

Article

Evaluation of Nature-Based Solutions to Improve the Urban Microclimate in Mediterranean Climate Conditions: A Case Study of Izmir-Karsiyaka

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Abstract: Today, rapid urbanization and increasing human activities have affected the climate at macro and micro scales in cities and caused unfavorable conditions in terms of human thermal comfort, especially in outdoor spaces. In this context, new solutions need to be researched, developed, tested, and updated to improve thermal comfort in cities. Using ENVI-met 5.1 software, this study investigated the effects of different NBS combinations on the urban microclimate and human bioclimatic comfort in Izmir (Turkey). The current situation, the scenarios where some nature-based solutions (NBS) are applied within the scope of the European Union's HORIZON 2020 "URBAN GreenUP" project, and two other scenarios planned within the scope of the study were evaluated. The findings of the study showed that both the NBS scenarios created within the scope of the EU project and the NBS scenarios with large deciduous trees had the most positive impacts on improving thermal comfort conditions in all three study zones and achieved temperature reductions of up to 2.5 °C in urban temperatures. In terms of thermal comfort, the most significant differences were calculated between the minimum PMV values and were close to 1 °C. In addition, the simulation results showed positive changes in psychological stress levels.

Keywords: ENVI-met; thermal comfort; nature-based solutions; Izmir; urban microclimate; Urban GreenUP



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1. Introduction

As population density and urbanization have reached incredible levels, extreme weather events have become more frequent, and approximately 70% of disasters are climate-related [1,2]. Many studies in recent years have also confirmed this [3–6]. According to climate projections, a strong temperature-increase trend is expected in the next few decades, with extreme increases in daily temperatures, longer hot periods, and more intense heatwaves [5,7]. Cities are particularly vulnerable because they are exposed to the urban heat island phenomenon in addition to global warming [1,2]. The UHI is characterized by increased temperature values, lower relative humidity, and moderation of wind velocity, resulting in unpleasant microclimatic conditions for humans [8]. Unpleasant climatic conditions in outdoor areas not only result in less comfortable urban environments but also increase pollutant concentrations, causing health problems and increasing the cooling load of buildings [9–11].

Therefore, thermal comfort is one of the main determinants to consider when designing an outdoor space and is influenced by a wide range of variables [12]. In hot, humid climates, it is crucial to consider the provision of shade and ventilation in urban outdoor spaces in urban design and planning [13]. Martinelli et al. (2015) reported that shade has positive effects on human thermal comfort and engagement in Rome [14]. In addition, green

spaces and surface materials play an important role in improving outdoor thermal comfort. Shasua-Bar et al. (2012) identified the thermal effect of trees as the dominant factor in improving thermal comfort in their study in Athens [15]. In the study by Lobaccaro et al. (2015) in Bilbao (Spain), the highest PET reduction was calculated in scenarios where the presence of trees and grass was combined [16]. In addition, the materials used in urban landscapes play a crucial role in urban thermal balance, as they absorb incoming solar radiation and increase the ambient temperature by dissipating the heat absorbed through convective and radiative processes in the atmosphere [17,18]. Accordingly, in recent years, it has become very important to turn to nature, to obtain help from nature, and to produce solutions inspired by nature in combating the problems created and to be created by climate change and to provide more comfortable thermal conditions in cities. NBSs incorporate natural elements into urban structures under the premise of restoring landscapes altered by humans [19–21]. Both public and private organizations and the international community recognize nature-based solutions as an important key component for combating climate change, assuming that they can meet 30% of the Earth's potential, on average, to mitigate climate change [22].

However, natural phenomena are often very complex, which makes them difficult to study and understand [23,24]. In this context, analysis models that allow the understanding and prediction of these phenomena have come to the fore. In recent years, researchers have been using software such as ENVI-met, Rayman, CFD, and Design Builder to assess the impact of urban morphological changes on local meteorological conditions. For example, Sayad et al. (2021) in Guelma (Algeria) and Mosca et al. (2021) in Genoa (Italy) used Envi-Met software (version 4.4.4 and 4.4.5) to simulate scenarios testing the benefits of NBSs, and used their outputs as a reference for urban design in order to reduce the effects of heat islands in urban areas and improve the thermal comfort of users [25,26]. Majidi et al. (2019) in Bangkok (Thailand) used ENVI-met software (version 4.1.3) to evaluate the potential locations of small-scale NBSs for implementation [27]. In the study of Gomez et al. (2021) in Badajoz (Spain), Evora (Portugal), and Porto (Portugal), NBSs that can be applied to three different educational buildings were tested with Design Builder software (version 4.7) [28]. Although many studies have examined the effects of NBSs on urban temperatures and thermal comfort around the world, very few scientific studies have been performed in Turkey. However, there is a need for more studies on the anthropological effects on microclimate and how these effects can be minimized in densely built cities such as Izmir where heat island effects are becoming more and more evident.

This research is part of the Urban GreenUP project funded under the European Union's Horizon 2020 program. Its aim is the development, implementation, and replication of urban plan renewal in partner cities in Spain, the United Kingdom, and Turkey, with the aim of mitigating the effects of climate change, improving air quality and water management, and increasing the sustainability of cities through innovative NBSs [29]. It is also crucial in terms of the implementation and testing of some of the NBSs (permeable concrete applications, green roofs, etc.) evaluated in the research. The results of the research are expected to contribute to the development of Izmir's existing green infrastructure strategy and provide a basis for the production of plans and actions [30]. In addition, the study is expected to set an example for other studies to be conducted in the country.

In this context, the aim of this study was to examine which combinations of NBSs perform better in improving thermal comfort and reducing urban temperatures in three different study areas identified in the city of Izmir (Turkey), where heat island effects are becoming increasingly evident. The influence of urban morphology and environmental conditions on the microclimatic performance of NBSs was also investigated. In simulations prepared using ENVI-met 5.1 software, microclimatic changes and thermal comfort were analyzed according to air temperature, wind speed, and Predictive Mean Vote (PMV) indices.

2. Materials and Methods

2.1. Study Area

Izmir is a coastal city in western Anatolia, located on the east of the Aegean Sea between 38°39' latitude and 27°28' longitude. It is located between the provinces of Balıkesir to the north, Manisa to the east, Aydın to the south, and the Aegean Sea. The İzmir peninsula is located between the Gediz and the Kucuk Menderes Valleys (Figure 1).



Figure 1. Location of study zones.

The main reason for choosing Izmir as the study area is that it is a city in Turkey with typical Mediterranean climatic conditions that has undergone a significant urbanization process in the last quarter century and is facing the urban heat island problem [31]. Within the scope of this study, three different locations were selected as study zones, where the effects of different NBSs on the urban microclimate were examined. The first zone is Girne Street in Karsiyaka, the second is Karsiyaka Provinces House Parking Lot, and the third is Sasalı Wildlife Park Parking Lot in Cigli (Figure 1).

Residential and commercial areas are located around Girne Street. Izmir Bay is located in the southwest of the area. The building heights vary between 15 and 35 m throughout the area. The street has four lanes of road flow, and in the middle of the street, there is a 5 m-wide median with grass and *Platanus orientalis* trees. Both sides of the area are suitable for parking, and there are *Platanus orientalis*, *Pinus pinea*, *Washingtonia filifera*, and *Cupressus macrocarpa* trees (Table 1).

Karsiyaka Provinces House Parking Lot is also located within residential and commercial areas, but the building heights are lower. The Tramway Road passes through the research area, which has Izmir Bay to the southwest. In addition to the parking lot, there are pocket parking lots along the road. There are *Ilex aquifolium*, *Robinia pseudoacacia*, *Schinus molle*, and *Washingtonia filifera* trees in the pocket parking lots (Table 1).

