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# Assessing Microclimate and Green Space at Nawroz University Using Climate Model ENVI-Met Simulation

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Microclimates are important for understanding the impact of urban areas on the environment. Although often overlooked, educational campuses cover large metropolitan areas that contribute to environmental harm in cities. This research focuses on studying the microclimate characteristics of Nawroz University's campus in Duhok City, Iraq. The study uses ENVI-met software to assess current conditions and a proposed Green-Belt (GB) scenario. The analysis focuses on mean radiant temperature (MRT) and air temperature at four specific times (4 a.m., 8 a.m., 2 p.m., and 10 p.m.). A comparison is made between a Baseline scenario and a Green-Belt scenario. The Baseline scenario shows high temperatures on sun-exposed surfaces. The Green-Belt scenario demonstrates temperature reductions at 2 p.m. up to 8°C, highlighting the importance of vegetation in mitigating heat. Temperature reductions of 3°C to 5°C were also observed at 8 a.m., underscoring the cooling benefits of the proposed vegetation. The results from the Baseline scenario indicate that surfaces exposed to the sun with low albedo have higher temperatures. Vegetation in urban planning improves campus thermal comfort, reducing urban heat island effects. The study highlighted green infrastructure potential in creating sustainable urban environments, notably in regions transitioning to sheltered areas adjacent to trees.

**Keywords:** microclimate, thermal comfort, urban spaces, Green-Belt scenario, ENVI-met software.

## Introduction

The correlation between natural environments and urban infrastructures substantially impacts human communities and ecosystems' health and longevity, resulting in significant implications for societies and the natural world (Vijayaraghavan et al., 2007; Semeraro et al., 2021). The complex interplay between these elements shapes and influences various facets of human existence, from outdoor livability to energy usage and urban development, highlighting the crucial role of microclimates in this intricate connection (Stewart and Oke, 2012; Liu and Russo, 2021). Acknowledging the significance of this interdependency, sustainable urban solutions necessitate well-planned initiatives and interventions aimed at improving resident well-being and contentment, thereby fostering a harmonious equilibrium between natural and man-made environments (Ren et al., 2022).

Incorporating natural elements into urban structures to restore landscapes disturbed by human activities is a practice that draws from natural solutions inspired by the environment (Al-Hinkawi et al., 2021). Educational zones within cities can hurt natural ecosystems due to human-nature interactions, making it necessary to implement sustainable measures to improve urban environments and address the challenges posed by artificial urban landscapes (Brozovsky et al., 2019; Zhang et al., 2023). Analyzing complex natural phenomena requires the use of analytical models. Climate models, like those studying urban morphological changes on microclimates, offer insights for decision-making by examining the impacts of climate change resulting from various factors (Forouzandeh, 2021).

Urban microclimates are crucial in urban planning to address the adverse effects of urbanization. Surfaces with low albedo, like asphalt and concrete, contribute to the urban heat island (UHI) effect, raising temperatures and discomfort in cities (Liang et al., 2021; Dutta et al., 2022). Urbanization and densification worsen this issue, increasing energy consumption and greenhouse gas emissions (Sen et al., 2020). Higher temperatures also worsen air quality challenges. Combining green spaces and high albedo materials can mitigate the UHI effect and improve urban microclimates. Prioritizing microclimate considerations in urban planning can create sustainable cities that prioritize the well-being of residents (Feinberg, 2020).

ENVI-Met is a recognized software for modeling urban climate and simulating atmosphere, vegetation, and surface interactions at the microscale level. It measures the impacts of architecture and urban planning on outdoor microclimate through simulation (Yang et al., 2021). ENVI-met excels in modeling the nearby effect of buildings on solar radiation and forecasting vegetation impact. Its primary advantage is accurately simulating atmospheric processes based on thermodynamics and fluid mechanics principles (Brahimi et al., 2023). In addition, ENVI-met simulations take daily cycles in intricate urban environments, integrating various buildings and vegetation from a microclimate viewpoint (Elraouf et al., 2022). The results are used as a guide for urban planning to reduce heat island effects and improve the thermal comfort of residents (Ma et al., 2023).

