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Research Article

ENVI-met Simulations of the Effect of Different Landscape Design Scenarios on Pedestrian Thermal Comfort: Haydar Aliyev Street

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Abstract: In the city of Erzurum, located in a cold climate region, it is important for pedestrian walkways and parks to be usable all year round. Haydar Aliyev Street, located on the city's new development axis, serves as both a pedestrian route and a park. Meteorological data was collected hourly throughout 2021 using a Vantage Pro 2 Plus device installed at a height of 1.5 m in the study area. The scenarios were analyzed using the ENVI-met BIO+ Science Software, with August (summer) and January (winter) identified as the hottest and coldest months, respectively. Sky View Factor (SVF) analysis was conducted using fisheye lens photos taken from different points in the area. Four different landscape design scenarios were created for the study area, consisting of plants, water surfaces, soil, and grass. It was found that the temperature decreased by an average of 0.2°C in the summer scenario when the number of plants was increased by 20%. Furthermore, it was determined that the deciduous tree scenario provided better thermal comfort compared to the treeless soil scenario for a pedestrian-friendly park during the winter months. The inactive water scenario for summer and winter was found to increase wind speed by a maximum of 1.3 m s^{-1}. The study concluded that different landscape design scenarios had an impact on outdoor thermal comfort and that further research was needed in this area. Such studies highlight the need for multidisciplinary teamwork to create healthy, sustainable, and livable urban environments in designing thermal-comfortable spaces.

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1. Introduction

In recent years, urban population growth has been rapidly occurring worldwide. According to the United Nations, the global urban population increased from 751 million in 1950 to 4.2 billion in 2018, a 4.6-fold increase. It is estimated that this number will further increase to 6.4 billion by 2050, with approximately 70% of the world's population living in cities. However, this rapid urbanization has led to the formation of Urban Heat Island (UHI), due to the increase of impermeable surfaces, decrease of green areas, construction of more buildings and workplaces, and increased use of personal vehicles (Oke, 2002; Mirzaei and Haghighat, 2010; Oliveira et al., 2011; Oke et al., 2017).

As a result of this temperature increase, UHI has become a widespread urban problem that can cause health problems in living organisms and an increase in energy demand (Okumuş and Terzi, 2021; IPCC, 2022). Efforts are being made to develop planning and design strategies that provide more livable micro-climate conditions for living organisms. Academic studies have experimented with different materials naturally to reduce the effects of UHI These materials include plants (Tan et al., 2016; Irmak et al., 2018; Yang et al., 2019; Ma et al., 2020; Yucekaya and Uslu, 2020), water surface options (Grimm et al., 2008; Wu et al., 2019; Gupta et al., 2019), street orientation and angle studies (Ali-Toudert and Mayer, 2007; Qaid et al., 2016; Yilmaz et al., 2018; Mutlu et al., 2018), roof-vertical gardens (Taleghani et al., 2015), and different ground covering materials (Irmak et al., 2017; Bozdogan et al., 2021). Urban parks have become increasingly important in reducing the effects of UHI. Urban parks not only meet the recreational needs of people but also improve outdoor thermal comfort. In particular, it is seen that urban parks can have a positive impact on thermal comfort in hot climate regions (Georgi and Dimitriou, 2010; Jamali et al., 2021). The positive contribution of urban parks has been determined in all perception models (Yilmaz et al., 2023) as well as in reducing stress (Yilmaz, 2022).

Numerous climate software models are used in the determination of outdoor thermal comfort. According to a review conducted in this field, it has been found that ENVI-met software is the most commonly preferred in 77% of the studies conducted in the last five years (Tsoka et al., 2018). Scenario analyses were conducted using ENVI-met to improve thermal comfort for pedestrians on streets and in urban spaces (Middel et al., 2015; De and Mukherjee, 2016; Yilmaz et al., 2021; Weng et al., 2022). In Japan, measurements were made on a university campus in hot weather, and scenarios were developed to design comfortable spaces by reducing the urban heat island effect by covering the entire ground with grass and implementing green roofs on buildings. As a result of increasing green areas, a cooling effect of between 0.24°C and 2.29°C was observed (Srivanit and Hokao, 2013). De Munck et al. (2013) emphasized that environmental factors lead to a temperature increase of between 0.5°C and 2.0°C in the streets of Paris. This suggests that if planning is done correctly, with proper guidance and road widths, and if plants are used, it may be possible to reverse this effect and cool the space. Measurements were made in six different parks in urban areas by Lin and Lin (2016) to examine their effect on the thermal comfort of the city. ENVI-met analyses showed that parks with good greenery and larger areas contributed more positively to the climate. In areas with asphalt surfaces, the temperature was found to be 6.0°C higher than in areas with grass surfaces. In addition, it was found that the use of vehicles, incorrect street orientation, and insufficient and incorrect open-green areas for air circulation lead to an environment that is 1.0 - 4.0°C warmer (Girgis et al., 2016). It has been determined through an analysis using ENVI-met in an urban park that the scenario involving trees and greenery lowered the temperature by 0.5°C compared to the current state (Teshnehdel et al., 2022). Measurements were made using the ENVI-met model by taking a neighborhood unit in Austria/Melbourne for the summer. Comparisons were made using different methods by looking at the street direction, street width, and floor heights in proportion, and their effects on thermal comfort were emphasized (Jamei and Rajagopalan, 2017; Menteş et al., 2023).

The Sky View Factor (SVF) is an important factor that affects the thermal comfort of pedestrians and the street in an urban street canyon. In urban space planning, factors such as street width, street orientation, and the heights of surrounding buildings (Qaid et al., 2016) have been examined for hot cities. Similar analyses have also been conducted for cold cities (Xu et al., 2018; Chen et al., 2018). Generally, these studies have determined that appropriate street design can affect thermal comfort and reduce temperature stress by creating air corridors. Needle-leaved or broad-leaved trees, shrubs, and spaces designed according to different planting techniques have been analyzed with SVF, and their effects on thermal comfort have been examined (Tan et al., 2017).

