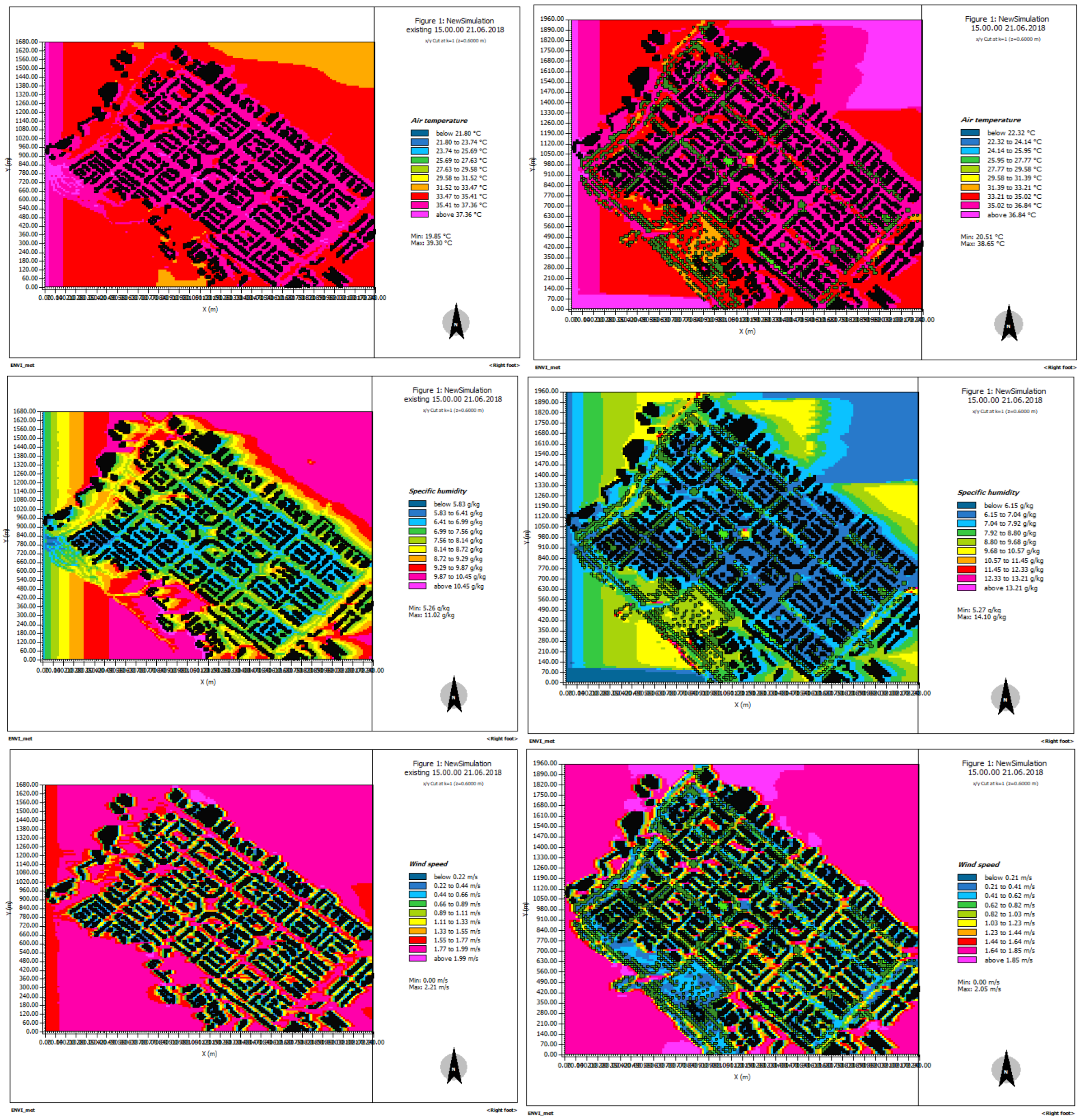
a- Air Temperature

We note from Tables 3 and 4, which the air temperature at point A at 3 o'clock decreases by 3 degrees Celsius after the activation process and represents the best results in terms of thermal comfort. Where the area is open, the canopy of trees helps to reduce temperatures. The same applies to point B for the width of the street and the presence of urban spaces on both sides of the street, as is the case for point E. As for point G, we notice a decrease in temperature by 2.5 degrees Celsius.