Several recent studies have focused on improving microclimates, understanding local weather patterns, and optimizing conditions. Chatzinikolaou et al. (2018) have modeled the Athens microclimate using the ENVI-met model, comparing rooftop and roadside vegetation. Vegetation affects temperature and comfort, with roadside vegetation most effective in mitigating UHI. Gusson and Duarte (2016) have calibrated the ENVI-met model for São Paulo, combining land use and campaigns. Ambrosini et al. (2014) have found limited effects of green and cool roofs in a small city. Urban geometry plays a crucial role in microclimate. Salih et al. (2021) have used ENVI-met software and found that street orientations and widths impact ventilation and energy use in Erbil. Shading mesh reduces radiant temperature. Traditional urban morphology is cooler than grid-iron planning. Ouali et al. (2018) have studied UHI in Baghdad, analyzing urban geometry and the impact of green areas on temperatures. Results emphasized the importance of height-to-width ratio and vegetation in UHI formation, aiding urban design and planning. Ibraheem and Abaas (2023) have demonstrated the effectiveness of urban intervention strategies in mitigating pedestrian heat stress, emphasizing ecological urbanization. Basee et al. (2024) have shown that compact urban forms and unplanned growth lead to higher temperatures and reduced thermal comfort. The addition of simulation modeling, remote sensing, and ecological insights can help urban planners improve campus sustainability.

This study aims to assess the prevalent microclimate conditions at Nawroz University Campus in Duhok city, Iraq. This investigation utilizes advanced simulation techniques, particularly focusing on the public infrastructure within the educational zone. The primary objective is to assess the potential benefits associated with the implementation of natural solutions for enhancing climate resilience within this urban environment.

## Methodology and Simulation Parameters

### Study area

The focus of this study is the campus of Nawroz University in Duhok city, Iraq, situated at 36.8599° N and 42.8963° E. The area of 0.04 km$^2$ comprises four academic buildings, two administration buildings, and two facility buildings. Furthermore, the campus includes a parking lot, green areas, and an open event space, as shown in *Fig. 1*.

The effects of urbanization on microclimates in Iraq have not been thoroughly investigated, resulting in higher temperatures, diminished air quality, and a decrease in green areas (Dhuoki and Çağnan, 2021). Educational campuses in urban environments face challenges with microclimate and sustainability. Albedo of surfaces affects urban microclimates (Zaki et al., 2020). These concerns underscore the need for specialized studies to create lasting urban remedies. Focusing specifically on the Nawroz University campus provides an opportunity to address and provide insights to improve the urban environment.

**Fig. 1.** *Structure map of the study area (Source: Google Maps)*

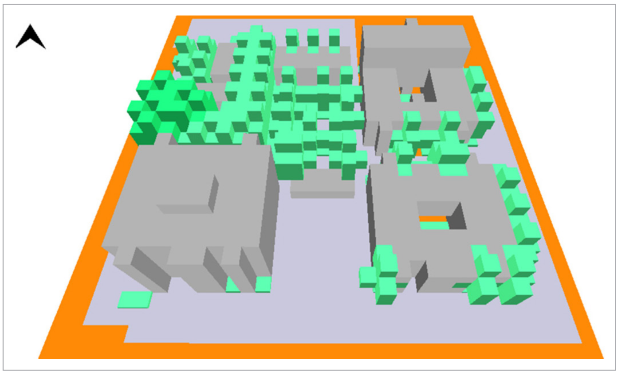
### Modeling

The study utilized the ENVI-met software to model the study area and simulate microclimate conditions, focusing on understanding the impact of architecture and urban design (Tsoka, 2023; Thomas et al., 2023). The model considers interactions among three layers: soil, surfaces (including buildings and vegetation), and the atmosphere. Meteorological data inputs included temperature, wind speed, humidity, and direction, as shown in *Table 1*. This study modeled two scenarios: the first representing the study area before recent interventions, and the second incorporating a Green-Belt scenario with added pine trees around the campus while maintaining consistent urban geometry and ground cover materials. After integrating 2D model inputs, ENVI-met generates a validated 3D representation for the study area (see *Fig. 2*). Using this model and meteorological data input, ENVI-met simulates conditions for the specified date and meteorological parameters.