In this context, it has been determined that the city of Erzurum has extreme features in terms of thermal comfort compared to other cities, due to its high altitude and harsh and long winter season (Yilmaz et al., 2022a). It is considered highly important for people to be able to use outdoor spaces comfortably throughout the year. With the aim of developing scenarios to increase pedestrian comfort year-round, Haydar Aliyev Street in Şükrü Paşa Neighborhood, which serves as both a park and pedestrian axis, located in the new development axis of Erzurum City, was Chosen. Different design scenarios were analyzed with ENVI-met to determine the most suitable design criteria. the results obtained are expected to be a valuable resource as they will be transferred to physical planning decisions prepared by local governments.

2. Material and Methods

2.1. Material

This research was conducted in the Şükrü Paşa neighborhood located in the north of the city of Erzurum, which is located in the Eastern Anatolia region. The Haydar Aliyev Park, located on Azerbaijan Boulevard, which is used as both a pedestrian axis and a park, was preferred as the study area. The area is approximately 2.8 km away from the city center and is surrounded by 5-story buildings. The park has a 2.80 m median strip in the middle of the two-lane road, approximately 20.4 m of road and green space on both sides of the traffic lane, and 4.80m pedestrian paths. The location map of the study area is given in Figure 1. The meteorological station established in this area is located at 39°55'29.26" N latitude, 41°16'2.65" E longitude, and an altitude of 1830 m.

Obtaining Meteorological Data on Site: In the study, a "Vantage Pro 2 plus" device was used to record microclimate data within the urban space. The meteorological data measurement device was mounted inside a 120x120 cm protected cage structure on Haydar Aliyev Avenue, next to the municipal and security unit. It was mounted on a metal rod 1.5 m high from the ground and placed on the ground (Morakinyo et al., 2019). Calibration was performed by the manufacturer and a meteorological engineer (within the scope of the TÜBİTAK 1001-TOVAG 119O479 project) (Figure 1). The recording device of the meteorological station was placed in a special security booth that provides security of the park and the electricity distribution company located within the study area. The meteorological station established in 2020 in the study area records the data on an hourly basis. 48-hour data representing hot and cold days recorded within the year 2021 were obtained from the collected data. 24 hours of these data were used in the ENVI-met analysis. The data obtained from the field included hourly air temperature (Ta-°C), humidity (RH -%), cloudiness (Octas), wind speed (m s^{-1}), and direction, which were processed in the software model.

Proposed Different Landscape Scenarios: Due to the fact that the workspace serves both as a park and a pedestrian path, there is a high demand for its use. Therefore, different landscape scenarios have been prepared in an area of 40250 m^2, including pergolas as landscape elements. The scenarios prepared for analysis are as follows: Firstly, an analysis of the current situation was conducted.

• A scenario with soil surface covering (10 000 m^2 throughout the space, covering 25% of it) was prepared.

• A scenario with grass surface covering (the entire surface covered with grass, with 10 000 m^2 of grass-covered area covering 25% of the space) was created.

• A scenario for increasing the tree-shrub ratio by 20% throughout the space; plant species commonly found in the region (*Pinus sylvestris* L. "Scots pine," *Betula verrucosa* L. (birch), *Ulmus glabra, Fraxinus excelsior, Cornus alba* "Siberian") were preferred. Scenario analyses were applied by increasing the number of existing trees by 20%.

• A scenario with a designed water surface within the ground (200 m^2 water surface) was planned.

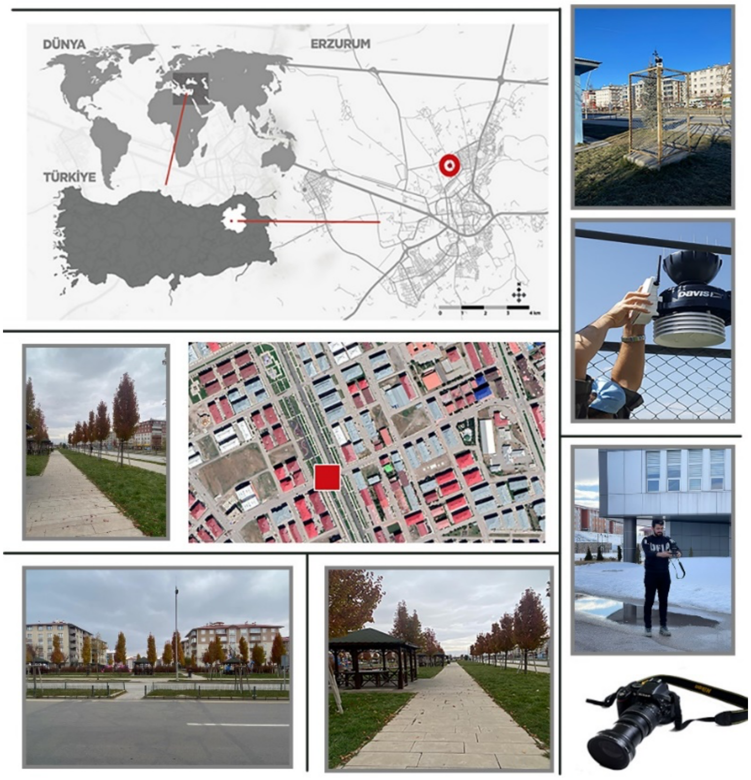

Figure 1. Haydar Aliyev Street study area location map (red square device location "Vantage Pro 2 Plus".

