# The Effects of Tree Cover Density on the Urban Heat Islands in the City of Adana

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**Abstract:** The detailed analysis and modelling of microclimate in the urban space has gained importance with the emergence of the urban heat island effect in recent years. ENVI-met is one of the commonly used microclimatic models to the microclimate variables of an urban fabric. Urban green spaces positively affect the urban climate. However, characteristics of these spaces within an urban fabric (the area size, location in the city, tree cover density, etc.) are important to change urban microclimate. Therefore, the aim of this study is to investigate the statistical relationship between the area size and the effect of the tree cover density in Adana City, Turkey. Three scenarios were primarily determined in order to explain the effect of the tree cover density on the urban heat island. Secondly, PET values were calculated for each urban green space by ENVI-met. Lastly, the mean PET values of each area size class for different tree cover were statistically analysed by ANOVA-Tukey HSD. Consequently, this paper aims to determine the suitable tree cover density for urban green areas and develop suggestions for planning and design strategies.

**Keywords:** ENVI-met, PET, tree cover density, urban green spaces, urban micro-climate

## 1 Introduction

Studies in urban physics aim to better understand the variance in micro-climatic conditions caused by factors such as building density, anthropogenic heat generation, traffic density, green areas, and water bodies. In recent years, the general awareness of urban microclimate has been continuously increasing. However, when population growth in cities around the world is considered, further research and planning are needed to better understand the impact of variance and development of the urban microclimate. An urban microclimate is critical for residents' health and well-being (thermal comfort, temperature stress, mortality rates) as well as for energy and environmental issues. Given the complexity of the urban fabric, it is widely accepted that heat storage in urban areas will be higher than in rural areas. The urban heat island (UHI), which defines the urban-rural surface and air temperature differences, is the most significant and studied urban climate phenomenon studied worldwide. Recent studies show that UHI is proportional to the urban area and population and varies according to the seasons and day and night (VOOGT & OKE 2003). The material properties of urban surfaces can cause higher urban temperatures. In general, undesirable thermal conditions in the urban environment are partly due to the characteristics of the materials used in constructing buildings, pavements and roads, and the reasons for urban settlement and structure, including topography, morphology, density and open space configuration. These factors can affect how solar radiation is absorbed by urban surfaces and air masses' flow through urban tissue. The urban microclimate not only increases the thermal comfort of people in cities but also increases the inconvenience caused by the overheating of indoor areas.

Most recent studies have analyzed the relationships between the physiological equivalent temperature (PET), mean radiant temperature (MRT) and vegetation density, vegetation spe-

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cies, water surfaces, shading elements, and albedo in highly urbanized hot cities with microclimate models such as ENVI-met and Rayman, in order to mitigate the urban heat island phenomenon. Studies evaluating the hottest period of the year to improve thermal comfort have examined areas with heavy pedestrian use, such as the squares (PERERA 2015, CHATZIDIMITRIOU &YANNAS 2016, MAKROPOULOU & GOSPODINI 2016, KÁNTOR et al. 2018,), urban green spaces (CHEN & WONG 2006, DUARTE et al. 2015, NASIR et al. 2015, LU et al. 2017, LEE & MAYER 2018), pedestrian zones (KETTERER & MATZARAKIS 2014, ELNABAWI et al. 2015, TALEGHANI et al. 2016, UNAL et al. 2018), urban canyons (ANDREOU 2013, PAOLINI et al 2014, BALLOUT et al 2015, LOBACCARO & ACERO 2015, ALCHAPAR & CORREA 2016, CHATZIDIMITRIOU & YANNAS 2017, SHARMIN et al 2017, DE & MUKHERJEE 2018), and campus areas (SALATA et al. 2017, TALEGHANI & BERARDI 2018).

The Physiological Equivalent Temperature (PET) is one of the most popular outdoor human comfort indices that can be used to evaluate both hot and cold conditions (HÖPPE 1999). Besides, it is widely used in different studies worldwide to analyze the thermal environment of cities in both local and microscale and investigate the effect of urban shading via ENVI-met.

