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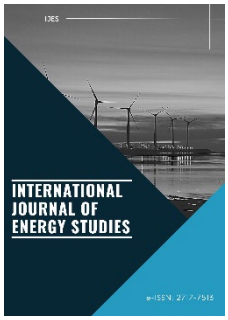



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# Investigation of the effects of different design scenarios of Hasan Pasha Han courtyard on the microclimate using ENVI-met analysis


**Medine ÇELİK [a*], Hasan YILMAZ [b]**

[a]*Atatürk University, Graduate School of Natural and Applied Sciences, Department of Landscape Architecture, Erzurum, Türkiye, ORCID : 0000-0002-3734-0979*

[b]*Atatürk University, Architecture and Design Faculty, Department of Landscape Architecture, Erzurum, Türkiye, ORCID : 0000-0003-3768-4760*

*(*Corresponding Author: clkmedine21@gmail.com )*


**Highlights**

- Courtyard temperature reduced by up to 9 °C using different plant design scenarios.
- Scenario 1 and 2 (with 25% and 40% green coverage) provided highest microclimate improvement.
- Dense overhead tree cover reduced wind circulation, limiting cooling efficiency.


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## ABSTRACT

The aim of the research is to determine the relationship between different planting design applications and microclimate values in the example of a traditional Turkish courtyard garden in the city of Diyarbakır, where the temperature values are very high in summer. As a result of the Envi-Met analysis, different temperature values were determined as a result of the current situation of the courtyard and the Envi-Met analysis of 4 different plant design scenarios for the courtyard. The current temperature of the courtyard (39,40 °C) was reduced by various plant design scenarios, which contributed to the microclimate of the courtyard. Better results were obtained from 4 different scenarios used than the planting design S1 and 2. It was determined that the courtyard temperature decreased to 30,40 °C (24%) with an average decrease of 9 °C in S1 (25% covered with plants) where only grass surface was used and S2 (40% covered with plants) where grass surface and trees were used. In S3 (50% covered with plants) and S4 (60% covered with plants), where more top-branching trees were used, there was no significant decrease in temperature values. However, it was determined that there was a temperature drop of 10% in S3 and 11% in S4 compared to the current situation. It is thought that this may be due to the cooling effect of the wind is reduced by blocking the wind movements inside the courtyard of trees that branch heavily from the top. In the study, it was concluded that planting designs to be made in courtyard gardens have a positive effect on the microclimate of the area, but planting designs that prevent wind movements particularly should be avoided.



**Keywords:** Courtyard gardens, Microclimate, Envi-Met, Planting designs scenarios, Diyarbakır.

## 1. INTRODUCTION

Thermal comfort has been correlated with the factors of change in the residences of rural areas and with the relationship between mass space [1]. Thermal comfort is a design criterion that ensures that the thermal comfort of humans and animals is at a normal level. Thermal comfort is not only heat data, but also includes various atmospheric factors such as relative humidity, wind speed, radiant heat, wind speed, metabolic temperature, and heat emitted by humans or machines [2]. It has been observed that there is a bond that can hardly be broken between bioclimatic parameters and that it causes observable shifts as a solution to climate change [3]. In neighborhoods where sensible heat flux is high and latent heat flux is low, reducing three-dimensional surface distortion and increasing vegetative greening can help create a more thermally comfortable environment [4]. Thermal comfort significantly contributes to the development of sustainable living spaces. By incorporating meteorological data analysis into the landscape design process and assessing different Envi-Met simulation scenarios suitable for spatial use, it is possible to design more livable and comfortable outdoor environments [5]. Increasing thermal comfort in summer and winter is one of the important guiding criteria for planning decisions to be taken in envi- met scenarios to ensure thermal balance [6].

In order to prevent heat stress in people's living spaces and to create comfortable spaces, scenarios are analyzed with the Envi-Met model and the application of the most appropriate scenario to the living space should become the most important step of the design stage criteria [7]. The fact that the plants used in the designs reduce the effect of the sun's rays, allows you to cool down and increase the comfort of the environment in which they are used by evaporation [8], [9]. It is also observed in studies conducted that plants used in cities balance thermal comfort both in summer and in winter [10].

In the analysis carried out using the Envi-Met model, the levels of thermal comfort ratios in summer and winter can be determined. It has been found that the thermal comfort rate increases in scenarios where green areas show density [11]. In a study conducted in Seoul, Korea, the microclimate and thermal comfort of various plant designs on a hot summer day were analyzed with ENVI-met. It was concluded that densely wooded areas can reduce the cooling effect [4].

When the Envi-Met program analysis was performed to determine the thermal comfort in cities, it was found that the regular structures were cooler in summer and the courtyard-type structures were

warmer in winter [12]. The courtyard is known for its characteristic of a place defined by climatic conditions. It is an introverted system that is less affected by climatic factors without a top cover, which is a different design principle from the usual spaces, provides privacy, prevents noise and creates comfort with the microclimate feature in the living areas formed around it. With the conscious realization of these factors of courtyard gardens, their use in residential buildings has become widespread in many regions [13]. Thermal comfort values determine better utilization of outdoor spaces. In order to make better use of the outdoors, the climatic data of these areas should be analyzed well. ENVI-met technology, which is a climate model for the climate improvement of outdoor vegetation, has been increasingly used [14], [4], [15], [16], [17], [18].