**Table 1.** *Simulated meteorological parameters of the study area*

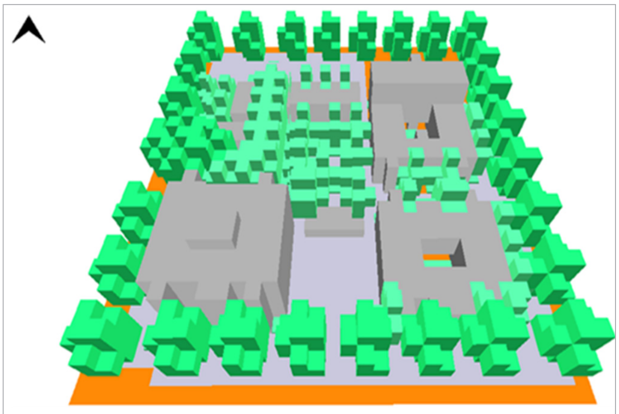
| Time (hours) | Temperature (°C) | Relative humidity (%) | Wind speed (m/s) |
|---|---|---|---|
| 0:00:00 | 27 | 27 | 4.47 |
| 1:00:00 | 26 | 25 | 4.92 |
| 2:00:00 | 26 | 26 | 4.92 |
| 3:00:00 | 25 | 26 | 5.36 |
| 4:00:00 | 24 | 26 | 4.92 |
| 5:00:00 | 24 | 27 | 5.36 |
| 6:00:00 | 25 | 27 | 5.36 |
| 7:00:00 | 27 | 23 | 5.81 |
| 8:00:00 | 31 | 19 | 6.26 |
| 9:00:00 | 34 | 15 | 7.6 |
| 10:00:00 | 36 | 14 | 9.39 |
| 11:00:00 | 38 | 12 | 10.28 |
| 12:00:00 | 40 | 10 | 11.18 |
| 13:00:00 | 42 | 10 | 10.73 |
| 14:00:00 | 43 | 9 | 9.83 |
| 15:00:00 | 42 | 9 | 9.39 |
| 16:00:00 | 40 | 10 | 9.39 |
| 17:00:00 | 40 | 10 | 8.94 |
| 18:00:00 | 39 | 11 | 8.05 |
| 19:00:00 | 36 | 20 | 6.71 |
| 20:00:00 | 34 | 26 | 6.26 |
| 21:00:00 | 31 | 28 | 4.92 |
| 22:00:00 | 30 | 31 | 4.02 |
| 23:00:00 | 29 | 32 | 4.02 |

**Fig. 2.** *Existing 3D model of the study area*



For this site, a nature-inspired solution was devised, 27 pine trees were planted square-shaped around the boundaries of the campus site. Each tree has a dimension of 15-m height and 7-m crown width. In selecting the Green-Belt scenario (*Fig. 3*), it was assumed that trees would exhibit maximum vegetative growth. The species planted was well-suited to the local climate conditions and posed no phytosanitary issues. They were chosen for their suitability for low-cost and easy maintenance solutions.

**Fig. 3.** *Suggested (Green-Belt) 3D model of the study area*



### Computer simulation of microclimates

The microclimatic computer simulation of the urban environment involves a simplification of actual scenarios, aiming to replicate the attributes of the elements within that space. Nevertheless, it is not all depiction of the real world as it does not replicate its entire complexity.