ENVI-met is a widely validated and respected model for urban microclimate assessment and is the only model with the features and capabilities required for microclimatic studies (SHARMIN et al. 2017). ENVI-met has been widely used to evaluate outdoor thermal environments, tested, and approved for the assessment of different urban areas. ENVI-met processes and calculates the following variables:

- Short and longwave radiation flows related to shading, reflection, and re-radiation from building systems and vegetation;
- Surface temperatures in horizontal and vertical surfaces, such as floors and walls;
- The temperature in the soil and water, and heat change due to water bodies;
- Sensible heat flow as a result of interactions between plants and air, in which all the physiological processes of vegetation (photosynthesis, transpiration, evaporation, etc.) are included.

The three-dimensional presentation of vegetation including dynamic water balance modeling of plant species (EMMANUEL & FERNANDO 2007, ALCHAPAR & CORREA 2016) is also utilised to reveal the UHI.

The main purposes of this study were (1) to determine how tree cover density in urban parks affect the urban heat island in Adana, Turkey for August as the hottest summer month; (2) to identify the statistical relationship between PET according to the tree cover density and area size.

# 2 Materials and Methods

## 2.1 Study Area

In this context, in August, the hottest period in Adana, urban development and change of urban heat islands have been examined for the last thirty years (1990-2020). The Adana province in Turkey, an urban context that is characterized by a high density of urban settlements, is the most highly developed and fifth crowded area in the country (Figure 1). Adana has a typical Mediterranean Csa climate according to the Köppen-Geiger climate classification, with cool wet winters and hot dry summers. The mean daily maximum air temperature is approximately 31 °C in July and August (the hottest period), and approximately 15-16 °C in January and February (the coldest period). The weather in August is dry with no rainfall. However, during the year, the daily mean relative humidity remains high (above 80%). The dominating wind direction in Adana is northeast in winter and southwest in summer. Agriculture and agricultural industries have developed intensely because Adana covers the most productive agricultural land in the country. This development created a significant employment level, resulting in intense internal migration from rural to urban areas. The population was 500,000 at the beginning of the 1980s, rising to about 2,220,125 in 2018. Adana's development and improvements plan for 1985-2015 have been prioritized to meet housing needs due to the increasing population in the city center. The subsequent immense construction activities of this plan caused the rapid and unplanned urbanization of especially the Çukurova district located in the northern part of the city (Fig. 1) with a high number of urban green areas and dense high-rise settlement population.