Purpose of the study; The purpose of this research is to examine the microclimate conditions of courtyard gardens, which hold an important place in traditional Turkish landscape architecture, through the case of Diyarbakır. The Hasan Pasha Khan courtyard garden was selected as a representative example of these courtyards within the city. The study focuses on enhancing summer microclimate in this space through various planting design strategies. To achieve this, four alternative landscape design scenarios were developed based on the site's existing climatic data. By applying the Envi-Met model to each scenario, the study aims to determine how the proposed planting designs influence the courtyard's current thermal conditions.

The hypothesis of this study;
H1- Can thermal comfort be contributed by reducing the microclimate values of the courtyard during the summer months with different plant design scenarios?
H2- Do microclimate values vary depending on plant type?

## 2. MATERIAL AND METOD

### 2.1. Material

The primary focus of this study is the Hasan Pasha Khan courtyard garden, situated in the city center of Diyarbakır. In its current state, the courtyard lacks any plantings, and both the open space and the building structure are paved with basalt stone. A shadirvan is located at the center of the courtyard. Among the evaluated courtyard samples, this courtyard exhibits the highest shading, with a shadow ratio of 100%, achieved by installing a top cover (membrane). The area of the courtyard is also notably larger, covering approximately 75–100% more than the other courtyard examples considered. Due to its use for commercial purposes, the courtyard is frequently crowded.

The absence of vegetation combined with the relatively large size makes this site suitable for testing various landscape planting design scenarios. The location of Hasan Pasha Khan is illustrated in Figure 1.

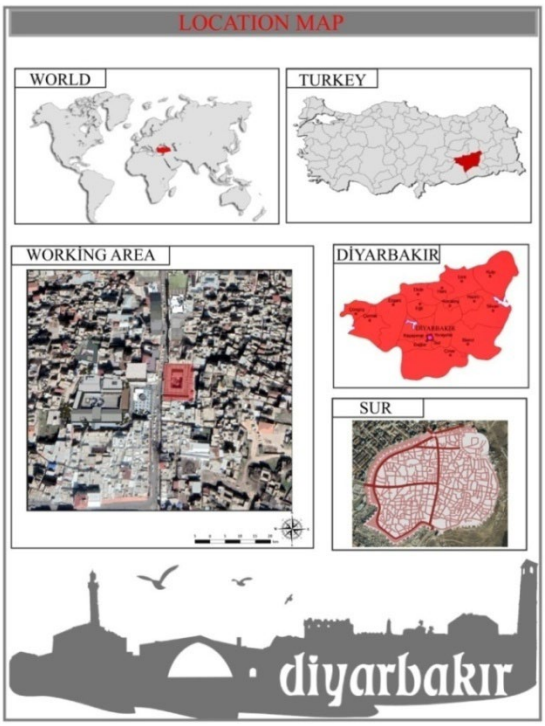


**Figure 1.** Hasan Pasha Khan location map

### 2.2. Methodology

Envi-Met model is a microclimate software that helps calculate climate values in cities and obtain more comfortable values through different simulations. It analyzes data by targeting radiation currents. It analyzes the meteorological situation of the area by taking the total of the soil structure, flooring and building materials, plant type, plant density, transition points and the effects of climatic conditions of the area where the model design is made [19].

The Envi-Met model has been applied to various plant landscape design scenarios. Meteorological data were obtained using the Envi-Met model for each scenario. Envi-Met the data used in the model are given in Table 1. The designs made were digitized with the Envi-Met program and the effects of the proposed landscape designs on the climate and comfort characteristics were determined according to the available meteorological data. In the study, Envi-Met analysis was performed in scenarios where the current situation and plant materials were used.

**Table 1.** Data used in the Envi-Met program for the study area

| | |
|---|---|
| Location | Hasan Pasha Khan of Diyarbakir |
| Total Simulation Time | 24 Hours for each project |
| Working Resolution | 1m×1m×1m |
| Model Rotation | 0° |
| Sky Condition | Open |
| Wind Speed (m/s) | 0,4 |
| Wind Direction (o) | South west |
| 24-Hour Air Temperature | + (Simple Coercion) |
| 24-Hour Relative Humidity | + (Simple Coercion) |
| Scenario 1 | 25% plant |
| Scenario 2 | 40% plant |
| Scenario 3 | 50% plant |
| Scenario 4 | 60% plant |
| Measure of area | 40×50 |
| The height of the khan | 8m |

## 3. RESULTS AND DISCUSSION

### 3.1. Meteorological Data Obtained in the Courtyard of Hasan Pasha Khan

In July, 24-hour measurements were conducted on three different days, and in August, 24-hour daily measurements were carried out under the current conditions of Hasan Pasha Khan courtyard. The analysis of the temperature measurements for the current state is presented in Table 2.

**Table 2.** Hasan Pasha Khan temperature measurement results

| | **11 July** | **20 July** | **29 July** | **17 August** | **Average of 4 days** |
|---|---|---|---|---|---|
| **The lowest °C** | 27,7 | 29,8 | 30,9 | 26,5 | 28,7 |
| **The highest °C** | 45,0 | 44,2 | 47,6 | 47,4 | 46,0 |
| **Average °C** | 32,6 | 35,8 | 35,6 | 32,5 | 34,1 |

was seen with 26,5 °C on August 17th in the current 24-hour temperature measurements.