Unlike the other areas, Sasalı Wildlife Park Parking Lot, located in a semi-rural area, is part of Sasalı Wildlife Park, located in the northwest of Izmir. The immediate surroundings

of the area, which contains a small number of *Robinia pseudoacacia* trees, grass, and soil surfaces, comprise woodland and mostly agricultural areas (Table 1).

Table 1. Some quantitative and qualitative information about the study areas.

	Widths of the Buildings (m)	Paving Materials	Type of Nearby Settlement	Plant Material Present
Girne Street	15–35	Granite	Residential and commercial	<i>Platanus orientalis</i> , <i>Pinus pinea</i> , <i>Washingtonia filifera</i> , and <i>Cupressus macrocarpa</i>
Karsiyaka Provinces House Parking Lot	10–15	Concrete paving	Residential and commercial	<i>Ilex aquifolium</i> , <i>Robinia pseudoacacia</i> , <i>Schinus molle</i> , and <i>Washingtonia filifera</i>
Sasalı Wildlife Park, Parking Lot	-	Concrete paving	Agricultural areas and woodland	<i>Robinia pseudoacacia</i> , grass

2.2. Introduction to ENVI-Met Model

In this study, experimental methods were applied to evaluate the microclimatic characteristics of the research areas based on scenarios that included different NBSs. ENVI-met 5.1 software was used, and the air temperature (°C), mean radiant temperature (TMRT), and predicted mean vote (PMV) from the thermal comfort indices were analyzed [32]. The current conditions of the research areas and the different scenarios created were evaluated through the analyses. The implementation process of the study method is explained in detail in Figure 2.

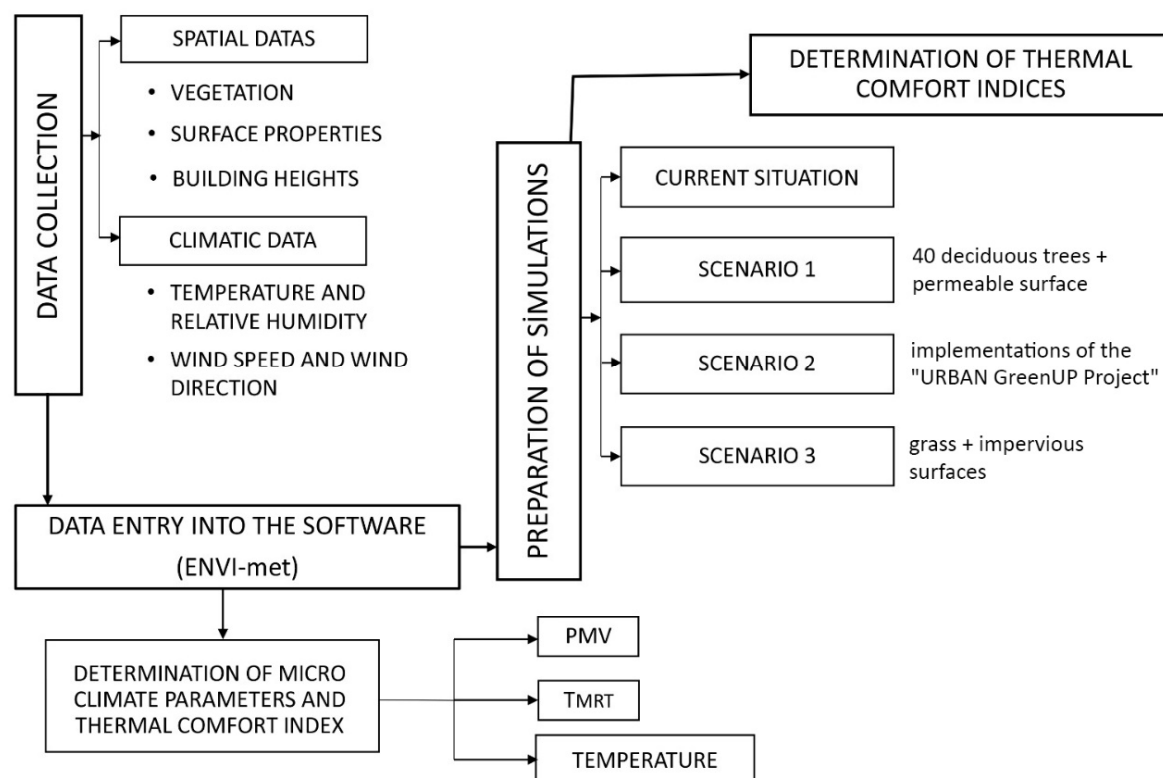


Figure 2. Application process of the working method.

Among the programs used to determine outdoor thermal comfort, such as Solweig, Rayman, and ENVI-met, ENVI-met is the simulation tool with the lowest margin of error [33]. For this reason, the ENVI-met program developed by Michael Bruse was used in this study. This software is also the simplest and most widely used atmospheric model-

ing platform. ENVI-met software, a widely used computational fluid dynamics package, involves a holistic microclimate model. It uses RANS equations to calculate the heat energy balance in urban environments and atmospheric conditions [34]. A set of spatial (location, surface characteristics of the area, plant species, and story heights) and climatic (temperature, humidity, and wind speed and direction) data are used to run the software.

According to the long-term temperature data obtained from the General Directorate of Meteorology, the highest temperatures in Izmir were measured in July and August. The days to be analyzed within the scope of the study were determined from this period range. As of December 2019, data were collected from meteorological stations (HOBO RX3000) installed within the scope of the European Union's Horizon 2020 project in the study zones [35]. In 2020, due to the extreme temperatures in Izmir in July, the measurements of 24–25 August were used for ENVI-met analysis within the scope of the study. The meteorological parameters used in the study are wind speed (WS), temperature (Tair), and relative humidity (RH). The sensor specifications of the meteorological stations are provided in Table 2. Meteorological stations collect data at 10 min intervals. ENVI-met simulation outputs based on the meteorological data measured in the study areas were evaluated according to 13.00 values. This period was determined considering that the study area has a Mediterranean climate [31].

Table 2. Sensor specifications of HOBO RX3000 meteorological station [36].

Specifications	WS	WD
Measurement Range	0 to 76 m/s (0 to 170 mph)	0 to 355 degrees, 5-degree dead band
Accuracy	± 1.1 m/s (2.4 mph) or $\pm 4\%$ of reading, whichever is greater	± 5 degrees
Resolution	0.5 m/s (1.1 mph)	1.4 degrees
Specifications	Tair	RH
Measurement Range	-40 to 70 °C	0 to 100% RH, -40 °C to 70 °C $\pm 2.5\%$ from 10% to 90% (typical) to a maximum of $\pm 3.5\%$ including hysteresis at 25 °C; below 10% RH and above 90% RH $\pm 5\%$ typical
Accuracy	± 0.25 °C from -40 to 0 °C	
Resolution	0.02 °C	0.01%

In this study, firstly, the current situation simulations of the research areas were produced. Then, three different scenarios with NBSs were generated and the effects of spatial characteristics on urban climate were analyzed. The model configuration and initialization parameter values for the baseline analyses are shown in Tables 3–5.

These scenarios were structured as follows (and are summarized in Figure 2 above):

Scenario 1: Maximum green space and permeable surface. In this scenario, all existing plants were removed and 40 deciduous trees were planted in each area. In addition to these, permeable surface material was preferred as the surface material.

Scenario 2: This scenario includes the implementations of the nature-based solutions “URBAN GreenUP Project” under the Horizon 2020 program. Within the scope of this project, in addition to the existing green areas, different applications were made for each area. Two parklets (short-term green resting areas) were built in opposite directions on Girne Street, increasing the green area by 40 m², and three *Platanus orientalis* trees and eight *Pinus pinea* were planted. In the Vilayeler House and Sasalı Wildlife Park Parking Lots, 285 m² and 1175 m² of green cover areas were constructed, respectively, and all concrete sidewalks were replaced with permeable surface materials. In addition, four *Plantanus orientalis* trees were planted in Vilayeler House and fifteen *Plantanus orientalis* trees were planted in Sasalı Wildlife Park Parking Lot [29] (Figure 3). Within the scope of the study, the success of the application was also tested by performing measurements and analyses before and after the application.