b - Relative humidity

Green areas and a high degree of whiteness (LAD) caused an increase in relative humidity and a decrease in temperature. In point A, we observe that when trees are added and LAD rises, the relative humidity also increases. Additionally, the presence of waterways increases the relative humidity, but the relative humidity is still low.

(a) (b)



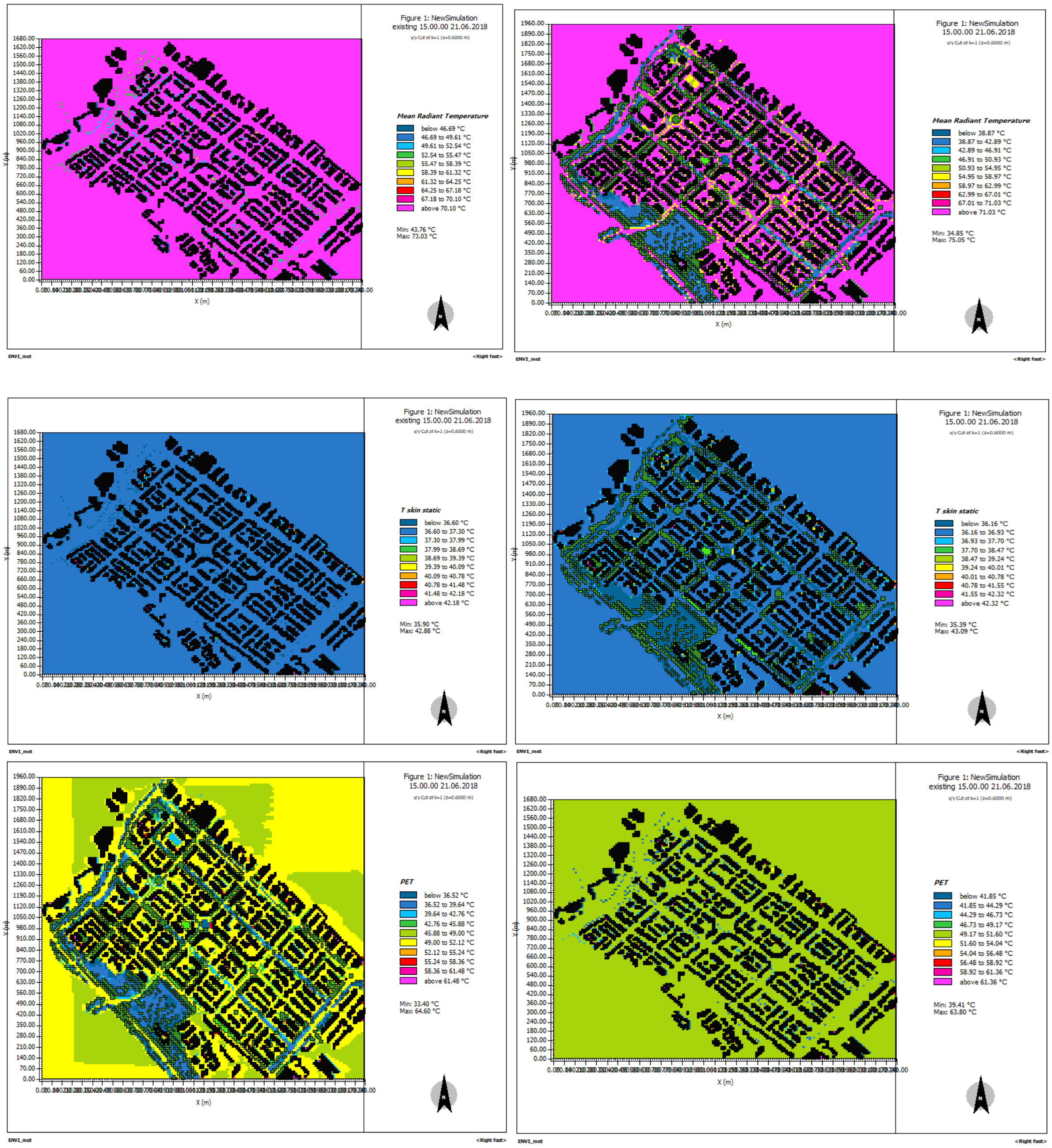


Figure 4 a. Base model Visualizations of Baghdad produced by the LEONARDO modeling program.
b. GI model Visualizations of Baghdad produced by the LEONARDO modeling program.

C-Wind speed

We notice that when afforestation increases, the wind speed decreases, as the trees act as natural windbreakers, except for points C and D, where the wind speed increased in this case, but the wind speed factor did not play an important role in improving the local climate and obtaining better PET results in this region.

d- Mean radiant temperature

We note a significant decrease in the degree of radiation of about thirty degrees Celsius in the entire region. As shown in Tables 3 and 4, these positive results indicate the importance of reducing radiation and its ability to reduce UHI and control the outside temperature as a result of the increase in afforestation and high-whiteness materials that contributed to reaching the thermal stage.

e-T—skin static

Surface temperature is a critical factor because it depends on many variables, including social and economic changes such as population density, human activities, carbon dioxide emissions, and urban surface features such as structural density, albedo characteristics, and