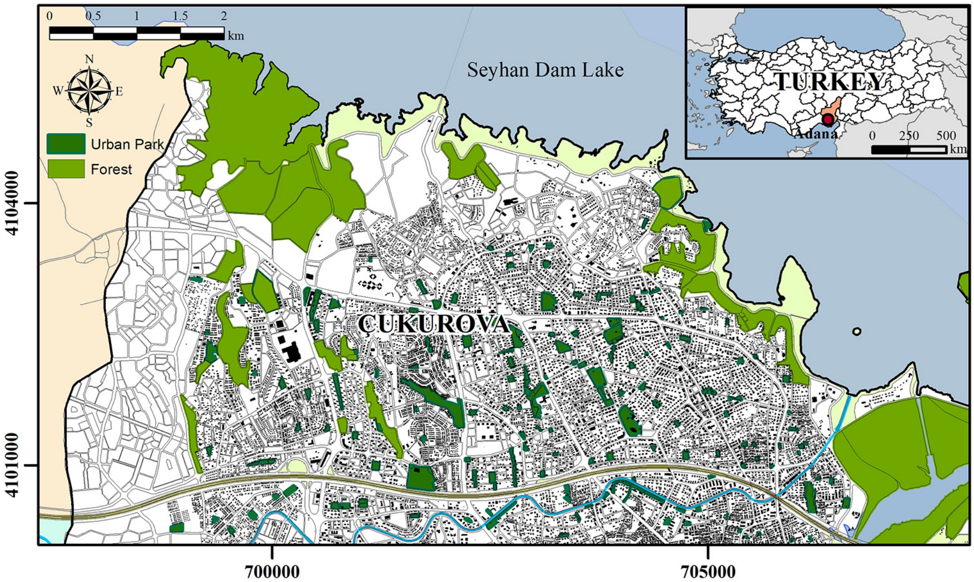



**Fig. 1:** Study area (Adana, Turkey)

## 2.2 Methodology

The study methodology consists of four main stages.

Firstly, three scenarios, including 100% grass cover, 50% tree cover, and 100% tree cover, were determined to obtain how vegetation cover density in urban parks affect the urban heat island.

Secondly, the thermal condition of Çukurova district was modelled with an ENVI-met microclimate model which simulates urban microclimate by taking into account many climatic parameters simultaneously. This model includes spatial, simulation and climate data. Moreover, it includes personal human parameters to calculate PET (Table 1). Therefore, GIS data used for digitizing study area and meteorological data and personal human parameters used to calculate PET were obtained before ENVI-met analysed. However, when it comes to mathematical computing, making a multidimensional spatial calculation of the urban space's microclimatic dynamics is very complex. The end time of simulation gets longer and it is difficult to perform for computers, as the study area size, spatial resolution, and simulation period increases. Therefore, the simulation period was determined as three hours including the hottest hour of the day in this study.

**Table 1:** Parameters used for ENVI-met simulations

<table>
<tr><td rowspan="10">Spatial data</td><td rowspan="10">with Spaces and Monde</td><td>Building height</td><td colspan="4">Variety</td></tr>
<tr><td rowspan="9">Outdoor surface Materials</td><td colspan="2">Roads and parking lots</td><td colspan="2">ST-Asphalt</td></tr>
<tr><td colspan="2" rowspan="3">Urban Green Spaces</td><td colspan="2">Scenario 1: 100% grass cover; Medium-density grass XX-50 cm tall</td></tr>
<tr><td colspan="2">Scenario 2: 50% tree, 50% grass</td></tr>
<tr><td colspan="2">Scenario 3:100% tree</td></tr>
<tr><td colspan="2">Other surfaces</td><td colspan="2">LO-Loamy soil</td></tr>
<tr><td colspan="2">Water surface</td><td colspan="2">WW-Water</td></tr>
<tr><td colspan="2">Forest area</td><td colspan="2">BS-20 m tree density, mixed crown</td></tr>
<tr><td colspan="2">Coast</td><td colspan="2">SD- Sandy soil</td></tr>
<tr><td rowspan="4">Simulation data</td><td rowspan="11">with ENVI-guide</td><td>Date</td><td colspan="2">8 August</td><td colspan="2">Hottest day</td></tr>
<tr><td>Start Finish</td><td colspan="4">12:00:00-15:00:00</td></tr>
<tr><td>Simulation period</td><td colspan="4">3 hours</td></tr>
<tr><td>Grid size (m)</td><td colspan="4">x =20; y=20; z=3</td></tr>
<tr><td rowspan="7">Climate data</td><td>Simulation day</td><td colspan="4">8 August (1990-2019 climate data)</td></tr>
<tr><td>Simulation hours</td><td>12:00</td><td>13:00</td><td>14:00</td><td>15:00</td></tr>
<tr><td>Air temperature (°C)</td><td>33.80 °C</td><td>34.45 °C</td><td>34.47 °C</td><td>33.92 °C</td></tr>
<tr><td>Relative humidity (%)</td><td>47.50 %</td><td>44.22 %</td><td>44.00 %</td><td>49.10 %</td></tr>
<tr><td>Wind speed (m/h)</td><td colspan="2">2.4 (min)</td><td colspan="2">2.9 (max)</td></tr>
<tr><td>Prevailing wind direction</td><td colspan="2">45° (NE)</td><td colspan="2">225° (SW)</td></tr>
<tr><td>Specific humidity (g/kg)</td><td colspan="2">2.2 (min)</td><td colspan="2">8.0 (max)</td></tr>
<tr><td rowspan="6">Personal Human Parameters</td><td rowspan="6">with Biomet</td><td>Age</td><td colspan="4">35</td></tr>
<tr><td>Size</td><td colspan="4">1.75 m (ISO 7730)</td></tr>
<tr><td>Weight</td><td colspan="4">75 kg</td></tr>
<tr><td>BMI</td><td colspan="4">18.5-24.9 kg/m$^2$ (healthy weight)</td></tr>
<tr><td>Metabolic rate</td><td colspan="4">1.4 (5 km/h walking speed)</td></tr>
<tr><td>Clothes</td><td colspan="4">0.60 clo in the summer (trousers or skirts and shirts made of fine fabric)</td></tr>
</table>