### 3.2. Envi-Met Values of the Courtyard According to Current Meteorological Data

The temperature measurements taken in the courtyard of Hasan Pasha Khan were averaged, and the resulting 24-hour dataset was processed in the Envi-Met program for analysis. The analysis indicated that the current temperature ranged between 37.00°C and 39.40°C. The plan view and the Envi-Met analysis of the current conditions are shown in Figure 3.

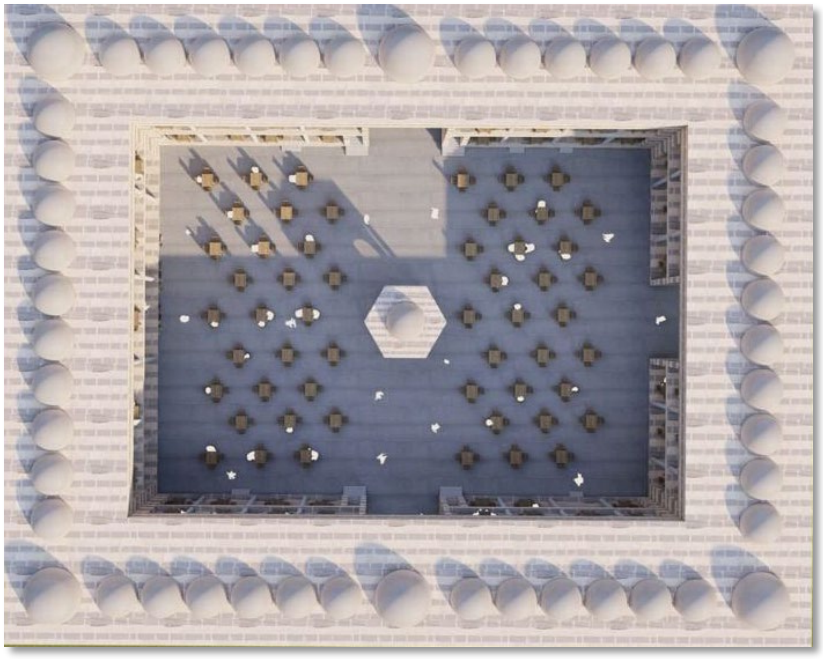

**Figure 2.** Current state

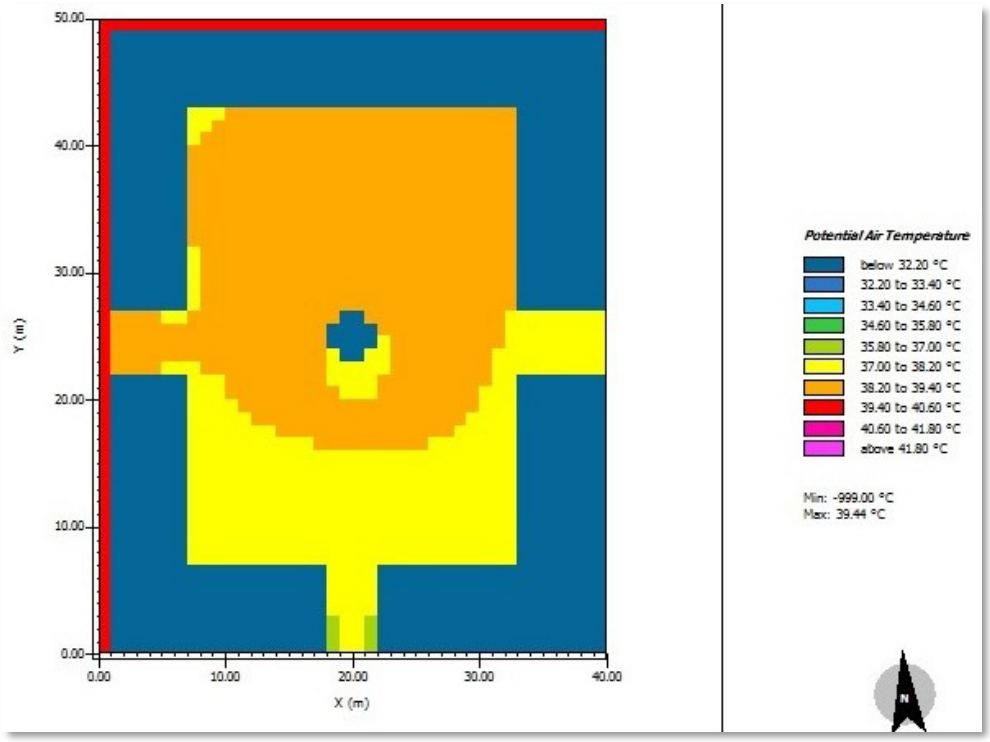


**Figure 3.** Results of the current state Envi-Met analysis

Figure 3 shows the results of the current state Envi-Met analysis. in the image, the blue color indicates the structure surrounding the area, and the temperature is 32,20 °C. The area where the shadirvan is in the center of the courtyard is also colored blue and the temperature is 32,20 °C.