2.2. Methodology

Overview of the ENVI-met model: The ENVI-met BIO+ Science Software computer model is used to generate possible scenarios for the better planning of urban spaces in terms of climate-focused thermal comfort. Developed by Bruse and Fleer (1998), this model allows the use of climate data in planning, producing simulations for thermal comfort in various settings, from regional planning to urban planning and even alternative designs for a house garden. In urban planning, simulations can be conducted by changing the position of buildings, the type of plant species, street orientation, building height, roof gardens, or alterations in surface materials. The different scenarios produced can be analyzed using the ENVI-met + BIO Science model, which is purchased under the TÜBİTAK project for future simulations. This study had a few scenarios that were specifically designed for the summer and presented at a symposium. However, the accuracy analysis comparing the measured data and simulations was not conducted during the symposium presentation. After the symposium, these analyses were learned and simulations were re-performed by evaluating the winter version as well (Yilmaz et al., 2022b). The software, developed by Bruse (2022), can provide up to 250 grids for a single structure, with a resolution between 0.5 and 10 meters, and can perform simulations for surface air in small-scale atmospheres in urban areas, using 24-hour data. The hourly data used in the analyses can be either daily meteorological values or 24-hour data containing averages (Bruse, 2022; Guo et al., 2023). The study utilized a model with a horizontal resolution of 0.5-5 m and spatial microclimatic parameters of 2.00x2.00x2.00 m and an area of 175 m x 230 m x 36 m (Table 1). ENVI-met software is based on fluid mechanics and thermodynamic theories (Zhang et al., 2022), and is widely used by planning and landscape architecture researchers to improve thermal comfort and reduce the urban heat island effect (Wang et al., 2019). According to ENVI-met software, a portion of the study area covering 40250 m^2 was included within the measurement station boundaries. The measurement device should be located within the study area for ENVI-met analyses, as this model simulates the area within a three-dimensional box that includes the ceiling, floor, and height (Bruse, 2022; Guo et al., 2023).

Table 1. ENVI-met model input data for winter and summer in 2021

Location	**Haydar Aliyev Street**	
Climate Type	Mountain Ecosystem	
Simulation Time	January and August	
Total Simulation Time	1st scenario (24 hours)	
Spatial Resolution	2m x 2m x 2m	
Field Size	175m x 230m x 36m	
	Model Angle	
	22.01.2021	29.08.2021
Basic Meteorological Input	Unshaded	Unshaded
Wind speed (m/s)	0.20	1.15
Wind direction	242,81 °C	176,25 °C
24-hour Air Temperature	+	+
24-hour Relative Humidity	+	+
Cloud cover (Octas)	0	0
Mina air temperature (Ta-°C) /h	-21,5 °C / 07:00	17,7 °C / 05:00
Max air temperature (Ta-°C) /h	-9,7 °C / 16:00	32,7 °C / 17:00
Min humidity (%)	% 65 / 16:00	%14 / 17:00
Max humidity (%)	% 86 / 05:00	%54 / 06:00
Sky View Factor (SVF)	Clear	Clear
Street and pedestrian road	Asphalt - Cement – Concrete – Granite – Grass - Soil	

Sky View Factor (SVF): The amount of solar radiation that affects any point depending on the settlement geometry is determined by a parameter called Sky View Factor (SVF). This value is calculated using the Rayman Pro 2.1 program and is expressed as a number between 0 and 1. In street canyons, as the value approaches 1, the space is wider, and as it approaches 0, the space becomes narrower. SVF is commonly used to prepare maps of thermal comfort streets, sidewalks, living spaces, and tree cover (Gülten, 2007; Algeciras et al., 2016; Li et al., 2020).

3. Results and Discussion

The thermal comfort of Haydar Aliyev Avenue, located in a densely populated modern residential area to the north of Erzurum city center, has been analyzed. This area stands out for its planned development on a slightly sloping area above agricultural land. The area consists of residential buildings along the road, with a ground plus five-floor structure on the front side and a ground plus seven-floor structure on the back side of the road. Each residential structure has green areas within its own parcel boundaries as per setback distances. The station is installed in an area suitable for the dominant detached and block construction styles prevalent in the Şükrü Paşa district. The residential areas are planned for balanced open and closed spaces with green areas and are planned for urban development. The street pattern is oriented in the southeast-northwest direction (TÜBİTAK 1st Development Report; Figure 2). SVF values above 0.9 were obtained for the main avenue and its immediate surroundings, indicating high openness and sky view factor in terms of SVF. In the backstreets, although not in many places, the value was found to drop below 0.5 (Figure 2) in terms of SVF.

ENVI-met Model Validation: The accuracy analyses of August 29, 2021 and January 22, 2021 were performed to represent hot and cold months from all data recorded within the study area. For the accuracy analysis of ENVI-met, 24 hours of 48 hours taken during summer and winter were used (Tables 2 and 3).

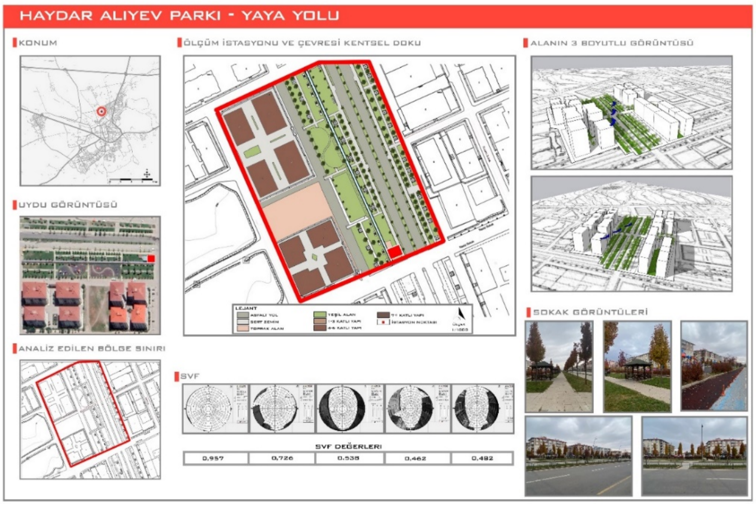

Figure 2. Haydar Aliyev Park and pedestrian road spatial texture analysis.