vegetation characteristics. With the ENVI-Met simulation, social and economic differences are not measured, and the focus is on vegetation cover, paving materials, urban structure, and their proportion. F-Physiological Equivalent Temperature (PET)

PET results for all points were obtained at 3 p.m. using LEONARDO modeling software. The PET area is located between neutral or comfort levels, meaning that increasing urban albedo in urban spaces of hot and dry climates, and neglected spaces, is a successful process of reducing UHI and thus creating a comfortable climate for interaction and communication.

Figure 4, and Figure 5 demonstrate how the two scenarios differ in terms of thermal comfort factors.

Table 3. Base scenario simulation results from LEONARDO, at three o'clock in the afternoon.

points	air temperature	relative humidity	Wind speed	Degree of radiation	T skin static	PET
(A) (30.53)	35.6C	8.3	1.78 ms	72.6 c	36.9c	49.7
(B) (35.87)	35.1c	8.7	1.6	72.2	36.8	49.4
(C) (61.125)	35	8.6	1.9	72.5	36.8	49.4
(D) (155.47)	36.1c	8.6	1.8	72.7	36.9	49.8
(E) (135.30)	37.4c	6.9	1.5	72.6	36.9	50.1
(G) (80.72)	35.5c	7.8	1.8	72.2	36.9	49.7
(F) (101.7)	35.5	7.4	1.7	73	36.9	49.9

Table 4. GI scenario simulation results from LEONARDO, at three o'clock in the afternoon.

points	air temperature	relative humidity	wind speed	degree of radiation	T skin static	PET
(A) (30.53)	32.6	9	0.4	38.6	35.5	34.82
(B) (35.87)	33.3	9	0.57	40.8	35.6	36.5
(C) (61.125)	33.8	9.2	1.3	40.3	35.5	35.5
(D) (155.47)	32.8	10.7	1.3	39	35.6	36
(E) (135.30)	32.8	9.8	0.6	40.44	35.7	35.8
(G) (80.72)	32	10.3	0.3	37.8	35.6	34.9
)F((101.7)	32.9	9.5	0.25	37.5	35.5	35

