ACTA Acta Sci. Pol., Administratio Locorum 21(4) 2022, 529–538.
https://czasopisma.uwm.edu.pl/index.php/aspal plISSN 1644-0749 eISSN 2450-0771 DOI: 10.31648/aspal.7879

ORIGINAL PAPER
Received: 08.06.2022 Accepted: 19.09.2022

URBAN ADAPTATION IMPACT ON OUTDOOR THERMAL COMFORT IN EDUCATIONAL COMPLEXES

Sarah Mohammed Jameel[1]✉, Susan Abed Hassan[2]✉

[2] ORCID: 0000-0002-3438-049X
[1] University of Babylon
P.O. Box 4, Hillah, **Iraq**
[2] Al-Nahrain University
P.O. Box 64040, Jadria, Baghdad, **Iraq**

ABSTRACT

Motives: This paper investigates the urban adaptation elements (vegetation cover, water bodies, and different shading patterns) effect on the outdoor thermal comfort for pedestrians in the educational complexes.
Aims: The aim of the research is to determine the impact of urban elements on outdoor thermal comfort in an educational campus with a hot-dry climate, the city of Babylon as an example, The research methodology depends on the ENVI-met program to simulate the case study.
Results: The results showed that urban adaptation elements which are the soft components of the environment include (vegetation cover, water bodies, and different shading patterns) can reduce the temperature by about 3 degrees Celsius in addition to reducing the mean radiant temperature by 8 degrees Celsius and reducing the sky view factor (SVF) by 20%.

Keywords: global warming, outdoor thermal comfort indices, ENVI-met, urban heat island, soft components, thermal adaptation

INTRODUCTION

Urban adaption is one of the strategies that can improve the outdoor environment in cities (Nasir et al., 2018; Archer et al., 2014; Manteghi, 2021). It is the process of dealing with actual and expected climate and climate risks with the aim of reducing negative effects such as reducing greenhouse gas emissions or reducing weather-related deaths (due to heat waves) and economic losses from extreme weather events, that adaptation to climate change include (urban energy transition, urban mobility, and the circular economy of cities, sustainable land use, and nature-based solutions in cities). It is an iterative process, and the adaptation process may be a local process due to the geographical, social, demographic, or economic characteristics of a particular place. Urban adaptation highlights the main issues that must be considered when planning and implementing adaptation. There are five essential steps to applying adaptation, designing an effective adaptation action plan, finding examples of adaptation action plans, mainstreaming, adaptation in urban policies and plans, addressing climate change through adaptation and mitigation, and implementing adaptation: Self-check (European Commission, 2022; Notre Dame Global Adaptation Initiative, 2022).

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

These main steps are divided into sub-steps, and for each sub-step, a summary of the specific problem is provided, followed by more detailed instructions. Adaptation includes a variety of methods, including the development of green spaces, climate-resistant infrastructure, and the establishment of vertical gardens, for example (by incorporating trees and plant life in urban architecture, where trees absorb carbon dioxide and convert it into oxygen and cool the environment, thus saving Protection in the hot months of the year.

The most common and environmentally friendly strategies that are used to improve heat sensitivity in hot, dry climates are tree planting and vegetation, which play an important role in the amount of solar radiation absorbed by roofs. Urban trees can modulate air temperature, increase humidity, reduce wind speed, reduce air pollutants, and have effects on the city's bioclimatic conditions, mean radiant temperature, and the human thermal index. Air temperature can also be affected by green coverage and leaf area index (LAI), which are important tree characteristics. Specific features of trees such as structure, tree top density, size, shape, and colour affect the performance of solar radiation, temperature, and air humidity. The amount of shade that trees provide depends on factors including the tree's canopy cover, the types of plants, and the arrangement of plants in the space. Tree shade is a rather adaptation strategy, especially for pedestrians in hot daytime. The use of roofs, arches, and columns (corridors), it is considered one of the elements of protection in a hot and dry climate, which provides shading by reducing solar radiation and thus enhances thermal comfort for humans. Where shade is a prerequisite for cooling outdoor spaces. The importance of shading is:

1. Protection from solar radiation, which has more physiological effects on reducing heat stress than on lowering the air temperature in outdoor spaces.
2. Shading does not include any expenditure of energy or water for irrigation to reduce the air temperature.