The study examines building interactions in the urban environment through simulation to understand urban thermal comfort. In addition, it uses on-site data collection including measurements of wind speed, direction, air temperature, and humidity. The software simulates climatic parameters for the entire day.

To accurately portray the local environment, data were gathered for integration into the ENVI-met simulation. Local spatial information was obtained through Google Earth and site visits. This process involved identifying land cover types, and building materials, and measuring the heights of existing buildings. Vegetation data included tree identification and 3D configuration. Surface materials were classified based on local comprehension. The simulation covered 24 hours, starting at 7 a.m. on July 01, 2023, and ending at 6:59 a.m. on July 02, 2023. Parameters for the ENVI-met simulation were determined using locally collected data as detailed in *Table 2*.

**Table 2.** *Configuration of climate data for ENVI-met microclimate simulation*

| Parameter | Maximum | Minimum |
|---|---|---|
| Ta (°C) | 43 | 24 |
| WS (m/s) | 3 | - |
| RH (%) | 21 | 16 |
| Windier (deg) | 315 | 315 |

*Ta, air temperature; RH, relative humidity; WS, wind speed; WindDire, wind direction.*

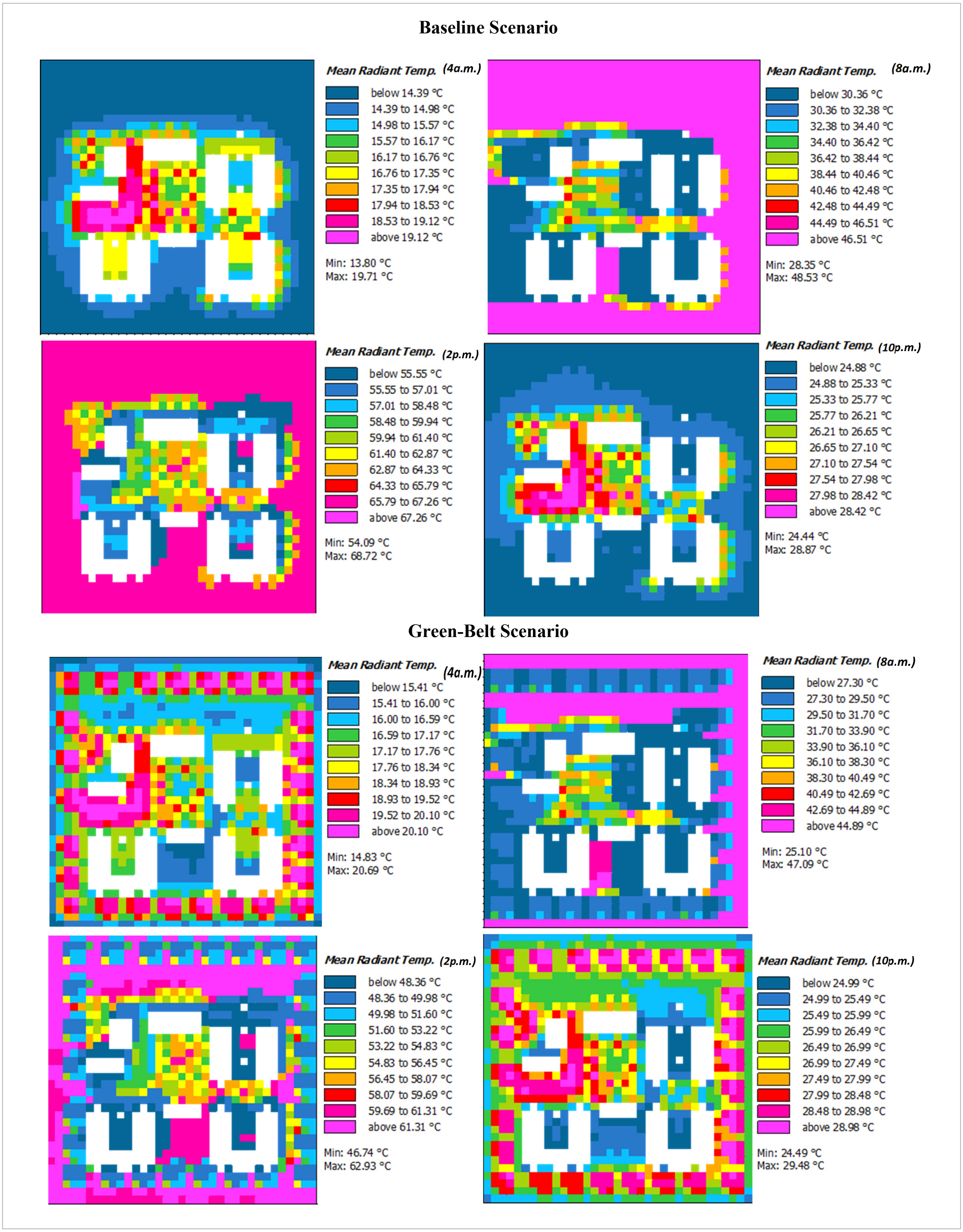
## Results and Discussion

### Mean radiant temperature (MRT)

In this study, the factor most noticeably influenced by the shadows created by buildings and trees is the mean radiant temperature (MRT). The figures in the simulations (*Fig. 4*) illustrate the variations of this variable at the pedestrian level (1.5 m) during the four simulation periods for the baseline and GB scenarios.

The potential influence of the suggested vegetation on microclimates, as assessed using the ENVI-met model, discloses noteworthy variances in mean radiant temperature (MRT) between the Baseline scenario and the Green-Belt scenario over the day. At 4 am, MRT has minimal disparity due to consistent thermal conditions and limited solar radiation. However, by 8 a.m., the flora decreases the minimum MRT from 28.35°C to 25.10°C in the vicinity of the albedo area, resulting in an