The temperature of the measurement days is one of the important variables used to verify the performance of the model. Seven statistical measures were used to calibrate the predicted (*P*) and observed (*O*) data of the street in the study area to evaluate the performance of the model. The statistical measures used are the determination coefficient (*R2*), efficiency coefficient (*E*), mean bias error (*MBE*), mean absolute error (MAE), root mean square error (*RMSE*), agreement index (*d*), and productivity coefficient (*E*). Agreement index (*d*) is a commonly used goodness-of-fit measure to evaluate model performance and is considered better than the determination coefficient (*R2*) (Qaid et al., 2016; Battista et al., 2016). Root-mean-square error (*RMSE*) and mean bias error (*MBE*) were evaluated regarding environmental prediction models. Simulation accuracy includes Willmott's (1982) agreement index (*d*). The accuracy of calculations depends largely on the grid size, model details, and input parameters. In the study, the calibration accuracy between the measured values and simulation analyses is given by the value of (*d*) and (*RMSE*). A value of (*d*) approaching 1 indicates that the simulation results are reliable (Qaid and Ossen, 2015; Yilmaz et al., 2021). *RMSE* is a measure that compares different prediction errors in the data set and indicates accuracy, showing that there are fewer errors in the prediction as the value decreases (Battista et al., 2016; Yavaş and Yilmaz, 2019).

Meanings of Abbreviations in the formula (Battista et al., 2016):
d : Index of agreement [–]
MAE : Mean absolute error [–]
MBE : Mean bias error [–]
ND : Number of analyzed data [–]
$\bar{O}$: Mean of the observed variable
Oj : Observed variables for each instant *j*
Pj : Model-predicted variables for each instant *j*

$$d = 1 - \left[\frac{\sum_{j=1}^{N_D} \left[\left(P_j - \bar{O} \right) - \left(O_j - \bar{O} \right) \right]^2}{\sum_{j=1}^{N_D} \left(\left| P_j - \bar{O} \right| + \left| O_j - \bar{O} \right| \right)^2} \right] \quad (1)$$

$$MBE = \frac{\sum_{j=1}^{N_D} \left(P_j - O_j \right)}{N_D} \quad (2)$$

$$MAE = \frac{\sum_{j=1}^{N_D} \left| P_j - O_j \right|}{N_D} \quad (3)$$

When the measured and simulated air temperature data for the current situation were evaluated for the summer months, the R^2 value was found to be 0.9897. The agreement index (*d*), which determines the accuracy of the data, was 0.99 (Figure 3a), indicating that the data is reliable as it is close to 1. The root mean square error (*RMSE*) is an indicator used to measure the inconsistency between the values estimated by the model and the actual observed values (Yu et al., 2023). The result of 0.7323 obtained in the study indicates the accuracy of the analysis, as the value is small, indicating that the model simulation is accurate (Figure 3a). In the accuracy analysis conducted for the winter month data, the (*d*) value was calculated as 0.63 and the (*RMSE*) value was 3.2986. The reliability of the simulation analyses was found to be lower for the summer months compared to the winter months (Figure 3b). Based on the above analysis, software validation is statistically good and can be used for this study.

Analysis of ENVI-met Proposed Scenarios: Different landscape design scenarios were analyzed to provide outdoor thermal comfort in all seasons for urban residents to spend time in outdoor spaces. Studies in this field have shown that when landscape designs are created in harmony with the natural structure of the area, thermal comfort in the space can be improved (Jamei and Rajagopalan, 2017; Morakinyo et al., 2019; Yucekaya and Uslu, 2020; Lai et al., 2022; Okumuş and Terzi, 2022; Yu et al., 2023). It has been determined that the right decisions regarding land use can be taken with the right planning (Şatır and Berberoğlu, 2021). For this purpose, four different landscape scenarios were analyzed using the ENVI-met BIO+ Science model for summer and winter, along with the current situation, and the obtained data are presented in Table 4. Simulation visuals for summer and winter are presented in Figures 4 and 5, respectively.

Table 2. Meteorological data of 29 August 2021 (summer day)

	Time	**Observed air temperature (°C)**	**Simulated air temp. (°C)**	**Difference**	**Difference square**	**The root mean square error (*RMSE*)**	**Index of agreement (*d*)**
29.08.2021	00.00	22.8	22.5	-0.3	0.09	0.732	0.99
	01.00	22.8	22.6	-0.16	0.025		
	02.00	20.2	20.8	0.6	0.36		
	03.00	20.3	20.6	0.3	0.12		
	04.00	21.4	21.3	-0.03	0.001		
	05.00	17.7	18.8	1.1	1..3		
	06.00	16.9	17.9	1.08	1.1		
	07.00	18.9	19.3	0.4	0.1		
	08.00	21.8	21.8	0.0	0.0		
	09.00	25.1	24.7	-0.3	0.10		
	10.00	25.8	25.9	0.1	0.01		
	11.00	27.9	27.4	-0.4	0.16		
	12.00	29.3	28.8	-0.4	0.21		
	13.00	31.6	30.4	-1.1	1.25		
	14.00	31.8	31.1	-0.6	0.42		
	15.00	32.6	31.7	-0.8	0.75		
	16.00	31.5	31.1	-0.3	0.09		
	17.00	32.7	31.3	-1.3	1.89		
	18.00	30.2	29.9	-0.2	0.07		
	19.00	28.2	28.3	0.1	0.03		
	20.00	27.4	27.4	0.0	0.0		
	21.00	24.4	25.3	0.9	0.83		
	22.00	22.1	23.4	1.3	1.75		
	23.00	20.8	22.2	1.4	1.96		