The design of the water elements positively affects the local climate by lowering the outside temperature through evaporative cooling, in addition to the fact that the fountains reduce the humidity in the air. And that these systems can reduce resource consumption and reduce long-term operating costs and offset the use of air conditioners.

LITERATURE REVIEW

Ridha et al. (2018) discussed possible mitigation strategies to ensure the improvement of thermal comfort at the pedestrian level in a designed area (high-rise buildings, large distances between buildings, lack of vegetation cover), by using the descriptive analytical approach and presenting four different scenarios to evaluate the role of vegetation elements and different shading patterns using the ENVI-met program. The study concluded that it is possible to reduce the physiological comfort index (PET) and reduce the temperature and the expected comfort coefficient PMV through vegetation cover and shadows (Ridha et al., 2018). The study of Othman et al. (2019) focused on conducting a field study on the campus of UPM University (University Putra Malaysia) by using a descriptive-analytical approach and assessing the thermal comfort of shaded outdoor environments in the hot and humid context of Malaysia and calculating the degree of temperature PET equivalent heat as a thermal indicator for outdoor environments using the Rayman program. The study found that the use of vegetation surfaces and site conditions that provide shades and suitable roofs have a significant impact on outdoor thermal comfort (Othman et al., 2019). While the study of Hwang et al. (2009) dealt with field experiments on the campus of the National University of Formos (NFU) using the method of comparative analysis, by selecting several sites with different levels of shading in different months to clarify changes in thermal conditions in seasons and comparing the measurement results for six selected sites within the university campus with the simulation results using Rayman program. The study concluded that areas with little or excessive shading have short thermal rest periods, and sufficient shading must be provided in trees and buildings to improve thermal comfort in summer (Hwang et al., 2009).

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

As for the study of Shashua-Bar et al. (2011) the comparative analytical method was used to show the effects of different landscape formations on heat and stress assessment using the data measured in two semi-enclosed (courtyard) spaces using Computing and virtual energy exchange between the urban environment and pedestrians in space. The study was conducted at the Ben-Gurion University Boker Campus in Negev Heights (30°50'N, 34°40'E) during the month of July to August. The study found that the urban treatment (trees and grass) achieves the highest levels of cooling and efficiency is achieved using the water element. It also showed that the vegetation cover contributes to thermal comfort not only by direct shading of the person, but by reducing long-wave emissions from the surfaces of the yard and by reducing from the amount of solar radiation reflected from them (Shashua-Bar et al., 2011).

MATERIALS AND METHODS

The study area

Babylon governorate is located in the central part of Iraq on the Euphrates River, where it is located at latitude 44° east and longitude 34° north. The city's climate is known to be hot and dry in summer and cold in winter. The maximum temperature recorded was 50°C in the summer. The study area is the University of Babylon, located in the city of Hilla (90 km south of Baghdad), about 14 km from the centre of the city of Hilla. The University of Babylon can be reached from 3 main roads: Baghdad-Babil Road, Babylon-Najaf Road, and Karbala-Babil Road. The main university complex includes 9 colleges with low-rise buildings with relatively close distances between the buildings. The number of employees at the university is about 2,869, while the number of students is 25,462 (University of Babylon, 2022). Figure 1 shows the geographical location of the university in relation to the city and the chosen study area.

ENVI-met program simulation

It is a three-dimensional digital program and model to simulate the interactions between surface, soil, and air in the urban environment. It is used to simulate the effect of urban vegetation cover on the urban microclimate (Zhang et al., 2017), and it also allows analysing the effects of small changes in urban design (trees, greening of internal courtyards, new buildings) on the local climate under medium-sized conditions. Several studies have proven the reliability of using ENVI-met to simulate the thermal performance of outdoor spaces, as these studies indicated that the data measured at local weather stations seem to be consistent with the data shown in the simulation (Sayad et al., 2021; Parapari, 2018; Ayşegül et al., 2020; Chen & Ng, 2013).