There are many differences in spatial data from the albedo varieties of roads, buildings, green areas, and water surfaces. To simplify these varieties, each land-use type was assigned a single type of material. Since the buildings' color differences affect thermal comfort, all building surfaces are considered the same color. Existing plants located in the street network, refuges, building parcels were ignored. Thus, it is aimed to determine the effect of green spaces on the building area.

Thirdly, PET was used to examine how human outdoor thermal comfort changed according to the cover density and area size of urban green areas. PET was calculated by Biomet and visualized by using Leonardo in ENVI-met for all scenarios before statistically comparing with one-way ANOVA. In addition to climatic and spatial data, personal human parameters were also used to calculate PET. PET values for each urban green spaces were categorised in terms of thermal stress (Table 2).

**Table 2:** PET categorised in terms of thermal stress (MATZARAKIS & MAYER 1996)

| PET (°C) | Thermal perception | Grade of physiological stress |
|---|---|---|
| <4 | Very cold | Extreme cold stress |
| 4.1 – 8.0 | Cold | Strong cold stress |
| 8.1 – 13.0 | Cool | Moderate cold stress |
| 13.1 – 18.0 | Slightly cool | Slight cold stress |
| **18.1 – 23.0** | **Comfortable** | **No thermal stress** |
| 23.1 – 29.0 | Slightly warm | Slight heat stress |
| 29.1 – 35.0 | Warm | Moderate heat stress |
| 35.1 – 41.0 | Hot | Strong heat stress |
| >41.0 | Very hot | Extreme heat stress |

Finally, the statistical relationship between six area size classes of urban green spaces and their mean PET values were determined by using ANOVA-Tukey Honestly Significant Difference (HSD) test for each scenario. However, ANOVA requires assumptions for variance analysis, such as normality and homogeneity (JACKSON & FERGUSON 1972). Therefore, normality tests with Kolmogorov-Smirnov tests, Q-Q plots, and histogram comparisons and a test of homogeneity of variances (Levene's test) were carried out to evaluate the assumptions of normality before the application of ANOVA (GELETIČ et al. 2016, 2019). ANOVA was generally used to examine the significance of the difference between groups and tried to determine whether there were any differences between groups, while it could not investigate which group or groups caused the differences. In this study, the Tukey HSD test was used to determine which pairs of tree cover density were significantly differentiated in terms of their mean PET according to the area size classes.

# 3 Results

In this study, three steps were followed to obtain the results. These steps comprised three scenarios where the **first** was concerned with the determination of the urban green spaces, namely as; (i) 100% grass cover, (ii) 50% tree cover, and (iii)100% tree cover. The PET values were calculated for each green space by ENVI-met according to these scenarios. Secondly, 205 urban green spaces with generally rectangular or square shaped were classified into six classes according to their area sizes in which the average PET values of the green areas differ statistically in 100%grass cover scenario. The mean PET values of six area sizes were determined for each scenario (Figure 2).