Table 3. Meteorological data of 22 January 2021 (winter day)

	Time	Observed air temperature (°C)	Simulated air temp. (°C)	Difference	Difference square	The root mean square error *(RMSE)*	Index of agreement (*d*)
22.01.2021	00.00	-17.1	-13.5	3.6	12.9	3.298	0.63
	01.00	-18.0	-13.6	4.3	19.1		
	02.00	-18.6	-14.1	4.4	19.4		
	03.00	-18.4	-14.4	3.9	15.2		
	04.00	-19.8	-14.8	4.9	24.6		
	05.00	-19.9	-15.1	4.8	23.1		
	06.00	-19.6	-15.2	4.3	19.1		
	07.00	-21.5	-15.5	5.9	35.8		
	08.00	-21.4	-15.7	5.6	32.1		
	09.00	-20.8	-15.8	4.9	24.8		
	10.00	-17.6	-15.4	2.1	4.6		
	11.00	-14.2	-14.5	-0.3	0.1		
	12.00	-14.3	-14.0	0.2	0.1		
	13.00	-12.8	-13.5	-0.7	0.5		
	14.00	-10.1	-12.6	-2.5	6.3		
	15.00	-10.5	-12.3	-1.8	3.3		
	16.00	-9.7	-12.7	-2.3	5.5		
	17.00	-12.0	-12.4	-0.4	0.2		
	18.00	-14.2	-13.1	1.1	1.1		
	19.00	-14.5	-13.4	1.1	1.2		
	20.00	-14.6	-13.5	1.0	1.1		
	21.00	-15.3	-13.7	1.5	2.4		
	22.00	-15.8	-13.9	1.8	3.5		
	23.00	-16.2	-14.1	2.1	4.3		

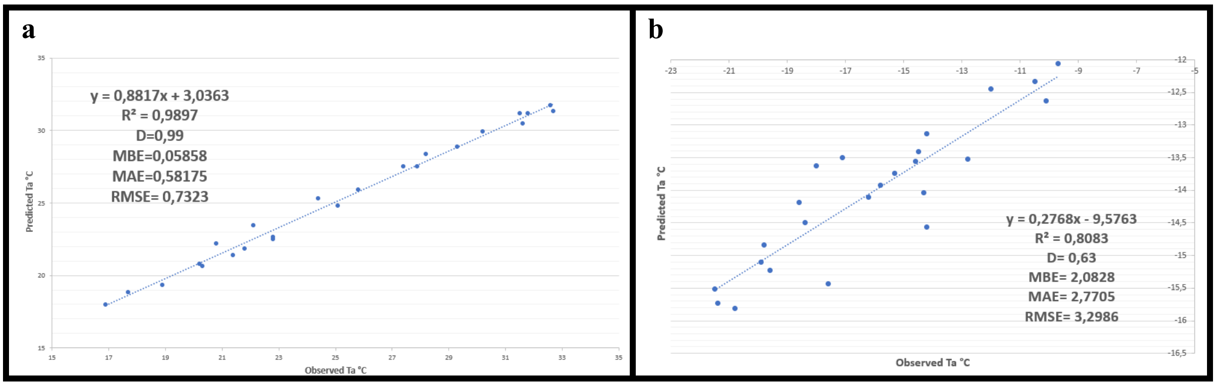

Figure 3. The observed (O) and the predicted (P) air temperature in summer (a) and winter (b).

In the analysis of the current situation, it was determined that there were no significant differences among the scenarios for the summer season. One of the important reasons for this is that the area has a dense and rich green area structure. The current situation was found to be 0.2°C warmer than the green area scenario for the summer season. In the summer season analysis, the scenario with the highest temperature of 30.9°C according to the mean values was found to be the scenario where green areas were increased. The analysis using ENVI-met showed that areas with dense vegetation had lower temperatures compared to other areas. In the summer analysis, the current condition was found to be only 0.2°C warmer than the green area scenario, with no significant differences among the scenarios. The scenario with increased greenery was found to be the coolest, with an average temperature of 30.9°C. Furthermore, it was found that areas with more plant material were cooler compared to other areas. In the summer analysis, the coolest area was found to be the one with the most vegetation cover.

In a study conducted on a city park using ENVI-met, it was found that the scenario with trees and green areas lowered the temperature by 0.5°C compared to the current condition. In the summer analysis, the soil scenario had the highest average temperature at 31.6°C and the lowest humidity at 20.2%. Similar results have been confirmed in various studies, which have identified the causes of differences in temperature, humidity, wind, and thermal comfort between areas with and without vegetation. These include the conversion of surface radiation into latent heat due to soil moisture, shade created by tree leaves, and the evapotranspiration effect of plants. For the winter months, the average temperature was found to be 1.3°C warmer on grass surfaces compared to the current condition. The relative humidity was found to be 107.5% in the grass scenario compared to 113.5% in the current condition.