Data entry for the model

The weather data used to start the simulation model was provided by the Meteorology and Seismology Authority (World Weather Online, 2022). The characteristics of the local climate represent the air temperature and relative humidity for June 21, 2021, the longest day of the year in terms of daylight hours and the hottest of the regional weather conditions. The basic meteorological settings for the initial conditions of the climate were 5 m/s for wind speed and 315° for wind direction. The simple effect of air temperature and relative humidity was used over a period of one day, where the maximum temperature was 46°C at 12:00, the lowest relative humidity was at 6 pm by 25%, and the maximum relative humidity at 6 am was (35%) (Time and Date, 2022). The total simulation time in the program is (24 hours). The total area specified for the study is (77 m* 86.5 m), the model area was made with the size of the grid (x=50, y=50, z=40), and the size of the grid is represented in the work of the program grid cells, which is: dx=1, dy=1, dz=2, the direction of the site relative to the main north direction is 15°.

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

Fig. 1. The geographical location of the university in relation to the city and the chosen study area
Source: own preparation.

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

Forming the model

The simulation work within the program focused on analysing the thermal comfort of humans at the pedestrian level in two models (the reality of the situation, the development proposal) and using different strategies for greening such as grass and different types of trees (palms and citruses) because they are local and evergreen trees (Ridha, 2017). A specific pattern of shading was also created and designed by assuming the presence of wooden roofs around the buildings and walkways. The goal of this model is to provide continuous shading for pedestrians by means of a network of canopies on both sides (Aram et al., 2020; Huang et al., 2015). The set of figures shows the simulation model (before and after) about buildings and pedestrian times as shown in Fig. 2–8.

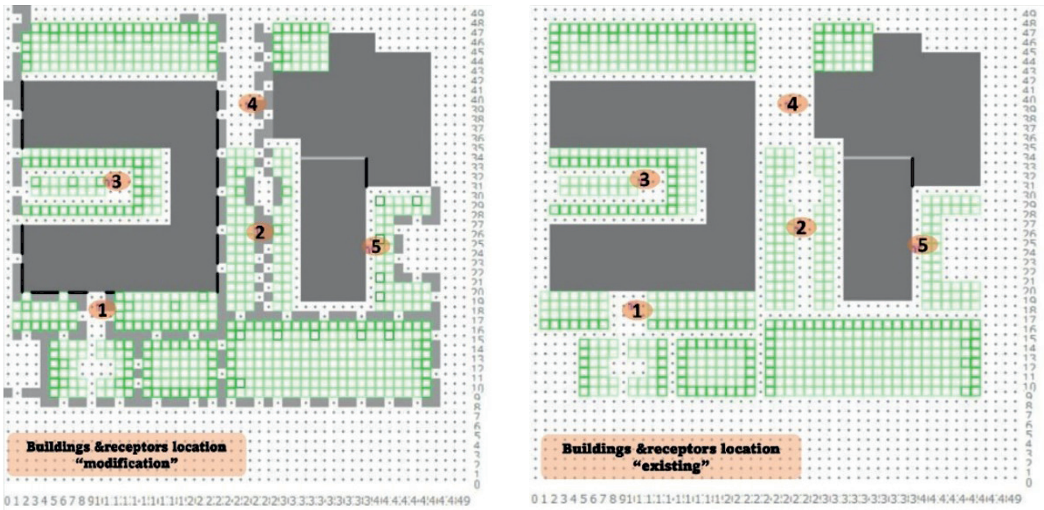

Fig. 2. Simulations plan for study case before and after modification
Source: own preparation.