The main entrance door opening to the courtyard from the three entrance doors of the courtyard is orange and the temperature is 38,20 °C -39,40 °C, and the temperature in the direction where the other two entrance doors are yellow is 37,00°C -38,20 °C. While the temperature of the yellow-colored area in the courtyard garden is 37,00 °C -38,20 °C, the temperature of the orange-colored area without the transition point is 38,20 °C -39,40 °C.

In the selection of plant species used in the proposed plant designs and in the plant designs;

- The plant species used are suitable for the local climate,
- They are coarse-textured, decorative plants that branch from the top and create shade,
- Both summer green and evergreen plant species can be used together.
- It was designed in pots so as not to disrupt the historical texture and not damage the existing structure.
- Plant designs are designed in a way that does not hinder the transportation and use of space within the area.

Distinctive features of the plants used in the design;

*Acer platanoides* 'Globosum'

- It is a spherical-shaped shrub that branches from the top and creates good shade.
- Its leaves are dark green and turn yellow in autumn.
- They are resistant to heat and drought.
- Resistant to air pollution

*Photiniaserratifolia*

- It is an evergreen tree that has a lot of shade and branches from the top.
- They are long-lasting and can be pruned easily.
- Its fruits ripen in autumn and are red in color.
- Leaf tips are red and the lower parts are shiny green.
- They grow healthily in places with plenty of sun.

*Parthenocissusquinquefolia*

- It is a climbing, creeping plant.
- It is a rapidly growing vine.
- Its leaves are green and turn red in the autumn before shedding leaves.
- Its fruits are bluish-blackish in color.
- Its fruits are poisonous to humans.
- It grows in sunny and semi-shaded places.

Grass surfaces; Grass surface was used as a ground cover in suitable places in the area, as a green texture that does not obstruct the passage and use of the area, does not hide the field of view, and gives depth and a green appearance to the area.

### 3.3. Envi-Met Values of Plant Design Scenarios

Scenario 1 (25% covered with plants/ grass surface only):

In S1, where grass surfaces are used as plant design, the temperature of the courtyard was determined to be between 30,40 °C and 32,00 °C. The plan view of S1 is given in Figure 4 and the Envi-Met analysis is given in Figure 5.

**Figure 4.**Scenario 1 (25% covered with plants /grass surface only

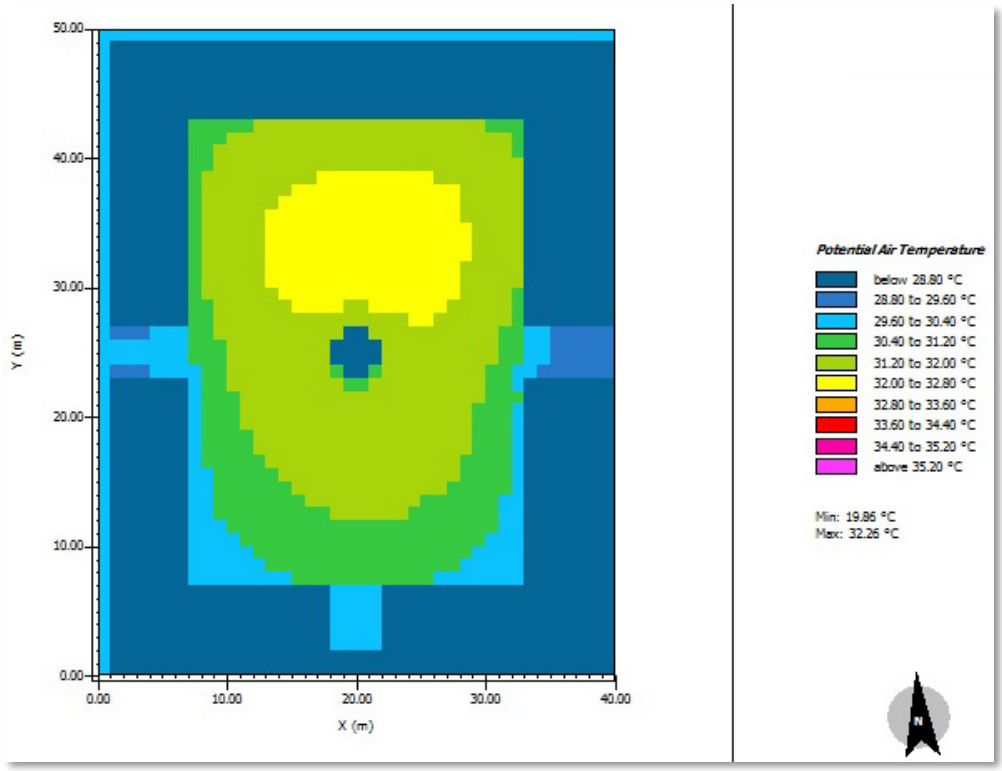


**Figure 5.** The results of Envi-Met analysis of Scenario 1 (grass surface by 25%)

Figure 5 presents the visual representation of S1 (with 25% grass coverage) along with the Envi-Met analysis results. The structure surrounding the blue-colored area shows temperatures ranging from 28.80°C to 29.60°C. The shadirvan located at the center of the courtyard is also depicted in blue, with the same temperature range of 28.80°C to 29.60°C. In the sections corresponding to the three entrance doors opening into the courtyard, temperatures are slightly higher, ranging from 29.60°C to 30.40°C. Within the courtyard garden, the light green and dark green areas exhibit temperatures between 30.40°C and 32.00°C, while the yellow areas, where temperature transition is less pronounced, reach up to 32.00°C.