**Fig. 4.** *Simulated mean radiant temperature for the Baseline and Green-Belt scenarios*



overall reduction of 3°C to 4°C, signifying an enhancement in thermal comfort. The most significant impact is evident at 2 p.m., as the MRT in the Baseline scenario ranges from 54.09°C to 68.72°C, while in the Green-Belt scenario, it is lowered to 46.74°C to 62.93°C, achieving a decrease of up to 8°C. This substantial cooling effect during the hottest part of the day is essential for improving outdoor thermal comfort and alleviating urban heat effects. At 10 pm, there is no substantial change in MRT between the scenarios due to the absence of solar radiation.

In the GB scenario, trees were key in shielding solar radiation and preventing direct exposure to shortwave radiation. Additionally, the grass between and around the buildings served as a reducer of reflected radiation by intercepting a portion of the shortwave radiation and incorporating it into physiological processes like photosynthesis. Consequently, it was anticipated that areas with the inclusion of vegetation, overall, would experience lower mean radiant temperatures after sunrise. In urban settings, radiation is the predominant factor in the energy exchange between the human body and its surroundings. The simulations during the night highlight the impact of trees, which can be elucidated by their energy balance, underscoring the software's capability to intricately model trees effectively.

The results are consistent with previous research on the impact of greenery and vegetation in urban areas on thermal comfort. Astita and Yola (2024) have observed similar temperature variations of 3°C to 5°C in Banteng Park, Jakarta, while Sinsel et al. (2022) have emphasized the significant influence of trees on thermal comfort and the software's ability to effectively model the energy balance of trees. Additionally, Liao et al. (2021) have reported that trees had a cooling effect on the mean radiant temperature of 17.7°C. These studies confirm the effectiveness of vegetation in urban environments and support the findings of the present study. Overall, the suggested flora effectively diminishes MRT during crucial daytime periods, presenting a feasible approach to enhancing urban microclimates and advocating for sustainable urban development.