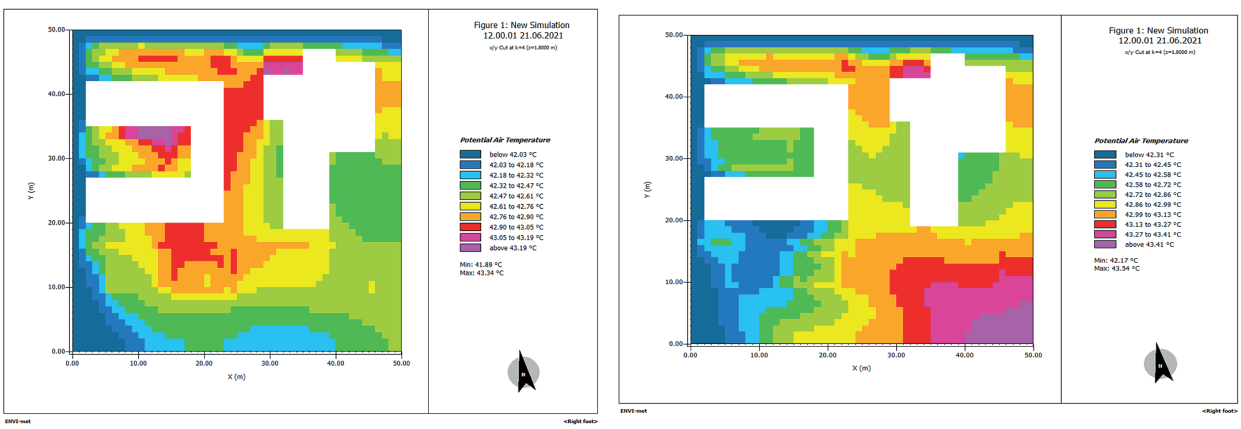

Fig. 3. Air temperature simulation before and after modification
Source: own preparation.

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

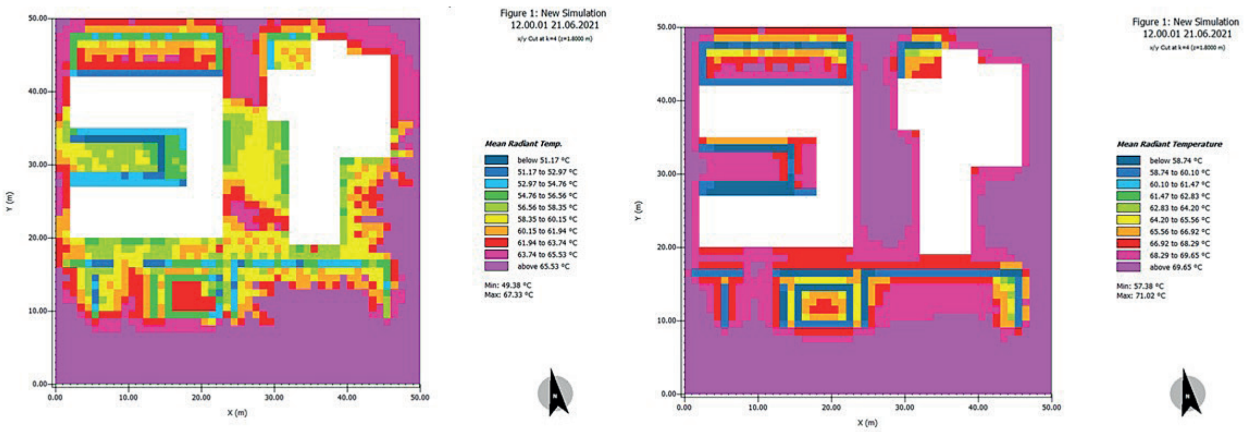

Fig. 4. Mean radiant temperature. Simulation before and after modification
Source: own preparation.

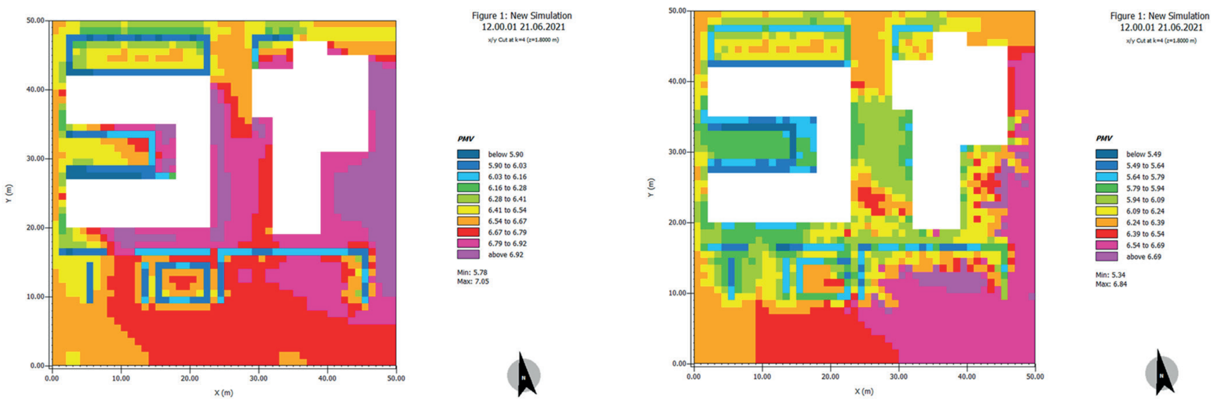

Fig. 5. PMV simulation before and after modification
Source: own preparation.