Table 3. The model configuration and initialization parameter values for Girne Street.

	Location		Girne Street	
Spatial data	Domain size (x, y, z)		50 m × 50 m × 30 m	
	Spatial resolution (x, y, z)		1 m × 2 m × 2 m	
	Model rotation		15°	
	Roughness		2	
	Roadway/parking		Asphalt	
	Pedestrian paths		Granite	
	Vegetation (permeable surface)		Medium density grass	
	The plants used		<i>Platanus orientalis</i> , <i>Pinus pinea</i> , <i>Washingtonia filifera</i> , and <i>Cupressus macrocarpa</i>	
.SIM data	Simulation period		24–25 August 2020	
	Simulation start time		13.00	
	Total simulation duration		24	
Climate data	Wind speed (m/s)		0.5	
	Wind direction (0:N, 90:E, 180:S, 270:W)		225°	
	Lowest in air temperature	Highest in air temperature	33.62 °C	39.49 °C
	Lowest inner humidity	Highest inner humidity	34.30 °C	71.97 °C

Table 4. The model configuration and initialization parameter values for Karsiyaka Provinces House Parking.

	Location		Karsiyaka Provinces House Parking	
Spatial data	Domain size (x, y, z)		50 m × 50 m × 30 m	
	Spatial resolution (x, y, z)		2 m × 2 m × 2 m	
	Model rotation		15°	
	Roughness		2	
	Roadway/parking		Asphalt	
	Pedestrian paths		Concrete paving	
	Vegetation (permeable surface)		Medium density grass	
	The plants used		<i>Ilex aquifolium</i> , <i>Robinia pseudoacacia</i> , <i>Schinus molle</i> , and <i>Washingtonia filifera</i>	
.SIM data	Simulation period		24–25 August 2020	
	Simulation start time		13.00	
	Total simulation duration		24	
Climate data	Wind speed (m/s)		0.5	
	Wind direction (0:N, 90:E, 180:S, 270:W)		225°	
	Lowest in air temperature	Highest in air temperature	32.18 °C	43.14 °C
	Lowest inner humidity	Highest inner humidity	21.77 °C	47.03 °C

Table 5. The model configuration and initialization parameter values for Sasali Wildlife Park Parking.

Location		Sasali Wildlife Park Parking	
Spatial data	Domain size (x, y, z)	50 m × 50 m × 30 m	
	Spatial resolution (x, y, z)	2 m × 2 m × 1 m	
	Model rotation	0	
	Roughness	1	
	Roadway/parking	-	
	Pedestrian paths	Concrete paving	
	Vegetation (permeable surface)	Medium density grass	
.SIM data	The plants used	<i>Robinia pseudoacacia</i>	
	Simulation period	24–25 August 2020	
	Simulation start time	13.00	
	Total simulation duration	24	
Climate data	Wind speed (m/s)	0.5	
	Wind direction (0:N, 90:E, 180:S, 270:W)	225°	
	Lowest in air temperature	Highest in air temperature	34.44 °C 39.49 °C
	Lowest inner humidity	Highest inner humidity	28.79 °C 71.97 °C

**Figure 3.** (Scenario 2) the implementations of the Nature-Based Solutions “URBAN GreenUP Project” (The green boxes in the photo of Girne Street are the places where the parklets are implemented) [29].

Scenario 3: Minimum green space and maximum impervious surfaces in the research areas. According to the current situation, all the trees were removed and grass surfaces were kept constant.

2.3. Predicted Mean Vote (PMV) Analysis

There are many indices that measure users’ satisfaction with the physical environment, such as Fanger’s (1972) [37] predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indices; Gagge et al.’s (1972) [38] effective temperature (ET) and standard

effective temperature (SET) indices; and Hoppe's (1999) [39] physiological equivalent temperature (PET) index.

The PMV index used in this study is one of the most popular indices used in the study of thermal comfort. PMV is defined as "an index that predicts the mean value of the votes of a large group of people on a seven-point thermal sensation scale" [37].

PMV is a system that rates the thermal satisfaction of people in a given environment and varies depending on six parameters. These are air temperature, average reflected temperature, wind speed, relative humidity, metabolic rate, and thermal clothing insulation [37].

After all these values were determined, PMV analyses were produced in the ENVI-met package program. The PMV results were evaluated according to the range of values provided by Matzarakis et al. (1999) [40]. The thermal index ranges for PMV are provided in Table 6.

Table 6. Thermal sensation and stress levels according to the PMV index.

PMV (°C)	Thermal Perception	Psychological Stress Level
−3.5	Very cold	Extreme cold stress
−2.5	Cold	Strong cold stress
−1.5	Cool	Moderate cold stress
−0.5	Slightly cool	Mild cold stress
0.5	Comfortable	No thermal stress
1.5	Slightly warm	Mild heat stress
2.5	Hot	Strong heat stress
+3.5	Very hot	Extreme heat stress

From Matzarakis et al. (1999) [40].

2.4. Validation of ENVI-Met Software

In many previous studies, validation of ENVI-met results was carried out by comparing the results of simulation and field measurements. Based on these results, it was determined whether the software simulated the environmental conditions with appropriate accuracy [10]. Lam et al. (2021) found that T_a is the most important validation parameter, followed by T_{mrt} and RH [41].

In this study, T_a is chosen as the validation parameter, and two different indicators were used to examine the validity of the simulation performance. The first indicator, the agreement index (d), has a value between 0 and 1. The closer this value is to 1, the more accurate it is. The other indicator, root mean squared error (RMSE), is a measure of accuracy that compares different forecast errors in a dataset. Smaller values indicate less error in prediction [42].

3. Results and Discussion

Depending on the scenarios created using different NBSs in the research zones, the air temperature (T_a) and PMV (predicted mean vote) index values were analyzed and evaluated with ENVI-met software.

Firstly, the T_a measurements and simulation values were compared and the results proved that the ENVI-met simulation results have an acceptable level of accuracy. The validity of the simulation performance was verified by root mean square error (RMSE) and consistency index (d). Accordingly, the agreement between field measurements and simulation data for each research area was calculated for a period of 24 h (Figure 4; Table 7).

Table 7. Simulation results validated for all research areas.

Research Areas	Root Mean Squared Error (RMSE)	Agreement Index (d)
Girne Street	1.68	0.952
Karsiyaka Provinces House Parking Lot	1.69	0.975
Sasalı Wildlife Park Parking Lot	0.96	0.974