Scenario 2 (40% covered with plants):

In S2, where12 *Photinia serratifolia*and 6 *Acer platanoides* 'Globosum' were used as plant design, the temperature was found to be between 30,40°C – 31,70°C. The plan view of S2 is given in Figure 6 and the Envi-Met analysis is given in Figure 7.

**Figure 6.** Scenario 2(40% covered with plants)

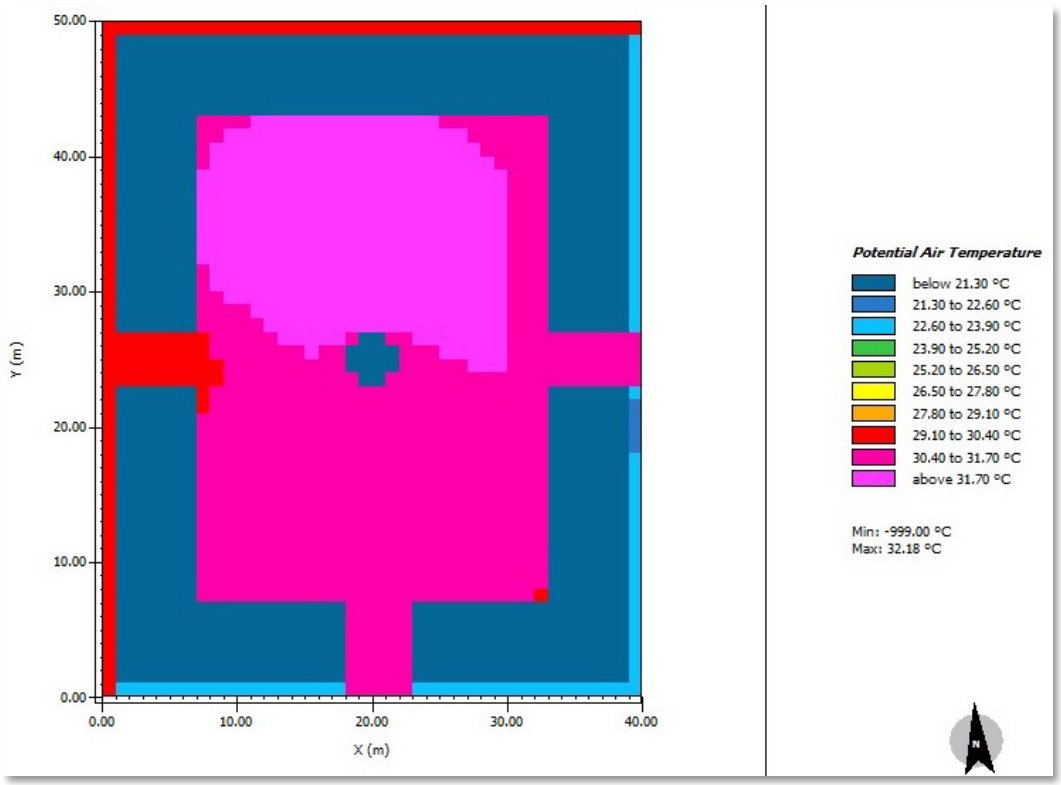


**Figure 7.** Envi-Met analysis of Scenario 2 (40% covered with plants)

The visual representation of S2 in Figure 7, which contains the Envi-Met analysis results, shows the structure surrounding the blue-colored area and the temperature is 21,30°C -22,60 °C. The area where the shadirvan is in the center of the courtyard is also colored blue and the temperature is 21,30 °C-22,60 °C. The main entrance door opening to the courtyard from the three entrance doors of the courtyard is red in color and the temperature is 29,10°C -30,40°C, and the temperature in the pink colored area in the direction of the other two entrance doors is 30,40°C -31,70°C. The temperature of the area with pink and light pink colors in the courtyard garden is 30,40 °C -31,70 °C.

Scenario 3 (50% covered with plants):

In S3 where 12 *Photinia serratifolia* and 18 *Acer platanoides* 'Globosum' were used as plant design, the temperature was found to be 31,00°C – 35,40°C. The plan image of S3 is given in Figure 8 and the Envi-Met analysis is given in Figure 9.