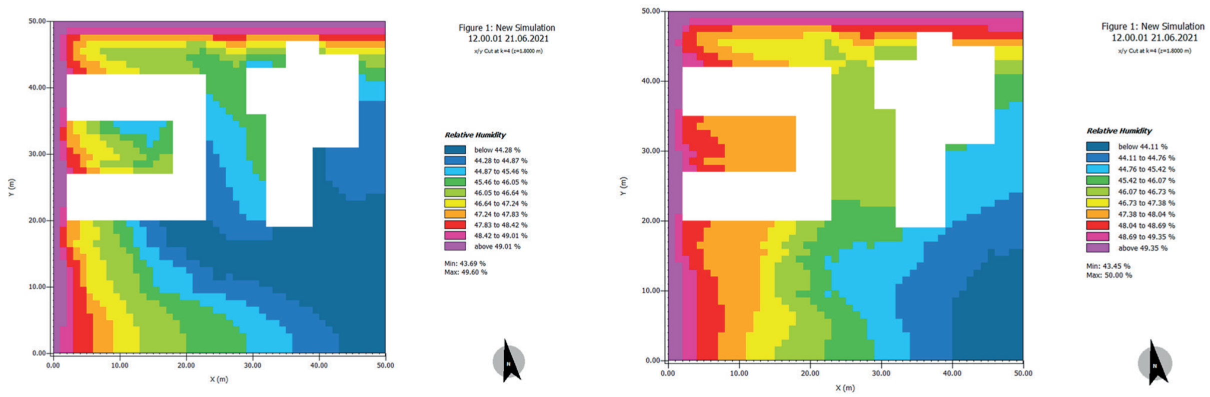

Fig. 6. Relative humidity simulation before and after modification
Source: own preparation.

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

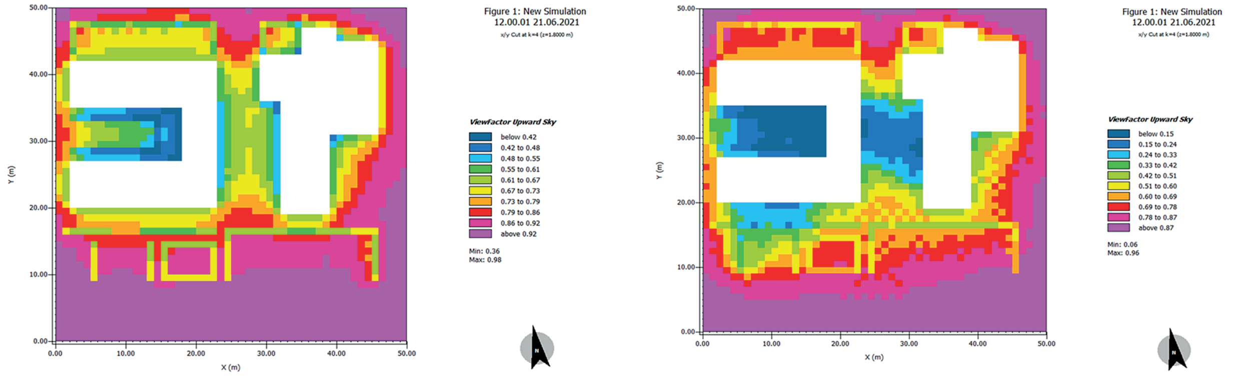

Fig. 7. Sky view factor simulation before and after modification
Source: own preparation.