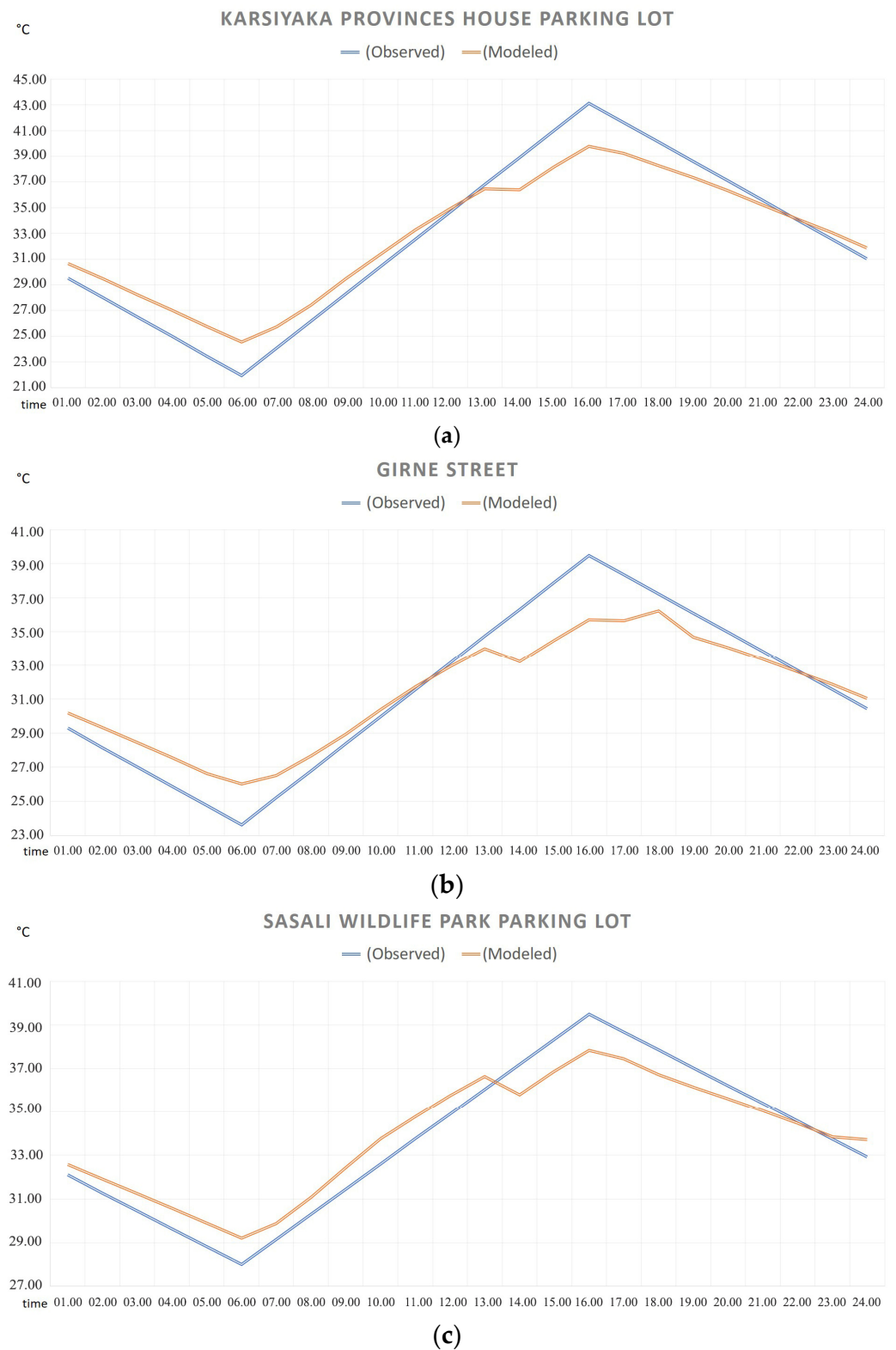


Figure 4. Comparison of measured and simulated air temperature values: (a) Karsiyaka Provinces House Parking Lot; (b) Girne Street; (c) Sasali Wildlife Park Parking Lot.

3.1. Air Temperature

According to the results of the baseline analysis, the air temperature range was 33.53–35.53 °C in Girne Street, 34.8–38.70 °C in Karsiyaka Provinces House, and 35.77–37.51 °C in Sasali Wildlife Park Parking Lot.

At the current air temperatures, Girne Street is the research area with the lowest air temperature. As Mochida and Lun (2008) [43], Park et al. (2012) [44], and Qaid and Ossen (2014) [45] also emphasized in their studies, trees on urban roads, which act as wind tunnels, have a cooling effect. It is thought that the 1–2 °C temperature change in Girne Street compared to the other study areas is due to this effect and the shade effect of the buildings. In addition, the fact that the current air temperature in the Sasalı Wildlife Park Parking Lot, which is surrounded by rural areas, has the highest value contrary to expectations is thought to be due to the fact that the measured area is completely covered with impermeable surface material and there are few trees in the area [46].

Piselli et al. (2018) stated that the urban microclimate is affected by land use [47]. Therefore, each research area located in a different urban environment was evaluated individually through the scenarios created.

In Girne Street, Scenario 1, which included 40 deciduous trees, was found to reduce the minimum temperature values by 0.88 °C, while the maximum temperature values were found to decrease by 1.54 °C. In the same area, Scenario 2, which included the current situation and Urban GreenUP project applications, was found to reduce the minimum temperature values by 0.93 °C and the maximum temperature values by 0.95 °C. Therefore, based on the simulation results, it is possible to say that this scenario has a positive effect on the microclimate. Finally, Scenario 3, which consisted of grass and impervious surfaces, was calculated to decrease the minimum temperature values by 0.05 °C and increase the maximum temperature values by 0.62 °C (Figure 5). According to these results, the scenario with the most positive effect on Girne Street was determined as Scenario 1 using deciduous trees. As Morakinyo et al. (2017) [48] stated in their study, the use of dense canopy trees such as *Platanus orientalis* on streets with low shading effects has a positive effect on air temperatures during hot summer days and evenings. The results clearly show that the use of deciduous trees can provide significant temperature reductions, even in micro-scale areas, during hot and dry summers.

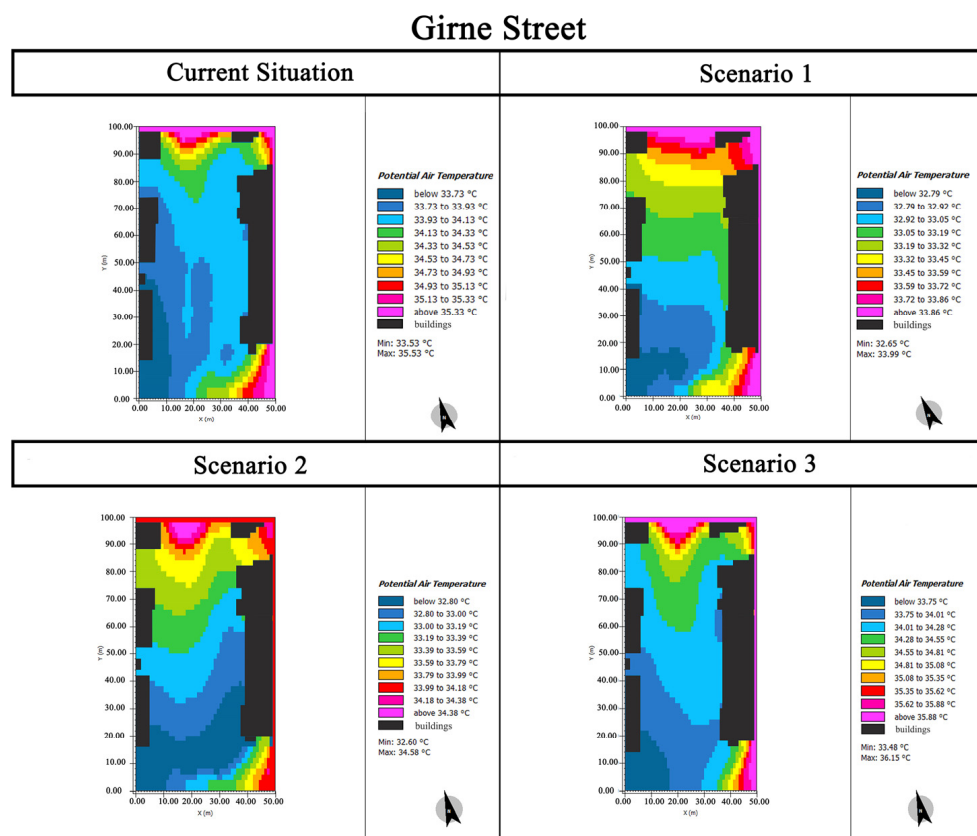


Figure 5. Girne Street air temperature ENVI-met analysis results.