Figure 2 shows that the 100% grass cover scenario has the highest PET (42°C), while the 100% tree cover scenario has the lowest PET (29°C). PET values generally increase as the area size increases in the first scenario. Small parks (S1) and large parks (S6) have the highest value with approximately 42 °C, while medium parks (S3) have the lowest PET with nearly 39°C. On the other hand, the PET value linearly decreases as the area size increases in the second (50% tree cover) and third scenarios (100% tree cover). However, the peak values in the same green space class especially in S4 are due to the building height and building density in the parcels adjacent to the green spaces.

| | | | Mean PET (°C) | | |
|---|---|---|---|---|---|
| | | The number of urban green spaces | 100% Grass cover | 50% tree cover | 100% tree cover |
| Area size ($m^2$) | S1: 400-1200 | 43 | 42,76 | 39,12 | 36,27 |
| | S2: 1201-3000 | 59 | 40,84 | 36,33 | 33,21 |
| | S3: 3001-5000 | 47 | 39,32 | 34,73 | 31,67 |
| | S4: 5000-20000 | 42 | 40,79 | 34,04 | 30,77 |
| | S5: 20001-40000 | 9 | 41,49 | 33,22 | 29,71 |
| | S6: 40000-90000 | 5 | 42,20 | 33,11 | 29,39 |
| | Thermal Perception | Slightly warm | Warm | Hot | Very hot |

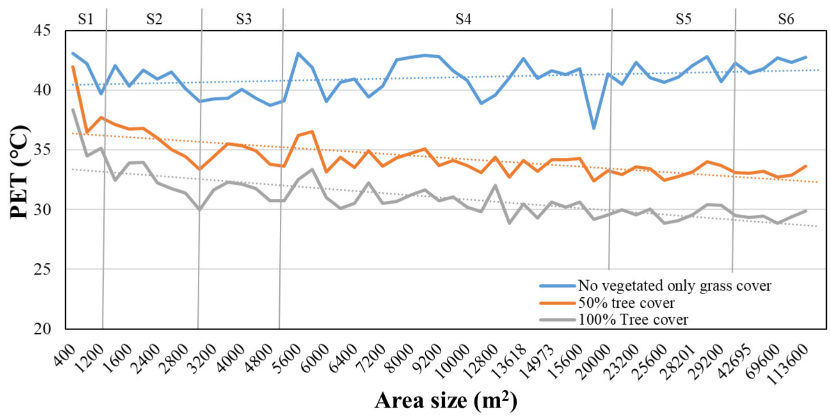



**Fig. 2:** Distribution of PET values by green space area according to scenarios

Thirdly, the ANOVA-Tukey HSD test was applied to determine statistically significant relationships between PET and area size according to three scenarios. Results were summarised in Figure 3. Figure 3 shows that all groups of 100% grass cover vegetated simulations are statistically differentiated from simulations with 50% (except S1) and 100% tree cover. While the 50% tree cover simulation PET results were approximately 3-9°C cooler than the 100% grass cover simulation, the 100% tree cover simulation PET results were roughly 6-13°C cooler than the 100% grass cover simulation (Figure 4). When we compare 50% and 100% tree cover simulations, all groups of scenarios are not statistically significant ($p>0,05$).

Because S5 and S6 area size classes in the 50% tree cover simulation and S1 and S2 in the 100% tree cover simulation have similar PET values. Moreover, the S1 class in the 100% tree cover is warmer than the S3-S6 classes in the 50% tree cover simulation and the statistically significant difference from the S4 class in 50% tree cover. It can be concluded that in order to obtain a park having thermal comfort, it can be designed and planned either as a very small area size with 100% tree cover density or a very large area size of 50% tree cover density.