**Figure 8.** Scenario 3(50% covered with plants)

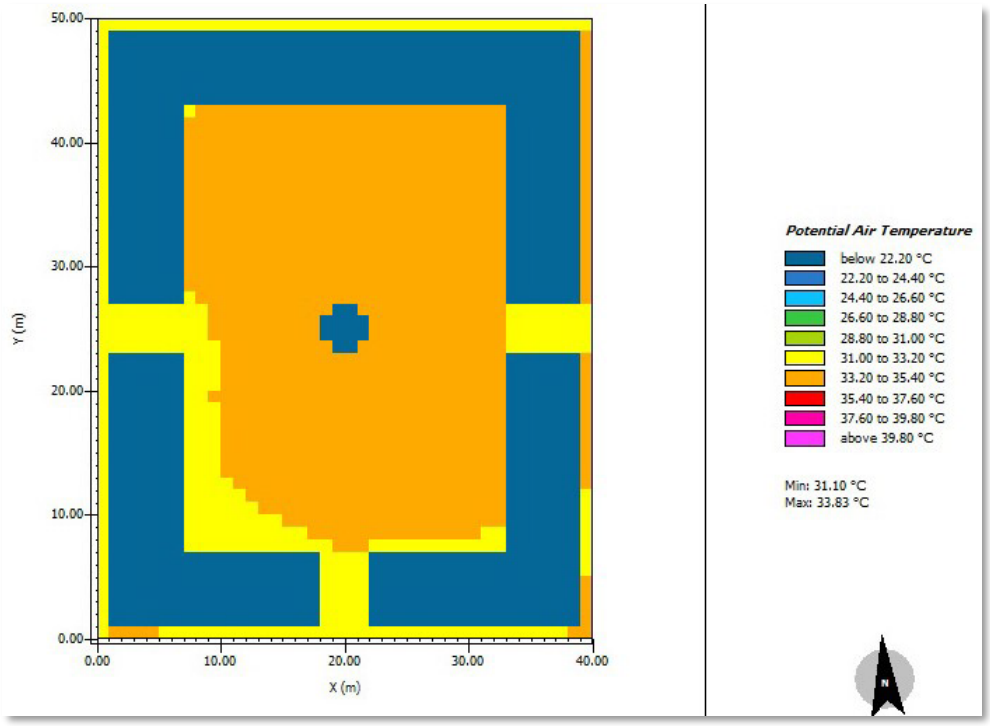


**Figure 9.** The results of Envi-Met analysis of Scenario 3 (50% covered with plants)

The visual representation of S3 (50% plant surface) in Figure 9, which contains the results of Envi-Met analysis, shows the structure surrounding the blue-colored area, and the temperature is 22,20°C-24,40 °C. The area where the shadirvan is in the center of the courtyard is also colored blue and the temperature is 22,20 °C -24,40 °C. The parts of the courtyard that open to the courtyard through the three entrance doors are colored yellow and the temperature is 31,00 °C - 33,20 °C. The temperature of the area with orange and yellow colors in the courtyard garden is 31,00°C – 35,40 °C.

Scenario 4 (60% covered with plants):

In S4, where 12 *Photinia serratifolia*, 6 *Acer platanoides* 'Globosum' and *Parthenocissus quinquefolia* were used as plant design, the temperature was found to be 34,56°C – 35,34°C. The plan view of S4 is given in Figure 10 and the Envi-Met analysis is given in Figure 11.

**Figure 10.** Scenario 4(%60 covered with plants)

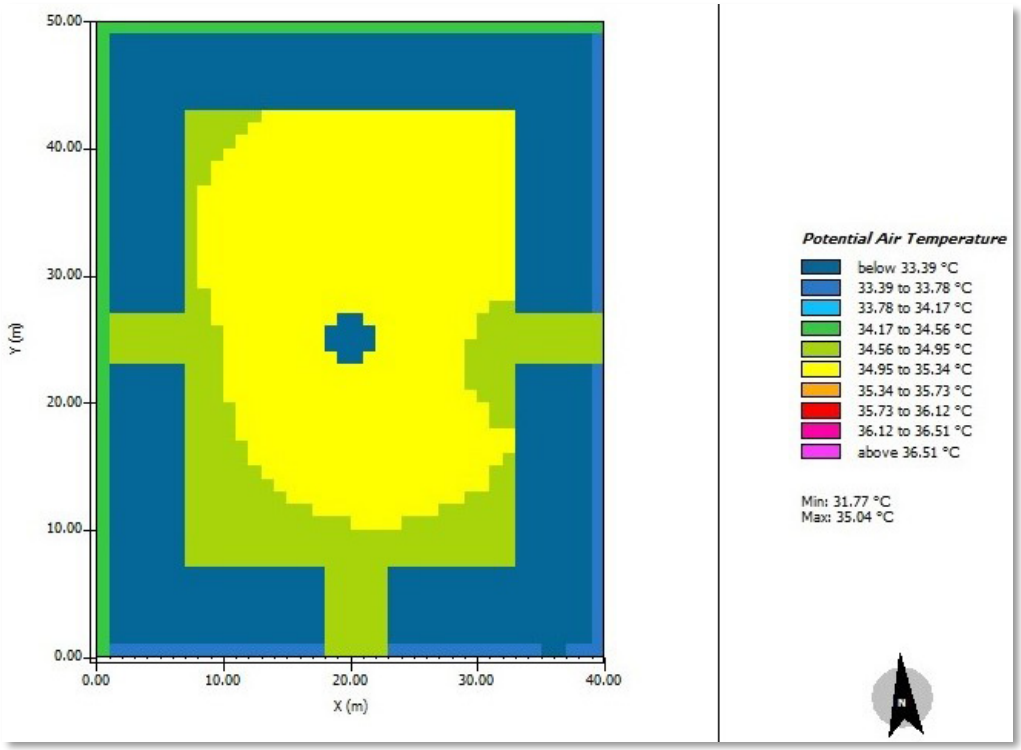


**Figure 11.** Envi-Met analysis of Scenario 4 (60% covered with plant)

The visual representation of S4 (60% covered with plants) in Figure 11, which contains the results of Envi-Met analysis, shows the structure surrounding the blue-colored area, and the temperature is 33,39°C-33,78 °C. The area where the sadirvan is in the center of the courtyard is also colored blue and the temperature is 33,39 °C-33,78 °C. The parts opening to the courtyard from the three entrance doors of the courtyard are green and the temperature is 34,56°C -34,95°C. The temperature of the area with yellow color in the courtyard garden is 34,95°C – 35,34 °C.