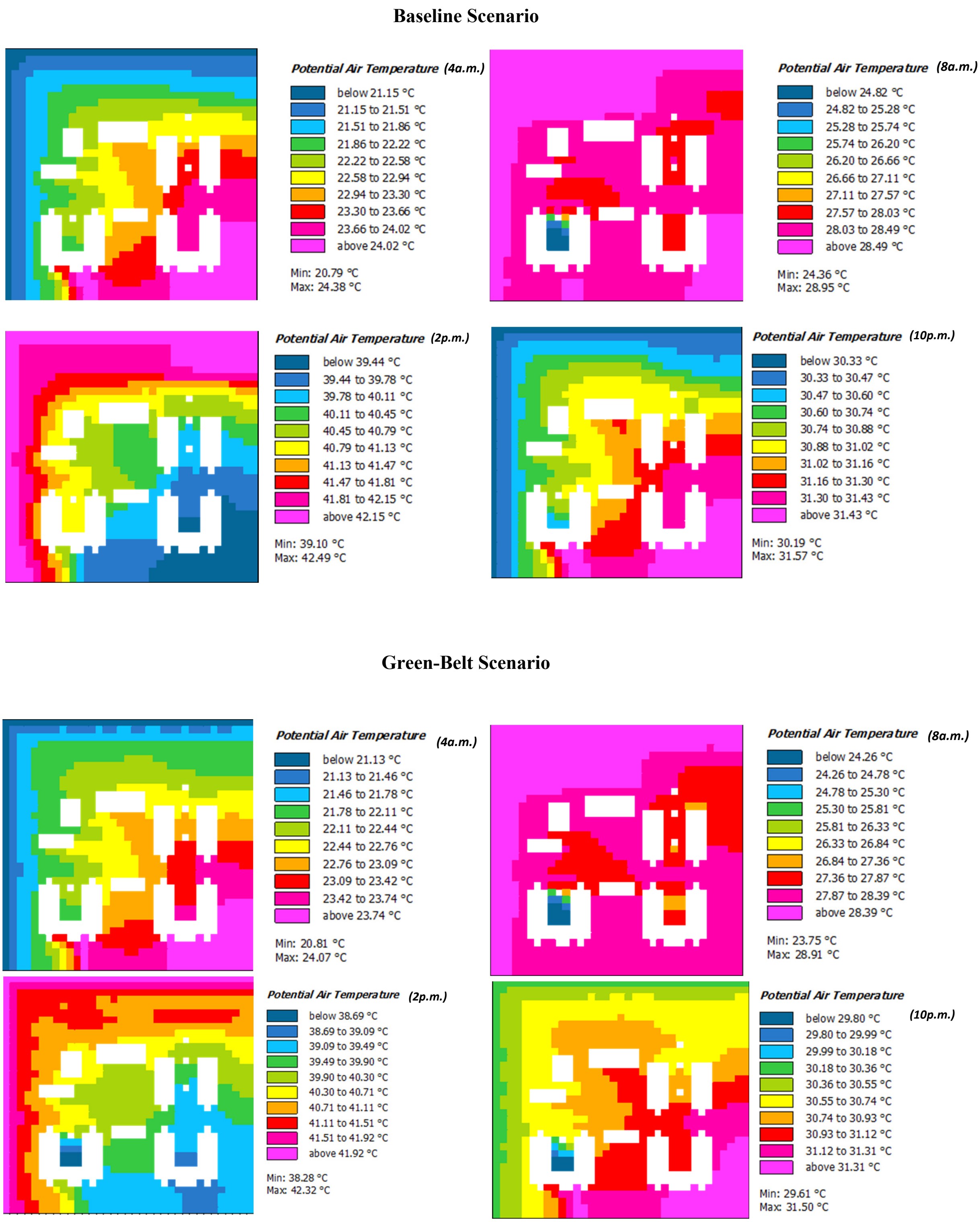
## Air temperature

ENVI-met was utilized to conduct simulations concerning air temperature (*Fig. 5*). Hourly maps were created for four distinct time points: 4 a.m. (before sunrise), 8 a.m. (after sunrise), 2 p.m. (afternoon), and 10 p.m. (night). The model data were observed at a height of 1.5 m. The simulations presented in *Fig. 4* enable us to predict how urban design might impact air temperature. The findings enable us to recognize the possible impact of the Green-Belt scenario in enhancing thermal comfort. They offer a comprehensive assessment of the advantages associated with incorporating vegetation into the infrastructure of urban public spaces in an educational zone. The Baseline scenario exhibited temperature variations of 3.59°C, 4.59°C, 3.39°C, and 1.38°C at simulated durations of 4 a.m., 8 a.m., 2 p.m., and 10 p.m., respectively. In contrast, the Green-Belt scenario simulations predicted temperature fluctuations of 3.26°C, 5.16°C, 4.04°C, and 1.89°C for the same time intervals.

Before the sunrise at 4 a.m., the simulated temperatures range from 20.79°C to 24.38°C. After the sun rises at 8 a.m., there is a noticeable temperature rise, particularly in proximity to surfaces with low albedo. Subsequently, in the hours following (2 p.m. and 10 p.m.), there is a significant overall increase in air temperature, reaching maximum values of 42.49°C and 31.57°C for the Baseline and Green-Belt scenarios, respectively. In the GB scenario, in contrast to the Baseline scenario, decreased temperatures were observed overall at the site, which is due to tree introduction, leading to the enlargement of the initial cool zones outlined in the Baseline simulation. The variations can be clarified by the fact that, from sunrise onwards, trees intercepted sunlight to some extent, resulting in reduced solar exposure. Moreover, trees contribute to lowering air temperature by releasing water vapor through transpiration. Grass surfaces, particularly when irrigated, also contributed to temperature reductions. Greenery within urban areas demonstrated effectiveness in controlling air temperature. The radiant energy received leads to significant evapotranspiration, especially when coupled with proper site irrigation. This combination helps sustain the ability of vegetation to enhance local thermal comfort.