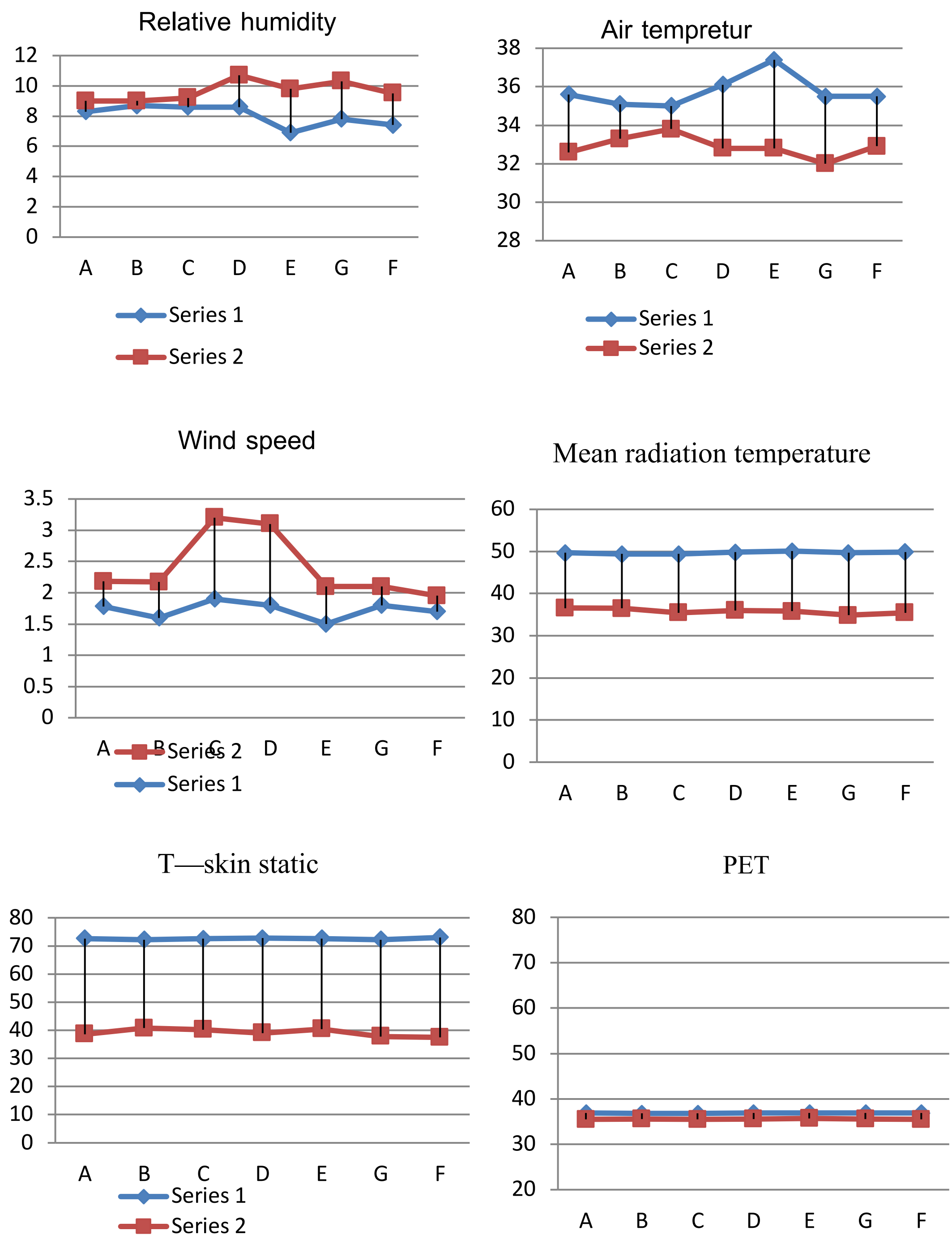


Figure 5. Illustrates the difference in thermal comfort variables between the two scenarios