ENVI-met model reliability and validation of results;
Measurements were made in the current state of the Hasan Pasha Khan courtyard on 3 different 24-hour days in July and on one 24-hour day in August. Envi-met accuracy analysis was made by taking 24 hours from these days.

Seven statistical measures were used to calibrate the predicted (P) and observed (O) data of the 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) [20].

İn the study, the values measured with modeling results two different indicators were used to evaluate the calibration between. First the agreement index (d), which is an indicator, takes a value between 0-1 and how much does this value reach 1. The closer it is, the more accuracy is ensured. The other indicator RMSE is a data It is a measure that compares different prediction errors in a set and indicates accuracy. Smaller values indicate less error in the prediction [21].

Meanings of Abbreviations in the formula [20];
d: Index of agreement
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
Indices used in validating the simulation

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

Simulated and measured Current state for RMSE when the agreement index between air temperature is 0,97 in a 24-hour period the value was calculated as 1,109 ( Table 3)

**Table 3.** Current state evaluation of measured and simulated temperatures.

| Time | Observed air temperature (°C) | Simulated air temp. (°C) | Difference | Difference square | The root mean square error (RMSE) | Index of agreement (d) |
|---|---|---|---|---|---|---|
| 12:00 | 34,3 | 33,6 | -0,7 | 0,49 | | |
| 13:00 | 34,8 | 33,8 | -1 | 1 | | |
| 14:00 | 35,0 | 34,1 | -0,9 | 0,49 | | |
| 15:00 | 35,6 | 34,7 | -0,9 | 0,49 | | |
| 16:00 | 35,5 | 34,6 | -0,9 | 0,81 | | |
| 17:00 | 35,1 | 34,1 | -1 | 1 | | |
| 18:00 | 34,2 | 33,4 | -0,8 | 0,64 | | |
| 19:00 | 33,8 | 32,9 | -0,9 | 0,81 | | |
| 20:00 | 32,8 | 31,9 | -0,9 | 0,81 | | |
| 21:00 | 31,9 | 30,4 | -1,5 | 2,25 | | |
| 22:00 | 31,2 | 30,5 | -0,7 | 0,49 | | |
| 23:00 | 30,8 | 29,2 | -1,6 | 2,56 | 1,109 | 0,97 |
| 00:00 | 30,3 | 29,2 | -1,1 | 1,21 | | |
| 01:00 | 29,6 | 28.1 | -1,5 | 2,25 | | |
| 02:00 | 28,9 | 27,0 | -1,9 | 3,61 | | |
| 03:00 | 28,7 | 27,5 | -1,2 | 1,44 | | |
| 04:00 | 28,0 | 27,3 | -0,7 | 0,49 | | |
| 05:00 | 27,7 | 27,0 | -0,7 | 0,49 | | |
| 06:00 | 28,1 | 27,9 | -0,2 | 0,4 | | |
| 07:00 | 29,2 | 28,8 | -0,4 | 0,16 | | |
| 08:00 | 32,3 | 31,6 | -0,7 | 0,49 | | |
| 09:00 | 45,0 | 43,0 | -2 | 4 | | |
| 10:00 | 35,5 | 34,7 | -0,8 | 0,64 | | |
| 11:00 | 34,9 | 33,4 | -1,5 | 2,25 | | |

The verification result of the measurements made in Hasan Pasha Khan was tested. It showed that the result could be calculated with a deviation of 0,97.

In addition to controlling climatic factors and bringing the courtyard gardens to a more comfortable state, the socio-cultural structure and the need for privacy are also an effective factor in the emergence of courtyard gardens. Hasan Pasha Khan courtyard is at the forefront of being one of the most sought-after historical sites of the city of Diyarbakır. In this study, which analyzed the design scenarios of the comfortable, convenient and visually aesthetically historical structure of the inn that is under the influence of Diyarbakır climatic factors, factors such as wind effect, insolation time, shadow effect, vegetative state, and the influence of materials used in the structure were analyzed.

When the current climate data obtained were averaged and transferred to the Envi-Met program, it was determined that the highest current state temperature was 39,40 °C. It has been determined that the temperature is high in the direction where the main entrance to the courtyard is due to the fact that the main entrance door of the courtyard receives sunlight directly in the early hours of the morning, and the temperature is low in the direction of the other two entrances. In addition, the temperature values also turned out to be high (32,00 °C -35,34 °C) because the central area where there is shadirvan was exposed to more sun. Since the two stories high side walls block the light, the wall edges are cooler (29,10°C -34,56°C) on all four sides.

Considering the current situation and 4 different scenarios in which Envi-Met analysis was performed, different temperature values were determined with plant designs and the results are summarized below.