In the Karsiyaka Provinces House, Scenario 1 was found to reduce the minimum temperature values by 0.08 °C and the maximum temperature values by 1.9 °C. Scenario 2 was found to decrease the minimum temperature values by 0.15 °C and the maximum temperature values by 0.35 °C. In this scenario, green shady structures were used to create the shade effect. However, the results show that green canopies are not as successful as broadleaf trees in improving the microclimate. As Hanafi et al. (2017) [49] and Kong et al. (2017) [50] concluded in their studies, deciduous trees with a high shade effect are very successful in reducing summer temperatures in hot and arid climates. Finally, Scenario 3 was found to reduce the minimum temperature values by 0.11 °C and the maximum temperature values by 0.33 °C (Figure 6).

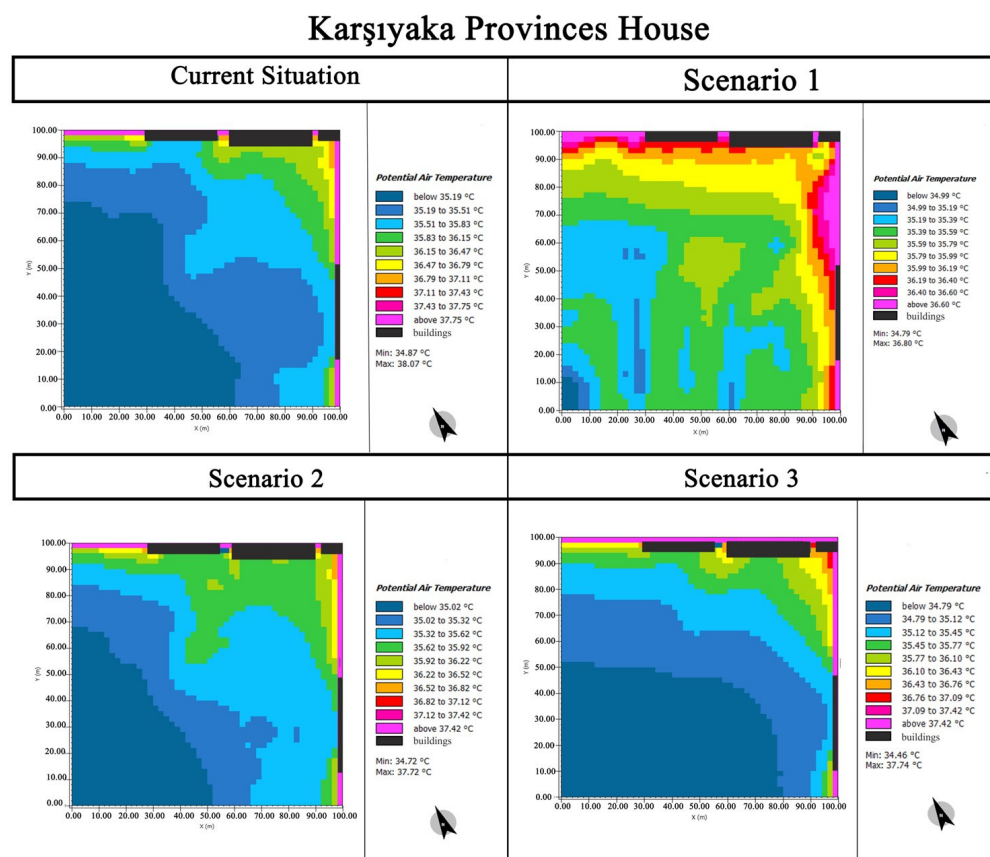


Figure 6. Karsiyaka Provinces House air temperature ENVI-met analysis results.

In Sasalı Wildlife Park Parking Lot, Scenario 1 was found to reduce the minimum temperature values by 2.68 °C and the maximum temperature values by 2.6 °C. Scenario 2 was found to decrease the minimum temperature values by 2.42 °C and the maximum temperature values by 2 °C. Finally, Scenario 3 was found to decrease the minimum temperature values by 1.76 °C and the maximum temperature values by 0.69 °C (Figure 7).

Among all the areas subject to the research, the largest differences between the scenarios and the current situation were calculated in Sasalı Wildlife Park Parking Lot. The reason for this is attributed to the fact that the whole area currently consists of impermeable surfaces that are directly exposed to sunlight. Therefore, each green surface added through the scenarios created positive climatic results in the area. Huang et al. (2016) [51], in their study of air temperature changes using surface characteristics in northwest China, also emphasized that increased green surfaces significantly reduced air temperature and average radiant temperature. The largest temperature decrease among the scenarios was calculated in Scenario 1, where 40 deciduous trees were added.

The analyses showed that the temperatures in Scenarios 1 and 2 were close to each other across the areas. The highest temperatures were generally calculated for Scenario 3.

Although the minimum air temperature values for the research areas were close to each other, temperature differences were observed more clearly at maximum values (Figure 8).

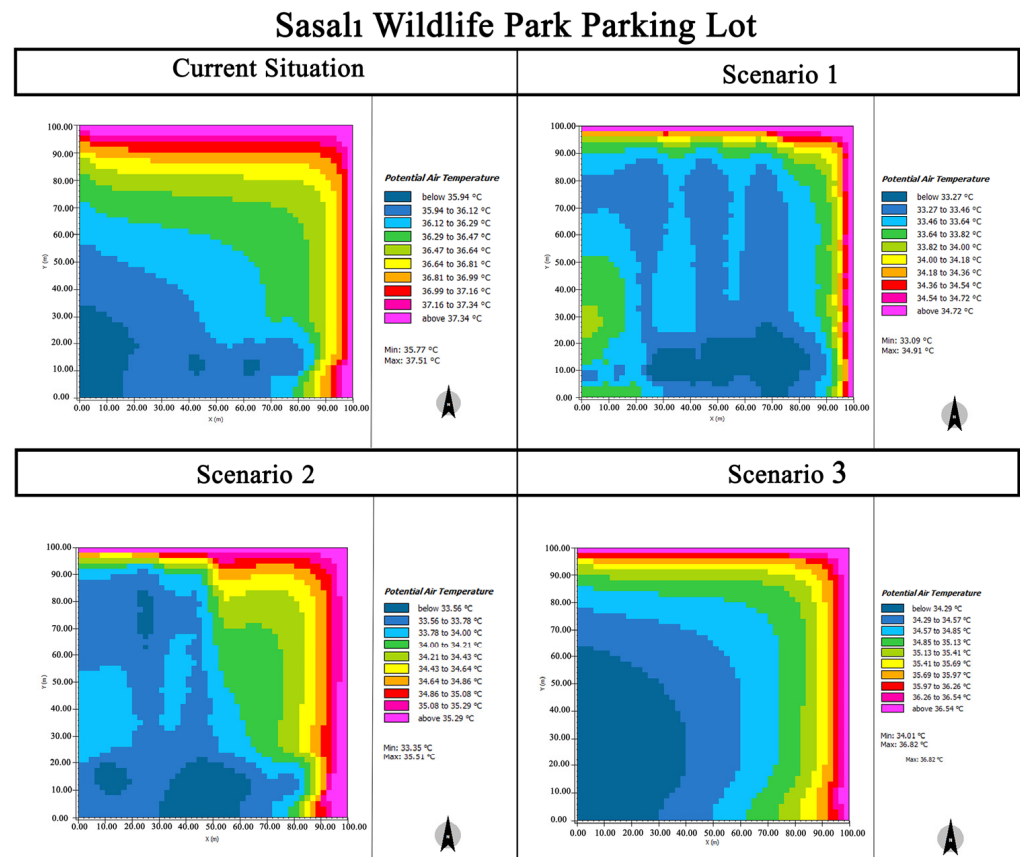


Figure 7. Sasalı Wildlife Park Parking Lot air temperature ENVI-met analysis results.