The physiological equivalent thermal comfort was calculated at three o'clock in the afternoon, where the maximum heat load is followed in the program's calculation mechanism, knowing that this hour does not represent the hours of the presence of residents and users of urban spaces. Given the importance of knowing the climate adaptation and the extent of development and change in the thermal comfort of the spaces, the comfort (PET) was calculated in the hours of people's presence (9–12 am) and the hours (6–10 pm), as noted in the chart 2. According to the graph, the equivalent physiological comfort rate in the region reached 27 at 10 a.m. and 28 at 7 p.m., which is within the limits of thermal comfort for Asian countries.

The simulation results showed that the first case of the urban area exacerbated the urban climate, where *the* climatic conditions are not suitable for living, interaction, or the practice of daily life activities. As for building the predictive urban-environmental model, a significant decrease and change were observed when modifying the spaces and adding trees, waterways, and roofs, as the vegetation cover contributed to reducing the temperature by two degrees, from 35 to 33 degrees Celsius.

The average relative humidity ranged from 7 to 9, the wind speed from 1.7 to 0.5, and the degree of radiation from 71 to 40. These factors contributed to achieving a comfortable and suitable PET reaction (from 45 to 35).

The simulation results showed the effect of the urban fabric structure in the area and the ratio of the building height to the street width ratios. Therefore, narrow spaces can be easily shaded by the surrounding buildings, and the use of trees and paving materials of high whiteness affects the effect of the UHI heat island positively, and the effect can be negative. The reason for this is that trees can be strategically placed and thus have the opposite of the desired effect. Therefore, the best tree species suitable for the local climate of the area, their locations, and materials for each UHI-reduced urban structure must be determined by professionals.

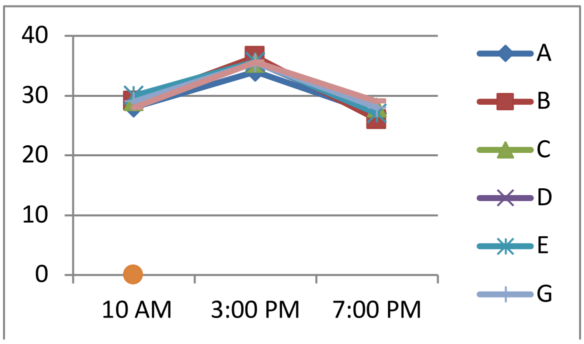


Chart 2 depicts pet thermal comfort at (10 a.m.-3 p.m.-7 p.m.).

5. CONCLUSION

The potential advantages of introducing GI in reconnecting urban space were calculated in this study using climate modeling and ENVI-Met simulation. It was feasible to determine differentiating patterns in the performance of air temperature, relative humidity, radiant temperature, and wind speed for two scenarios: a base scenario and a GI scenario, using this modeling software.

The results demonstrate prospective air temperature decreases as a potential result of the implementation of a GI project, comprising new vegetation features, modifications to land cover, and the addition of water bodies, for a summer day. For the specific study, green infrastructure worked effectively, showing that it is feasible to transform cities towards a greener and more creative models. This idea enhances urban resilience and livability while offering substantial promise for reducing the effects of climate change and adapting to it.

REFERENCES

[1] U. Nation, "World Urbanization Prospects 2018: Highlights," Department of Economic and Social Affairs, Population Division, 2019.

[2] L. Schell, M. Smith and A. Billsborough, "Human biological approaches to the study of Third World urbanism," Urban ecology& health, pp. 1-9, 2009.

[3] M. G. Flanner, "Integrating anthropogenic heat flux with global climate models. Geophysical Research Letters," vol. 36, no. 2, p. 5, 2009.

[4] K. Jin, F. Wang, D. Chen, H. Liu, W. Ding and S. Shi , "A new global gridded anthropogenic heat flux dataset with high spatial resolution and long-term time series," Scientific Data, vol. 6, no. 139, p. 14, 2019.