The current situation of the courtyard is 39,40 °C, with the vegetative designs of the courtyard, providing a reduction of 9°C (24%) in S1 (25% covered with plants /only grass surface) and S2(40% covered with plants) temperature to 30,40 °C. decreased (Table 4). In S3 (50% covered with plants) and S4 (60% covered with plants), it was determined that the top-branching crown plants, which are used extensively, are not very effective in reducing the temperature by preventing or reducing the wind circulation. However, it was concluded that S3 helped reduce the temperature by 10% and S4 by 11% compared to the current situation (Table 4). In the current situation, it has been determined that the courtyard is under the influence of strong heat, and when the temperature values decrease, the courtyard is under the influence of medium temperature and provides a comfortable environment. It is thought that there is no linear relationship between overuse of plants and temperature drop in the area, and this situation prevents the wind movements of the plants branching from the top, causing the temperature to stay in the area. Indeed, studies show

[22] it has been found that the intensive use of trees reduces the speed of the wind and destroys its refreshing effect. Similarly to, it was concluded that shrubs do not have a positive effect on microclimate. The effect of the plant species to be used in the plant designs to be made on microclimate should be analyzed well [23].

**Table 4.** Envi-Met analysis of the current situation and 4 different vegetative design scenarios climate data

| Climate data | Current situation | Scenarios | | | |
|---|---|---|---|---|---|
| | | **Scenario 1** (25%covered with plants) | **Scenario2** (40%covered with plants) | **Scenario 3** (50%covered with plants) | **Scenario 4** (60%covered with plants |
| **Lowest**°C | 37,00 | 30,40 | 30,40 | 31,00 | 34,56 |
| **Highest** °C | 39,40 | 32,00 | 31,70 | 35,40 | 35,34 |
| **Average** °C | 38,2 | 31,2 | 31,05 | 33,2 | 34,9 |
| **Reduction rates%** | %100 | %24 | %24 | %10 | %11 |

There are many studies that green spaces contribute to microclimate [24], [25], [22], [11], [26], [27], [28] are available and similar results have been obtained in this study.

This study only includes the results of microclimate values according to the meteorological data of Hasan Pasha Khan courtyard, which is the most intensively used area in Diyarbakir city. Although the microclimate values of other courtyard gardens located in the city are close to each other, they may differ. It is believed that comfort values obtained with green material can give similar results in other courtyards. However, microclimate ranges may also vary depending on many parameters such as the direction of each courtyard, wall height, insolation and lighting factors, space usage, size, location of the area against the wind direction. In terms of microclimate, there is a direct relationship between the building floor ratio and the vegetation surface [29].

In this study, it has been observed that various herbal designs within the scope of the courtyard reduce the temperature to a certain extent in summer and make a significant contribution to the microclimate of the space users. However, different plant species and different planting courtyard gardens design to increase the value of further research for different applications of thermal comfort by use of the most appropriate plant species and densities can be demonstrated. Urban green and blue infrastructure has been given importance in improving urban heat island and microclimate [30].

Factors such as the amount of urban green space, size, vegetation type are directly effective in reducing the urban heat island [31], [32]. Indeed, urban development should adapt itself to climate change [33], [34]. Microclimate is important for more livable urban spaces, and multidisciplinary studies are needed for this purpose [16], [35].

## 4. CONCLUSION

As a result of this research, in order to reduce the temperature effect of the area, more effective results were obtained when the designs that would not restrict the wind movement, branch from the top and cover the area, preventing or reducing the circulation were not made. The current situation of the courtyard is 39,40 °C, with the vegetative designs of the courtyard, providing a reduction of 9°C (24%) in S1 (25% covered with plants /only grass surface) and S2(40% covered with plants) temperature to 30,40 °C decreased. In S3 (50% covered with plants) and S4 (60% covered with plants), it was determined that the top-branching crown plants, which are used extensively, are not very effective in reducing the temperature by preventing or reducing the wind circulation. However, it was concluded that S3 helped reduce the temperature by 10% and S4 by 11% compared to the current situation In the research, it was determined that if green areas are well planned and implemented, even in a small area, it can significantly improve the climate in urban areas and contribute to microclimate. It has been concluded that planting designs to be made in courtyard gardens have a positive effect on the thermal comfort of the area, but planting designs that prevent wind movements especially should be avoided.

ENVI-met simulations are sensitive to the thermal properties of buildings and surface materials, as well as to the physical parameters of vegetation. In this study, the basalt stone pavement and the membrane shading element used in the courtyard of Hasan Paşa Han were included in the model; however, thermal parameters such as albedo, emissivity, and heat capacity of these materials were not measured in situ. Instead, the simulation inputs were defined based on values reported in the literature for similar materials.

Moreover, the effects of solar radiation reflected from building surfaces onto the membrane, as well as the surface temperatures and heat transfer processes occurring beneath the membrane, were not measured within the scope of this study. In future research, addressing these limitations through in situ measurements of material surface properties and reflected radiation analyses would contribute to more comprehensive and accurate microclimatic assessments.

## NOMENCLATURE

ENVI-met: Environmental Simulation Model

RMSE: The root mean square error

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Not applicable.

## DECLARATION OF ETHICAL STANDARDS

No ethical committee approval is required for this study.

## CONTRIBUTION OF THE AUTHORS

**Medine Çelik:** Performed the analysis and wrote the manuscript.

**Hasan Yılmaz:** Supervised the study and revised the manuscript.

## CONFLICT OF INTEREST

The authors declares that there is no conflict of interest.

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