Table 4. The temperature (°C) values of the scenarios for summer and winter with ENVI-met are as follows

Summer			
Scenarios / Temp. (°C)	**Min. temp. (°C)**	**Max. temp. (°C)**	**Mean temp. (°C)**
Current situation	29.2	33.0	31.1
Soil covered surface	29.9	33.3	31.6
Grass covered surface	29.8	33.2	31.5
Increasing the tree-shrub ratio by 20%	29.1	32.9	30.9
Water surface	29.2	33.0	31.1
Scenarios / Humidity (%)	**Min. humidity (%)**	**Max. humidity (%)**	**Mean humidity (%)**
Current situation	16.4	27.6	22.0
Soil covered surface	16.3	24.2	20.2
Grass covered surface	16.2	24.8	20.5
Increasing the tree-shrub ratio by 20%	16.4	28.0	22.2
Water surface	16.4	27.6	22.0
Scenarios / Wind	**Min. wind speed (m s^{-1})**	**Max. wind change ratio (%)**	**Mean wind change ratio (%)**
Current situation	0.5	157.3	78.9
Soil covered surface	1.6	182.1	91.85
Grass covered surface	1.5	177.9	89.7
Increasing the tree-shrub ratio by 20%	0.5	156.9	78.7
Water surface	0.5	157.3	78.9
Winter			
Scenarios / Temp. (°C)	**Min. temp. (°C)**	**Max. temp. (°C)**	**Mean temp. (°C)**
Current situation	29.2	33.0	31.1
Soil covered surface	29.9	33.3	31.6
Grass covered surface	29.8	33.2	31.5
Increasing the tree-shrub ratio by 20%	29.1	32.9	30.9
Water surface	29.2	33.0	31.1
Scenarios / Humidity (%)	**Min. hum. (%)**	**Max. hum. (%)**	**Mean hum. (%)**
Current situation	16.4	27.6	22.0
Soil covered surface	16.3	24.2	20.2
Grass covered surface	16.2	24.8	20.5
Increasing the tree-shrub ratio by 20%	16.4	28.0	22.2
Water surface	16.4	27.6	22.0
Scenarios / Wind	**Min. wind speed (m s^{-1})**	**Max. wind change ratio (%)**	**Mean wind change ratio (%)**
Current situation	0.5	157.3	78.9
Soil covered surface	1.6	182.1	91.85
Grass covered surface	1.5	177.9	89.7
Increasing the tree-shrub ratio by 20%	0.5	156.9	78.7
Water surface	0.5	157.3	78.9

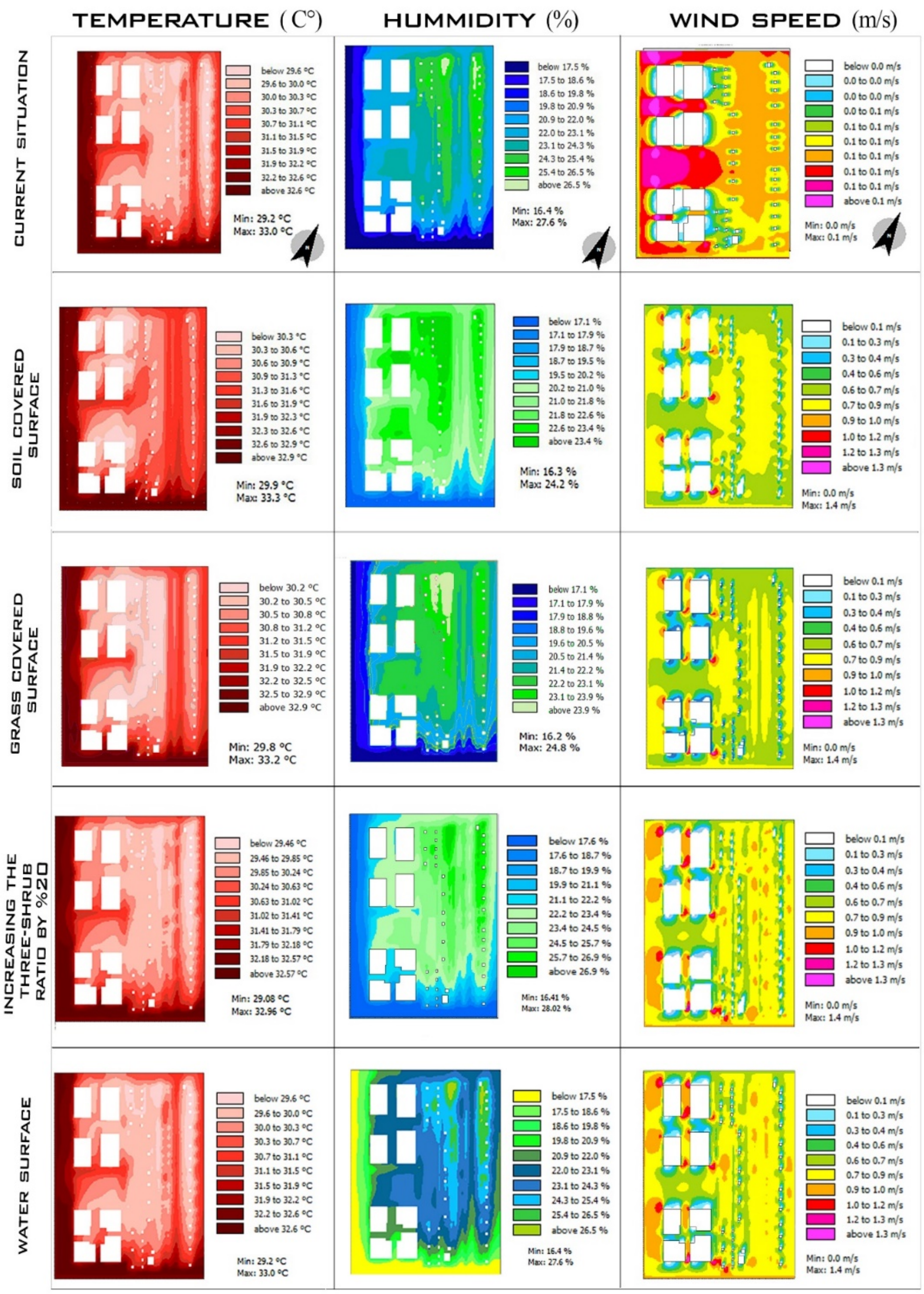

Figure 4. ENVI-met analysis for summer proposed scenarios.