In comparison to previous research, Ebrahimnejad et al. (2017) have discovered that the green roof on Tehran's Nature Bridge lowered the air temperature by 0.8°C, while Liao et al. (2021) have observed a decrease of 0.49°C as a result of urban greenery. The Green-Belt scenario in our study demonstrated even greater reductions in temperature, suggesting a more significant cooling effect from the proposed vegetation. Salvati

**Fig. 5.** *Simulated air temperature for the Baseline and Green-Belt scenarios*



and Kolokotroni (2019) have emphasized the significance of accurate simulation inputs such as air temperature. The results of ENVI-met align with this approach, affording a thorough evaluation of the impacts of urban design on air temperature and reinforcing the cooling advantages of greenery in urban planning.

## Conclusion

This study assesses the potential benefits of incorporating the Green-Belt scenario into the public urban spaces of an educational zone, specifically focusing on the Nawroz University Campus in Duhok city using ENVI-met simulations. The comparative analysis between the Baseline and Green-Belt scenarios shows significant reductions in air temperature and mean radiant temperature on a summer day, demonstrating the positive impact of implementing a Green-Belt project. Results indicate that the Green-Belt scenario effectively reduces temperatures, particularly during peak thermal conditions at 2 p.m., with reductions of up to 8°C. The addition of vegetation elements as part of the Green-Belt scenario proved effective in alleviating thermal stress and improving thermal comfort in the study area. These findings emphasize the possibility of transitioning the urban landscape into a more environmentally sustainable setting. The reductions in temperature highlight the tangible benefits of tailored green interventions in urban planning, and the study underscores the crucial role of strategic green infrastructure initiatives in promoting healthier and more livable urban environments. The examination within the educational precinct demonstrates that green infrastructure can significantly mitigate urban heat and enhance thermal comfort. Future urban planning initiatives should prioritize the integration of vegetation to create more sustainable and comfortable urban environments, thereby contributing to overall environmental quality and human well-being.

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