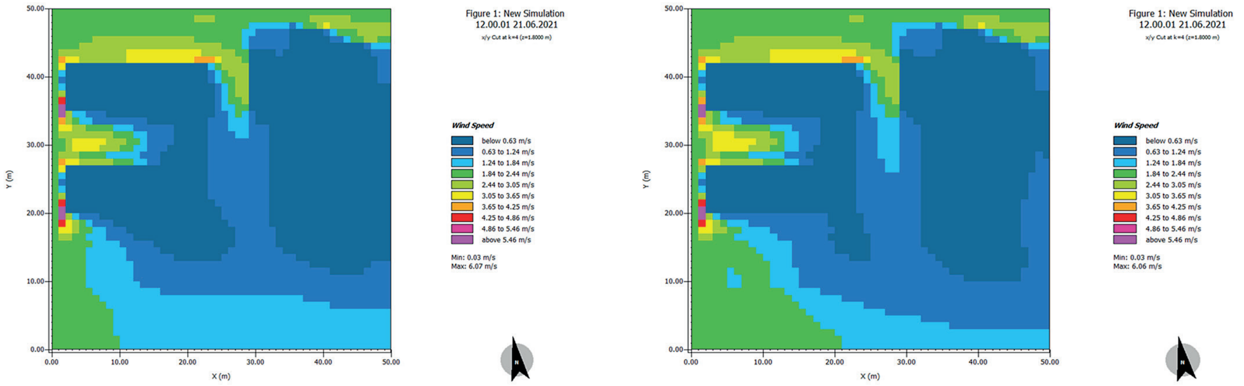

Fig. 8. Wind speed simulation before and after modification
Source: own preparation.

Simulation model of the development proposal

In order to assess the impact of the air conditioning elements on the study area, we have made a development scenario that includes levels of development: at the level of the individual building, and at the urban level. And then we compared the reality of the situation with the development scenario through simulation (noting that the development steps were suggested based on the actions mentioned in the previous studies), where they were reviewed and collected in one scenario. Following are the actions taken in the study area:

At the level of buildings:

1. Changing the materials for finishing the facades of buildings after they were covered with aluminium panels, as it was proposed to remove these panels and finish the facade with a material (stone).
2. A proposal to add green walls to the interior walls of the university presidency building and the Deanship of the Faculty of Engineering, especially in the walls overlooking the open space (the courtyard).

At the level of the site as a whole, and in open public spaces:

1. Adding wooden roofs, so that the site is completely free of them and exposes pedestrians to direct sunlight, to improve green spaces and create a comfortable atmosphere for pedestrians who walk under them.
2. Painting the streets within the study area with light-coloured paint to reduce the amount of heat absorbed and increase the reflectivity.

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

3. Adding all kinds of trees (palm trees and citrus fruits) because these types are evergreen, as well as because the study area is free of trees after they were gradually and completely cut down so that the area became free of any vegetable element for shading.
4. Adding water bodies (fountains) to moisten the atmosphere and reduce the temperature on both sides of the corridors leading to the entrance to the University Presidency Building and the Deanship of the College of Engineering.

RESULTS

A set of results was reached regarding the external thermal comfort indicators and how the complementary elements affect them, and the following is a summary of the results as follows:

Air temperature: The temperature decreased on average by 3°C when read by the receptors. It was projected to five different locations and fixed in the graph. This decrease in temperature occurred in the areas where roofs and trees were added in addition to water bodies (especially since the roofs were designed in such a way that they permeate the spaces in which plants were added) and this difference in temperature is explained as in the Table 1.

Table 1. The existing and modified simulation results for air temperature. *Source*: own preparation

Existing simulation results (air temp.)	Modified simulation results (air temp.)
R1 = 42.71ºC	R1 = 40.27°C
R2 = 42.69ºC	R2 = 40.81°C
R3 = 42.88ºC	R3 = 40.63°C
R4 = 42.92ºC	R4 = 40.08°C
R5 = 42.45ºC	R5 = 40.69°C

Mean radiant temperature: its value decreased by 8°C, the existing: min. 57.38°C, max. 71.02°C, the modified: min. 49.38°C, max. 67.33°C.

Average expected temperature (PMV): The percentage of areas that obtained a value (less than 50%) reached 40% of the site area as a whole. As for the development proposal, the percentage of areas that obtained a value (less than 50%) amounted to 70%, i.e. a change of not less than 30% as a result of the changes that occurred in the study area.