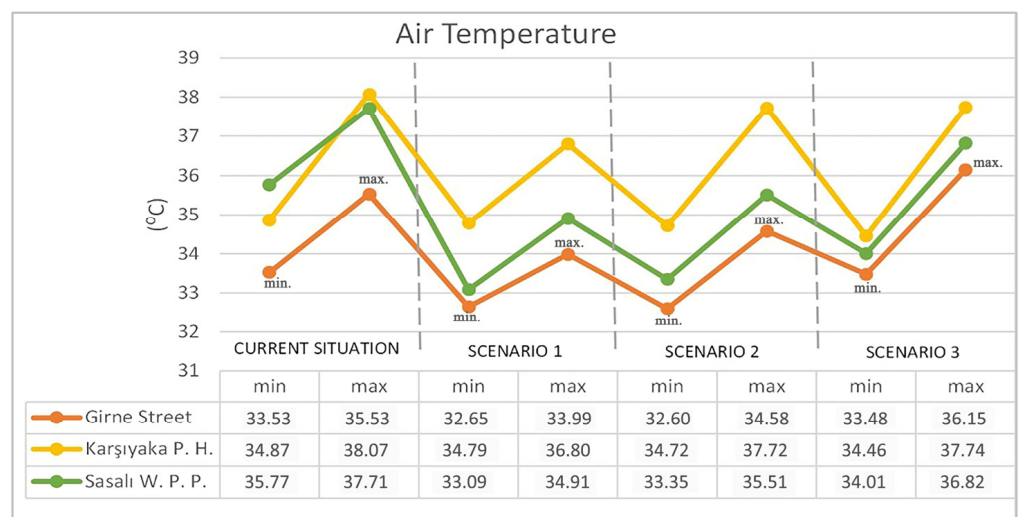


Figure 8. Comparison of minimum and maximum air temperature values of each scenario based on 13.00 data.

In particular, Scenario 1 was calculated to provide temperature reductions of up to 2.5 °C in the study areas. Among the study areas, the change in Sasalı Wildlife Park Parking Lot stands out the most. In this area, Scenarios 1 and 2 were found to have similar effects in reducing the temperature values. Scenario 2, which involved the installation of a very large green canopy, is thought to cause a significant decrease in surface temperatures by reducing

solar radiation, as mentioned by Mohajerani et al. (2017) [52] in their study. In this context, parklets developed and implemented within the scope of the Urban GreenUP Project may also be a solution [29]. Although the most significant differences in all areas mentioned above were generally calculated in Scenario 1 with 40 deciduous trees, it is possible to say that even the smallest increase in green space has positive effects on air temperatures. Similarly, many researchers such as Makhelouf (2008) [53], Ambrosini et al. (2014) [23], and Vartholomaios (2017) [54] have argued that green spaces in cities have positive effects on urban climate at both macro and micro scales.

3.2. Predicted Mean Vote (PMV)

According to the simulation results of the PMV values for the current situation throughout the area, the PMV value in Girne Street varies between 3.03 °C and 4.93 °C. In parallel with the air temperature values, Girne Street has lower temperature stress in terms of PMV values than the other research areas. In Karsiyaka Provinces House, the PMV value varies between 4.02 °C and 6.23 °C and the area is under extreme heat stress. In Sasalı Wildlife Park Parking Lot, the PMV value varies between 4.10 and 8.82 °C and the area is under extreme heat stress. This is thought to be due to the high amount of impervious surface, as stated by Girgis et al. (2016) [55] and Taleghani et al. (2015) [56].

When each research area was evaluated individually through the scenarios created, the PMV values of Girne Street decreased by 0.5 °C at minimum values and 0.75 °C at maximum values in Scenario 1. Although there was a change of approximately 1.5 °C between the scenarios, the thermal comfort level in the area did not change (Figure 9).

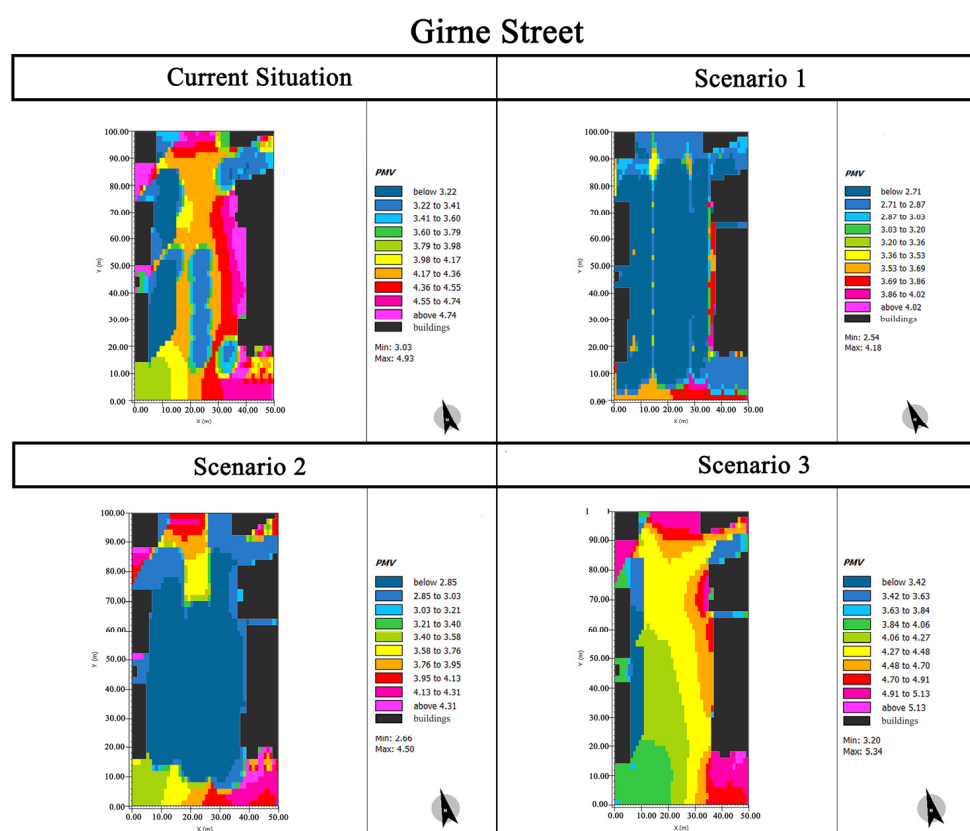


Figure 9. Girne Street PMV value ENVI-met analysis results.

In Scenario 2, the PMV values decreased by 0.37 °C at minimum values and 0.43 °C at maximum values. In Scenario 3, the worst values in terms of thermal comfort were calculated. In this area, PMV values increased by 0.20 °C at minimum values and 0.41 °C at maximum values. Based on these results, it is clear from the simulations that replacing green spaces with built surfaces leads to poor thermal conditions [57].

In Sasalı Wildlife Park Parking Lot, while the PMV value was between 4.10 and 5.82 °C at baseline, it decreased to 3.12–4.66 °C in Scenario 1 with the cooling effect of deciduous trees, similar to the study results of Karimi et al. (2020) [58]. While Sasalı Wildlife Park Parking Lot had extreme heat stress at baseline, in Scenario 1, the research area decreased to a strong heat stress thermal level. Nasibeh (2016) [59] similarly found an average reduction of 7.3 °C in road surface temperatures under tree shade.