According to the scenario-based analysis provided in Figure 6, it has been determined that the average wind speed change in the region with a high density of plant materials during the summer wind analysis has the lowest wind speed change with 78.7%. Similar analyses have shown that plants reduce wind speed by blocking wind circulation when they are not planted in a certain order (Vogel, 1989; Yilmaz et al., 2017; Chan and Chau, 2021; Orhan et al., 2022). In the winter analysis, the highest wind speed change rate in wind data was measured in the grass scenario with 227.9%, while the lowest change was determined in the soil scenario with 136.8%. This is due to the absence of any obstacles limiting wind movement in both scenarios. In the winter analysis, significant differences in the wind were also found between the current situation and the grass scenario, and it was determined that wind speed increased.

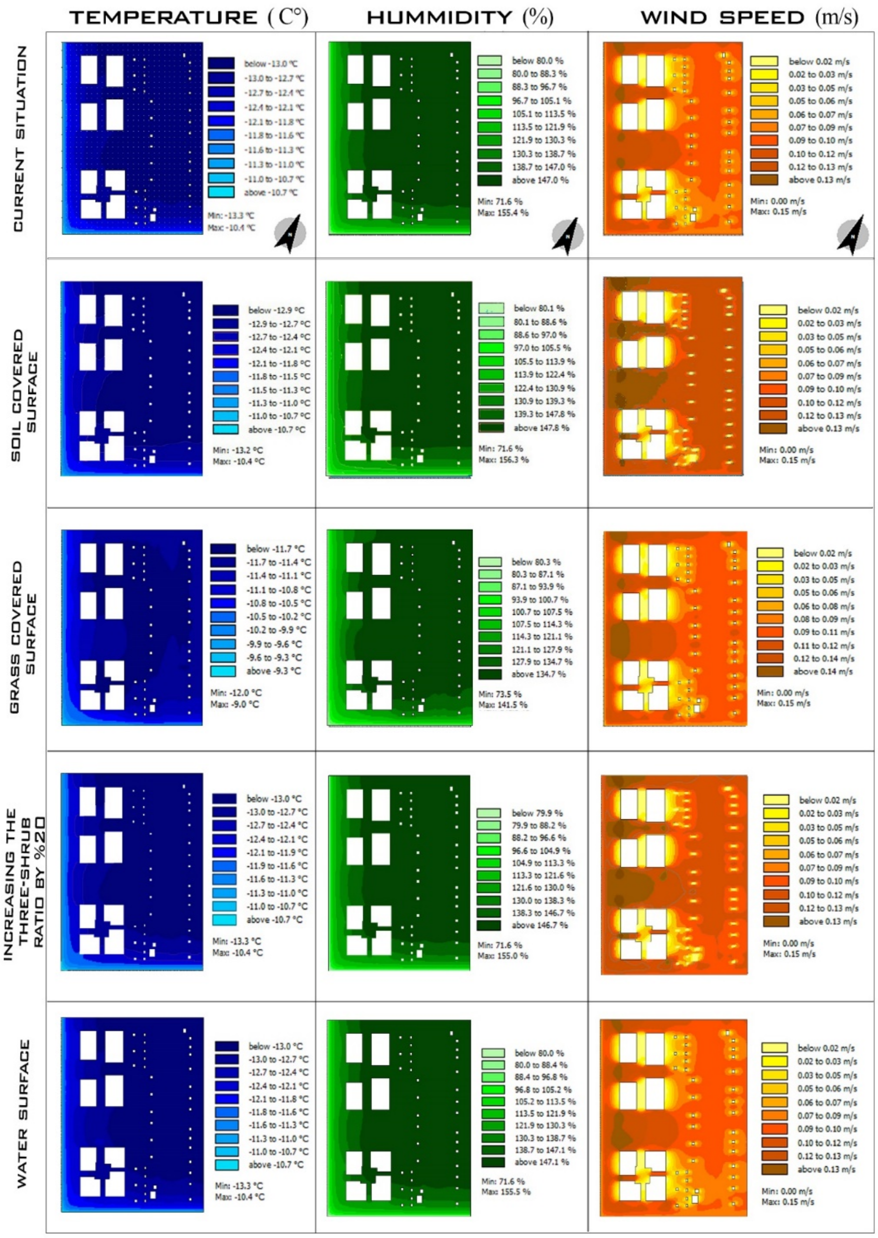

Figure 5. ENVI-met analysis for winter proposed scenarios.

The current wind speed change rate is 70.5%, while the change rate in the grass scenario has increased to 114.6%. In a study conducted in a park in the city of Qinhuangdao in China, it was found that scenarios prepared compared to the current situation improved the thermal comfort of the environment. According to the ENVI-met analysis conducted in this study, the temperature, relative humidity, and wind speed were 31.1°C, 49.70%, and 2.3 m/s, respectively, in the current situation, while in the scenario analysis, these values were improved to 29.7°C, 51.64%, and 1.0 m/s, respectively (Lai et al., 2022).