Relative humidity: The relative humidity increased by 2%, as a result of adding plants, green walls and shading areas, the existing: min. 43.69%, max. 49.60%. The modified: min. 43.45%, max. 50.00%.

Sky view factor: the value of this factor decreased as a result of adding trees (palms and citrus trees). The existing: min. 0.36, max. 0.98. The modified: min. 0.06, max. 0.96.

Wind speed: its value decreased by a very small amount. The existing: min. 0.03 m/s, max. 6.07 m/s. The modified: min. 0.03 m/s, max. 6.06 m/s.

CONCLUSIONS

Urban vegetation are considered the most effective element in improving thermal comfort levels, through the effect of shading, which is controlled by the physical properties of trees and their location in space. Trees also help to cool the surrounding environment through evaporation, which depends on the leaves, texture and mass of trees.

The assessment of thermal comfort is subjective and dynamic, dynamic in the sense that adaptation to the surrounding thermal state is naturally progressive, and subjective in view of the fact that thermal sensation is determined primarily through personal experience and subjective evaluation. Therefore, the static and objective aspects of knowledge provision must be measured in terms of the local climate.

The thermal properties of surface materials effectively affect the urban climate, by controlling the amount of solar radiation absorption.

Adaptation provides an opportunity for transformative change in social entities and institutions at the national and local level by encouraging participatory planning or by promoting research into internal planning processes.

The community can provide an insight into the city's development plans and activities that deal with adaptation, and here comes the role of local

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

organizations and government bodies to ensure that opinions are converged and taken into account when planning.

The final results of external thermal comfort indicators can lead to recommendations on urban planning for the municipality and city planners, especially since the university is considered a basic nucleus in the city through its active role in providing research on the environment and climate, and involving scientific disciplines in making effective proposals that can be tested on campus of the university.

Author contributions: Authors have given approval to the final version of the article. Authors contributed to this work as follows: Sarah Mohammed Jameel developed the concept and designed the study, collected the data, Susan Abed Hassan analysed and interpreted the data, prepared draft of article, revised the article critically for important intellectual content.

Funding: This research was not undertaken from any project or funded grant.

Supplementary information: Authors acknowledge the University of Bablyon and Al-Nahrain University for help with the preparation of the article.

REFERENCES

Aram, F., Solgi, E., Garcia, E.H., & Mosavi, A. (2020). Urban heat resilience at the time of global warming: evaluating the impact of the urban parks on outdoor thermal comfort. *Environmental Sciences Europe*, *32*(1), 1–15. https://doi.org/10.1186/s12302-020-00393-8.

Archer, D., Almansi, F., DiGregorio, M., Roberts, D., Sharma, D., & Syam, D. (2014). Moving towards inclusive urban adaptation: approaches to integrating community-based adaptation to climate change at city and national scale. *Climate and Development*, *6*(4), 345–356. http://doi.org/10.1080/17565529.2014.918868.

Ayşegül, A.K.S.U., Yilmaz, S., Mutlu, B.E., & Yilmaz, H. (2020). Ağaçların Bina ile Olan Mesafesinin Dış Mekan Termal Konfor Üzerine Etkisi: Erzurum Kenti Örneği [Effect on Outdoor Thermal Comfort of the Distance Between the Building and The Trees: A Case Study Erzurum]. *Journal of the Institute of Science and Technology*, *10*(2), 1298–1307. https://doi.org/10.21597/jist.635503.

Chen, L., & Ng, E. (2013). Simulation of the effect of downtown greenery on thermal comfort in subtropical climate using PET index: a case study in Hong Kong. *Architectural Science Review*, *56*(4), 297–305.

De Abreu-Harbich, L.V., Labaki, L.C., & Matzarakis, A. (2015). Effect of tree planting design and tree species on human thermal comfort in the tropics. *Landscape and Urban Planning*, *138*, 99–109. http://doi.org/10.1016/j.landurbplan.2015.02.008.

European Commission (2022). *Climate adaptation in cities*. Retrieved from: https://ec.europa.eu/info/es-regionu-ir-miestu-pletra/temos/miestai-ir-miestu-pletra/prioritetines-temos/prisitaikymas-prie-klimato-kaitos-miestuose_en (08.06.2022).