In Scenario 2, the PMV value decreased by 0.82 °C at minimum values and 0.85 °C at maximum values. In Scenario 3, with grass and impervious surfaces, the PMV values increased by 0.06 °C at minimum values and decreased by 0.75 °C at maximum values (Figure 10). When all the scenarios are analyzed, it can clearly be seen that Scenario 1, which contains the most deciduous trees, has the best values in terms of thermal comfort.

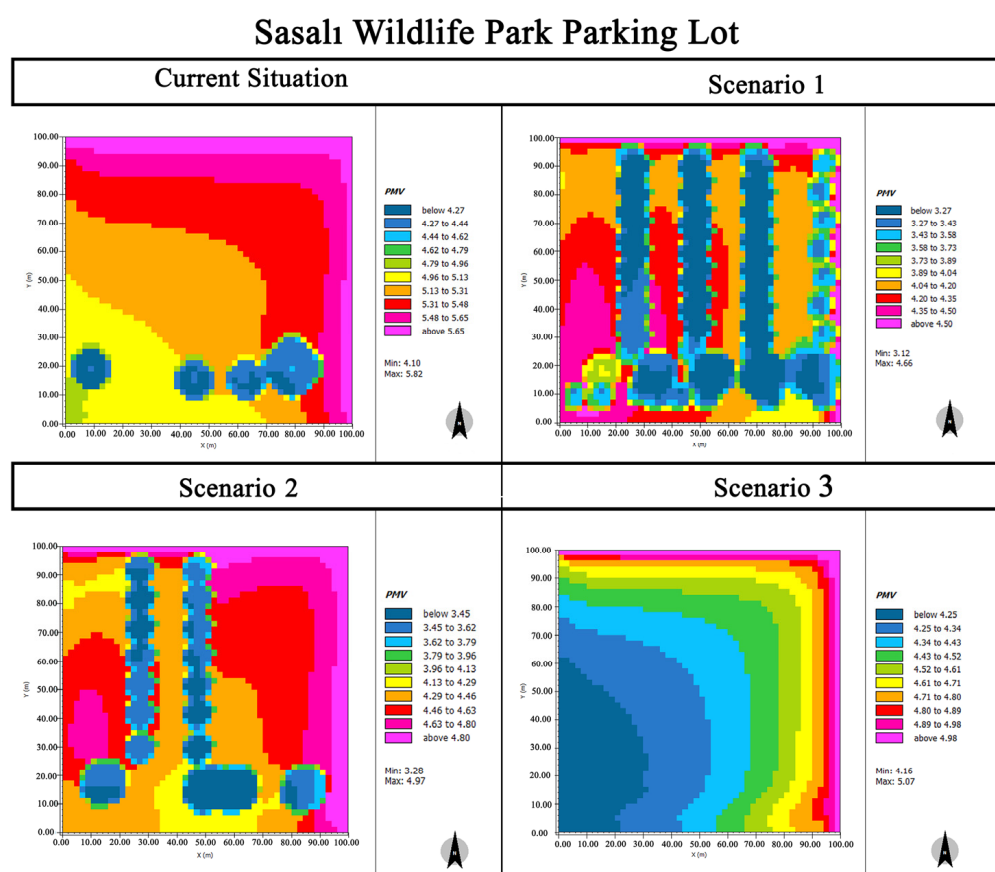


Figure 10. Sasalı Wildlife Park Parking Lot PMV value ENVI-met analysis results.

As mentioned by Narita et al. (2008) [60], Shahidan et al. (2012) [61], and Faghih Mirzaei et al. (2015) [9], dense tree canopies positively affect thermal comfort conditions as they effectively reduce solar radiation to the surface by providing high-quality shade during daytime hours (Figure 9).

In Karsiyaka Provinces House, the PMV change between the baseline and Scenario 1 showed a decrease of 0.38 °C in the minimum value and 1 °C in the maximum value. In Scenario 2, a decrease of 0.16 °C in the PMV minimum value and 0.34 °C in the maximum value was calculated. In Scenario 3, the PMV values decreased by 0.66 °C at the minimum value and increased by 0.2 °C at the maximum value (Figure 11).

In all the study zones, there were changes in the PMV values according to the density of the plant mass. In the analyses, it was determined that the use of dense trees has a greater effect on improving the PMV value and is directly beneficial in improving thermal comfort compared to the use of sparse trees, as stated by Altunkasa (2013) in his study at Cukurova University [62] (Figure 12).

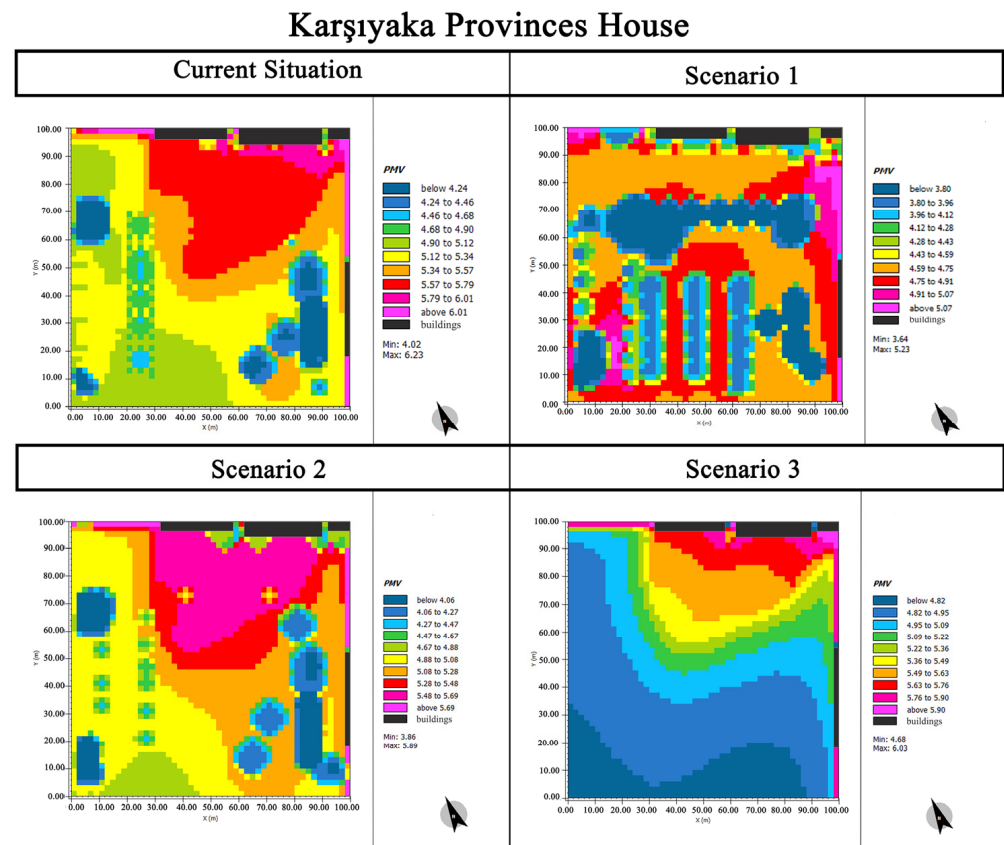


Figure 11. Karsiyaka Provinces House PMV value ENVI-met analysis results.