[5] CGD, 2019. [Online]. Available: http://www.cgd.ucar.edu (accessed on 16 August 2019).

[6] L. Chengyan and W. Kuan, "Urban Green Space System and Human Settlement Environment Planning," Green Technology, vol. 23, no. 11, 2021.

[7] E. Ng, L. Chen, C. YUAN and Y. Wang, Building and Environment, vol. 47, p. 256–271, 12.
[8] D. E. Bowler, L. Buyung-Ali, T. . M. Knight and A. S. Pullin, "Urban greening to cool towns and cities: A systematic review of the empirical evidence," Landscape. Urban Plan, vol. 97, p. 147–155, 2010.
[9] A. Dimoudi and M. Nikolopoulou, "Vegetation in the urban environment: microclimatic analysis and benefits," Energy Build, Special issue on urban research, vol. 35, no. 1, pp. 69-79, 2003.
[10] K. Hagen, B. Gasienica-Wawrytko, W. Loibl, S. Pauleit, R. Stiles, T. Tötzer, H. Trimmel, M. Köstl and W. Feilmayr, "Smart Environment for Smart Cities: Assessing Urban Fabric Types and Microclimate Responses for Improved Urban Living Conditions," in Proceedings REAL CORP 2014 Tagungsband, 2014.
[11] M. Bruse, 2015. [Online]. Available: http://www.envi-met.com.
[12] E. Fernández-Juricic, "Spatial and temporal analysis of the distribution of forest specialists in an urban-fragmented landscape (Madrid, Spain): Implications for local and regional bird conservation. Landsc. Urban Plan.," p. 17–32., 2004.
[13] H. Akbari, P. M and H. Taha, "cool surfaces and shade trees to reduce energy use and improve air quality in urban areas," Solar Energy, vol. 70, p. 295–310, 2001.
[14] M. Fahmy, S. Sharples and M. Yahiya, "LAI based trees selection for mid-latitude urban developments: A microclimatic study in Cairo, Egypt," Building and Enviroment, vol. 45, p. 345–357, 2010.
[15] S. GILL, . J. HANDLEY, . A. ENNOS and S. PAULEIT, "Adapting cities for climate change: The role of the green infrastructure," Built Environment, vol. 33, p. 115–133, 2007.
[16] J. A. Byrne and Y. Jinjun, "Can urban greenspace combat climate change? Towards a subtropical combat climate change? cities research agenda," Australian Planner, vol. 46, p. 36–43, 2009.
[17] L. Chen, Y. Wen, L. Zhang and Wei-Ning , "Studies of thermal comfort and space use in an urban park square in cool and cold seasons in Shanghai," Building and Environment, vol. 49, pp. 644-653, 2015.
[18] M. R. M. Daneshvar, A. Bagherzadeh and T. Tavousi , "Assessment of bioclimatic comfort conditions based on Physiologically Equivalent Temperature (PET) using the Rayman Model in Iran," Central European Journal of Geosciences, vol. 5, p. 53–60, 2013.
[19] Z. R. Abaas, "Impact of development on Baghdad's urban microclimate and human thermal comfort," Alexandria Engineering Journal,, p. 16, 2019.
[20] W. N. Hien, "Urban heat island research: Challenges and potential," Frontiers of Architectural Research, p. 276–278, 2016.
[21] F. Salata , I. Golasi, E. D. L. Vollaro, F. Bisegna, F. Nardecchia, M. Coppi, F. Gugliermetti and A. D. L. Vollaro , "Evaluation of Different Urban Microclimate Mitigation Strategies through a PMV Analysis," Sustainability , vol. 7, no. 7, p. 2015.
[22] D. E. Bowler, L. Buyung-Ali, T. M. Knight and A. S. Pullin, "Urban greening to cool towns and cities: A systematic review of the empirical evidence," Landscape and Urban Planning, vol. 97, no. 3, pp. 147-155, 2010.