Huang, K.T., Lin, T.P., & Lien, H.C. (2015). Investigating thermal comfort and user behaviors in outdoor spaces: A seasonal and spatial perspective. *Advances in Meteorology*, *2015*(423508). https://doi.org/10.1155/2015/423508.

Hwang, R.L., Lin, T.P., & Matzarakis, A. (2009). *Outdoor thermal comfort in university campus in hot-humid regions*. In Proceedings of the Seventh International Conference on Urban Climate, 29.06–3.07.2009, Yokohama, Japan (Vol. 29).

Manteghi, G. (2021). A Seasonal Field Investigation to Perceive Outdoor Thermal Comfort and Thermal Adaption at Malacca Tourist Area-A Pilot Test. *Preprints*, *2021020370*. https://do.org/10.20944/preprints202102.0370.v1.

Nasir, R.A., Ahmad, S.S., & Zain-Ahmed, A. (2013). Adaptive outdoor thermal comfort at an urban park in Malaysia. *Journal of Asian Behavioral Studies*, *3*(10), 1–16.

Notre Dame Global Adaptation Initiative (2022). *Urban adaptation assessment. Better data for planning for your city's future*. Retrieved from: https://gain-uaa.nd.edu/?referrer=gain.nd.edu (08.06.2022).

Othman, N.E., Zaki, S.A., Ahmad, N.H., & Abd Razak, A. (2019). Outdoor thermal comfort study of an urban university campus in Malaysia. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *57*(2), 288–296.

Parapari, D.M. (2018). *Outdoor Thermal Comfort in Informal Settlements*. Retrieved from: https://

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq

www.researchgate.net/profile/Danial-Monsefi-Parapari/publication/325114620_Outdoor_Thermal_Comfort_in_Informal_Settlements/links/5af844ee0f7e9b026bea8c3c/Outdoor-Thermal-Comfort-in-Informal-Settlements.pdf (08.06.2022).

Ridha, S. (2017). *Urban heat Island mitigation strategies in an arid climate. In outdoor thermal comfort reacheable* (Doctoral dissertation, INSA de Toulouse).

Ridha, S., Ginestet, S., & Lorente, S. (2018). Effect of the shadings pattern and greenery strategies on the outdoor thermal comfort. *International Journal of Engineering and Technology*, *10*(2), 108–114. https://doi.org/10.7763/IJET.2018.V10.1043.

Sayad, B., Alkama, D., Rebhi, R., Menni, Y., Ahmad, H., Inc, M., Sharifpur, M., Lorenzini, G., Azab, E., & Elnaggar, A.Y. (2021). Outdoor Thermal Comfort Optimization through Vegetation Parameterization: Species and Tree Layout. *Sustainability*, *13*(21), 11791. https://doi.org/10.3390/su132111791.

Shashua-Bar, L., Pearlmutter, D., & Erell, E. (2011). The influence of trees and grass on outdoor thermal comfort in a hot-arid environment. *International Journal of Climatology*, *31*(10), 1498–1506. https://doi.org/10.1002/joc.2177.

Time and Date. (2022). *Past weather in Baghdad, Iraq – June 2020*. Retrieved from: https://www.timeanddate.com/weather/iraq/baghdad/historic?month=7&year=2020 (08.06.2022).

University of Babylon. (2022). *University of Babylon – website*. Retrieved from: https://www.uobabylon.edu.iq/ (08.06.2022).

Venhari, A.A., Tenpierik, M., & Hakak, A.M. (2017). Heat mitigation by greening the cities, a review study. *Environment, Earth and Ecology*, *1*(1), 5–32. https://doi.org/10.24051/eee/67281.

World Weather Online. (2022). *Baghdad historical weather*. Retrieved from: https://www.worldweatheronline.com/baghdad-weather-history/baghdad/iq.aspx (08.06.2022).

Zhang, H., Gao, Z., Ding, W., & Zhang, W. (2017). Numerical study of the impact of green space layout on microclimate. *Procedia Engineering*, *205*, 1762–1768. https://doi.org/10.1016/j.proeng.2017.10.027.

✉st.sarah.mohammed.jameel@ced.nahrainuniv.edu.iq, ✉dr.susan.a.hassan@nahrainuniv.edu.iq