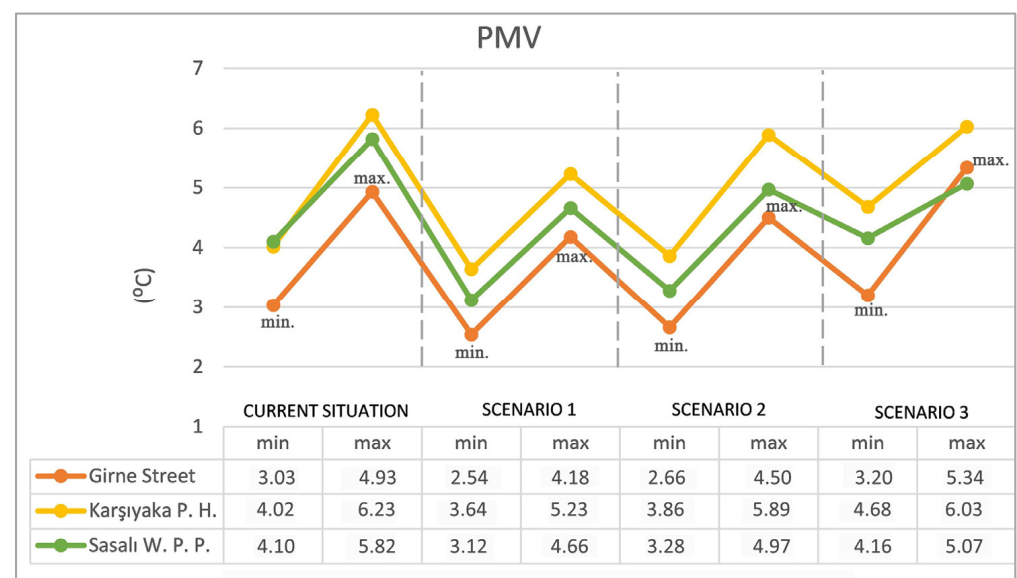


Figure 12. Comparison of minimum and maximum PMV values of each scenario based on 13.00 data.

The results of the four different analyses conducted in three different areas clearly show that different surface cover and vegetation types significantly affect both air temperatures and ambient thermal comfort (Table 8). In these analyses on micro-scale study areas, it can clearly be seen that the type and density of vegetation in the environment are the main determinants of temperature and thermal comfort. Although many studies suggest that the nearby urban morphology and prevailing wind direction also have an impact on thermal comfort, this effect was not clearly observed in our study areas.

Table 8. Changes in minimum and maximum temperature and PMV value across the areas.

	Current Situation		Scenario 1		Scenario 2		Scenario 3	
	Min	Max	Min	Max	Min	Max	Min	Max
Girne Street								
Temperature (°C)	33.53	35.53	32.65	33.99	32.60	34.58	33.48	36.15
PMV (°C)	3.03	4.93	2.54	4.18	2.66	4.50	3.20	5.34
Karsiyaka Provinces House								
Temperature (°C)	34.87	38.07	34.79	36.80	34.72	37.72	34.46	37.74
PMV (°C)	4.02	6.23	3.64	5.23	3.86	5.89	4.68	6.03
Sasalı Wildlife Park Parking								
Temperature (°C)	35.77	37.71	33.09	34.91	33.35	35.51	34.01	36.82
PMV (°C)	4.10	5.82	3.12	4.66	3.28	4.97	4.16	5.07

Chen et al. (2008) [63] argued that the effect of urban trees on outdoor thermal comfort and daytime microclimate (e.g., air temperature, surface temperature, and mean radiation temperature) is the combined result of two opposing mechanisms. These are (i) a reduction in surface temperatures due to tree shade and (ii) a reduction in wind speed due to tree cover (resulting in less ventilation and an increase in air temperatures). This study showed that the first effect is dominant, as the temperatures were significantly lower in all the study zones due to the shade effect of trees. Similarly, Cohen et al. (2012) [64] argued that the thermal benefits of trees, such as reductions in surface temperatures and solar radiation, are more effective than other parameters when wind speed is low. As a result of random urbanization, impervious surfaces in cities currently occupy a significant area. One of the most important consequences of this situation is undoubtedly the occurrence of urban floods due to the high amount of water flowing as surface runoff in cities. Using permeable paving materials in areas such as roads, sidewalks and parking lots would make a significant contribution to the urban climate by storing more energy and preventing heat island formation. The widespread use of permeable concrete and asphalt today greatly expands the scope of action on this issue. For instance, permeable concrete was applied in a pilot scheme around Peynircioglu Creek in the Mavisehir neighborhood of Karsiyaka (Izmir) district [29]. Although this application is important, the main goal should be to make such applications widespread throughout cities.

According to the findings of the research, although the positive effects of increasing green space and permeable surfaces were noted, it should not be forgotten that there are many more factors affecting the urban climate, such as albedo and sky view factor [2,5,10]. Conducting further studies with more variations and in different seasons and places will provide much more precise data and bases from which to produce projects that can be widespread throughout the city. Additionally, the contribution of NBSs should be emphasized. These areas, which are an integral part of urban landscapes and an important indicator of the quality of urban life, are vital for creating resilient urban spaces today and in the future, when global climate change will be more severe.

4. Conclusions

In this study, the effects of different NBS combinations on the urban microclimate and people's bioclimatic comfort were examined in three different research zones in Izmir (Turkey) in Mediterranean climate conditions. Using Envi-Met 5.1 software, three different scenarios with different NBS combinations were developed in addition to the current situation analysis of the research sites.

In light of the findings from this research, the following conclusions can be drawn:

- At the urban micro scale, NBSs resulted in temperature changes of up to 2.5 °C in the research areas. Also, in terms of thermal comfort, the most significant differences

were found between the minimum PMV values, close to 1 °C. In particular, the implementations of the nature-based solutions “URBAN GreenUP Project” (Scenario 2) were tested and proven to have a microclimate-improving effect. As suggested by this study and others, it is important to develop climate-sensitive policies and projects for cities, from physical planning to design. Taking into consideration climate-sensitive criteria in designs at all scales is crucial for creating more livable cities in terms of thermal comfort.

- The presence of green spaces alone is not sufficient to improve the microclimate; the size of green spaces is also very important. As observed in Scenario 1, the size of green areas greatly affects the quality and quantity of their contribution to climate. According to the analysis results, a temperature difference of 2.8 °C in the maximum temperature values in Sasalı Wildlife Park parking lot was calculated (Scenario 1), which included the largest green area. Green areas should be designed with the largest possible size, contain large permeable surfaces, and be composed of deciduous trees with large crowns. The existence of an urban green infrastructure system is necessary for the realization of all these factors.
- Deciduous trees were found to be more effective than palm trees in improving the urban climate (Scenario 1). In terms of other ecosystem services, it would be better not to preferentially use palm trees, especially in areas where shade is needed, but to use deciduous and wide-crowned species instead.
- As seen in Scenario 1, trees used continuously along the road on streets with a canyon effect, such as Girne Street, have a positive effect on improving the urban climate. According to the analysis results, a difference of 1.54 °C in the maximum temperature values in this area was calculated. This should be taken into consideration in street landscape designs. However, first of all, it is necessary to create the conditions and areas suitable for plant growth in street and alley designs. In these conditions, plants and especially trees that will reach their ideal form will be able to show the maximum desired effect.
- As a result of random urbanization, impervious surfaces such as parking lots occupy a significant area in cities. If they are treeless, as in the current situation of the Sasalı Wildlife Park parking lot, they significantly increase the ambient temperatures. Although Sasalı Wildlife Park is located in an area more rural than other areas, according to the current situation measurement results, it is 2.24 °C warmer than Girne Street and 0.9 °C warmer than the Vilayetler Evi parking lot in terms of the minimum temperature values. In areas consisting of large impervious surfaces such as parking lots, as in Scenario 3, trees with wide crowns should be preferred as permeable surfaces and shading elements to reduce heat stress. In addition, a design approach that combines appropriate sustainable rainwater facilities will provide an advantage in the fight against the heat island.
- According to the results of the research, it is clearly understood that, in this study conducted in Mediterranean climate conditions, especially in NBS scenarios, deciduous trees with large crowns have the most positive effect on reducing urban temperatures and improving thermal comfort conditions in all research zones. In Turkey, with different climate types, future studies should be conducted in different climatic conditions. Recommendations should be developed while taking into consideration the requirements of each specific climate type.

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