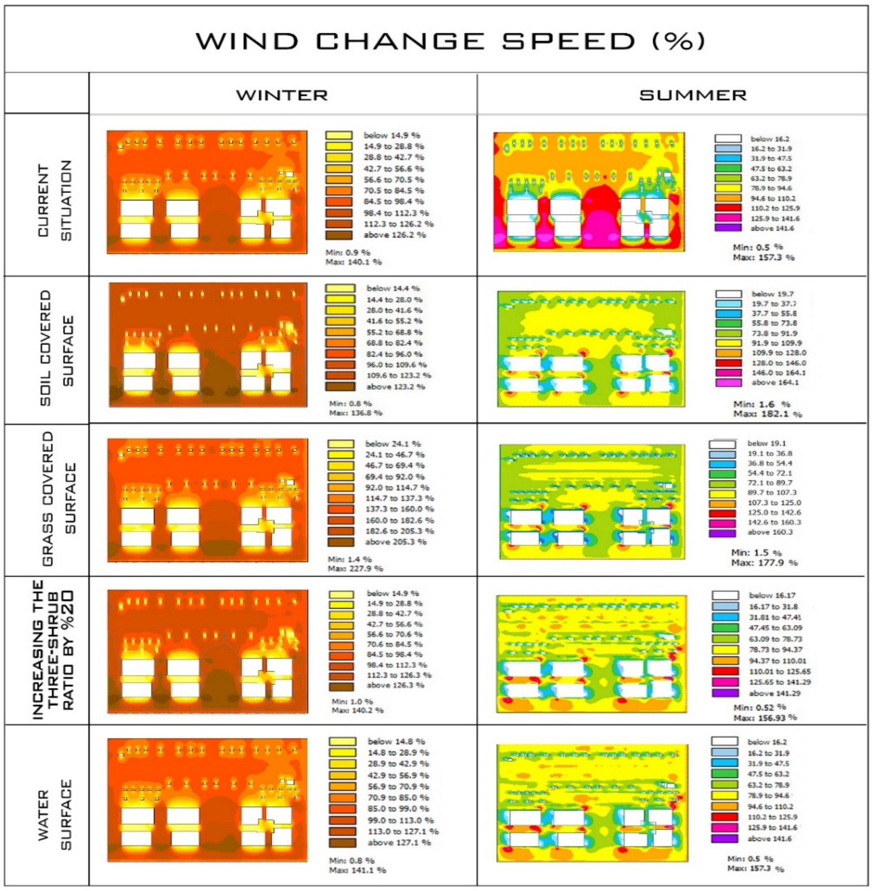

Figure 6. Wind change speed visualization with ENVI-met analysis in proposed scenarios.

In the winter scenario, it has been determined that the change in wind speed increases by an average of 0.4% in the water scenario. In the water scenario, it was observed that the temperature of the decorative pool was 0.7°C cooler than the soil scenario in summer analyzes. The cooling effect of the water has also been confirmed during the summer months (Yilmaz et al., 2021), and it has been found that the cooling effect of the water is also related to the size of the water surface (Wang et al., 2018). In a study, it was determined that the cooling effect of a large single water surface is greater than that of a fragmented water surface (Yücekaya et al., 2022). In fact, in an ENVI-met analysis conducted in a park in Valladolid, Spain, it was calculated that the scenario with water and plants was 4.3°C cooler than the current situation (Alves et al., 2022). Again, a cooling effect of between 0.8 and 1.3°C was determined in the water scenario during the summer months (Xu et al., 2019).

However, some ENVI-met studies have reported that the software does not provide the desired result in wind analysis when the wind speed is less than 2.0 m s^{-1} (Song et al., 2014; Acero and Arrizabalaga, 2018). It has been found that humidity and wind speed yield similar results in some scenarios and do not create significant differences. In fact, in a study, it was determined that water surfaces do not create a significant difference in wind speed up to a certain size (Yücekaya et al., 2022). In the winter scenario, there is no significant change in temperature and humidity, while there is a 0.4 m/s increase in average wind speed compared to the current situation. When scenarios were prepared by increasing the vegetation ratio by 20%, it was observed that the humidity in the region where the vegetation materials were dense decreased, and as a result, cool air was formed compared to the current situation analysis in summer analysis. When maximum humidity values in summer were examined, it was determined that the area with increased vegetation cover had the highest humidity with 28.0%, while the soil area had the lowest humidity with 24.2%. In summer analysis, it was observed that humidity decreased compared to winter and varied in the region where vegetation material was dense. In the winter analysis of the scenario, it was observed that humidity increased compared to summer. At the same time, a homogeneous appearance was exhibited in the area where vegetation materials were dense. Similar results were found in all scenarios except for the grass scenario when winter humidity values were examined. In the winter scenario, the grass scenario had an average of 6% lower humidity compared to the current situation. According to the analysis results, it was observed that the vegetation cover or increased green area improved the thermal comfort of the environment more in summer compared to winter. Similarly, in similar academic studies, the effect of green areas on thermal comfort in winter was found to be less effective compared to summer (Gatto et al., 2020).

4. Conclusion

The results of this study have shown that improving outdoor thermal comfort can only be achieved by designing in accordance with the natural features of the area. Undoubtedly, plants are the most environmentally friendly landscape element for landscape architects. In the summer scenario where the number of plants was increased by 20%, it was determined that the temperature decreased by an average of 0.2ºC. The scenario with an increased number of trees was found to cool the environment in the summer and improve thermal comfort in the winter by reducing wind speed and allowing sunlight to enter the space. In the study area scenario, it was determined that the 200 m^2 water surface designed for summer and winter had no effect on temperature. However, the winter water surface scenario was found to increase wind speed by a maximum of 1.3 m s^{-1}. Low wind speed in the city center of Erzurum made it difficult to obtain accurate data in the analyses. In the future, it is aimed to produce locally specific scenarios for Erzurum to minimize the effects of climate change on the city. Ultimately, the data obtained will shed light on proposed new environmental planning schemes and will provide a foundation for creating climate-sensitive and thermally comfortable spaces.

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