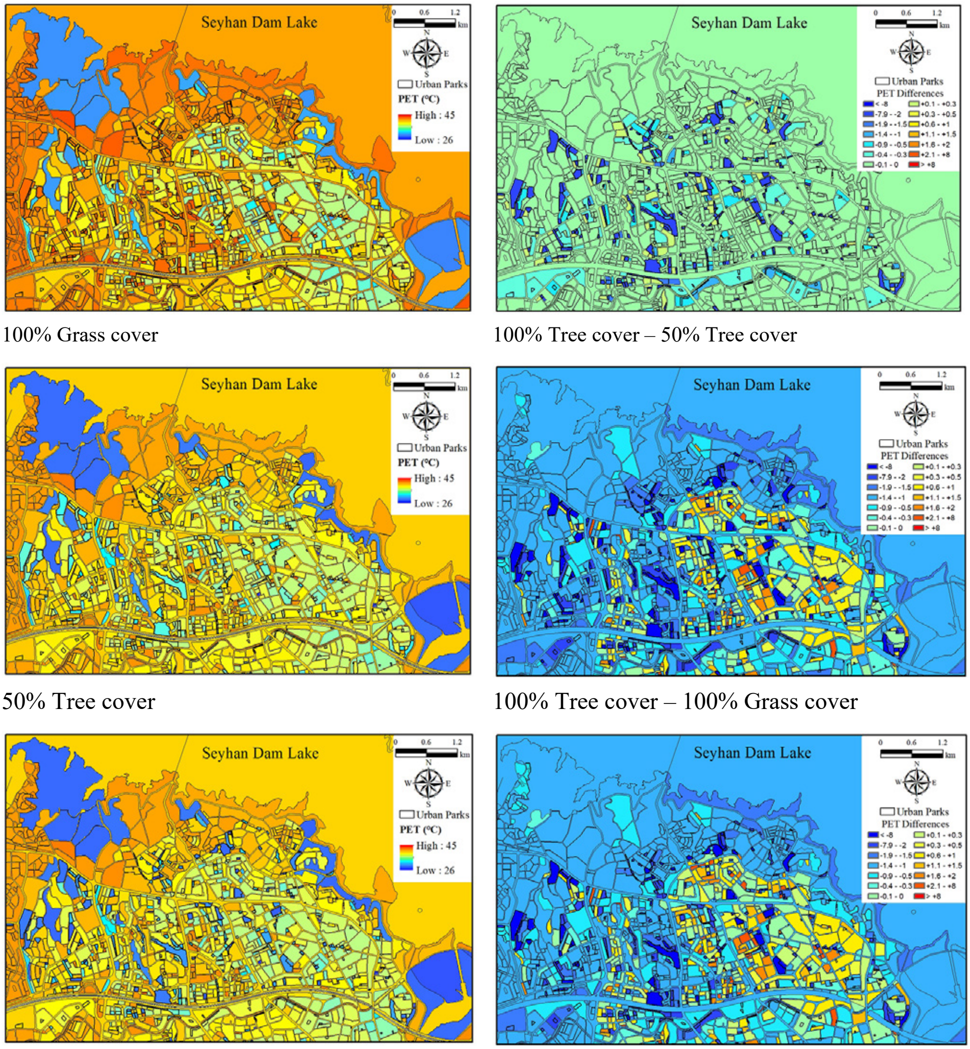
| | 100% grass cover | | | | | | 50% tree cover | | | | | | 100% tree cover | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S4 | S5 | S6 | S1 | S2 | S3 | S4 | S5 | S6 | S1 | S2 | S3 | S4 | S5 | S6 |
| 100% grass cover S1 | | 1,9 | 3,4 | 2,0 | 1,3 | 0,6 | 3,6 | 6,4 | 8,0 | 8,7 | 9,5 | 9,7 | 6,5 | 9,6 | 11,1 | 12,0 | 13,1 | 13,4 |
| 100% grass cover S2 | | | 1,5 | 0,1 | -0,7 | -1,4 | 1,7 | 4,5 | 6,1 | 6,8 | 7,6 | 7,7 | 4,6 | 7,6 | 9,2 | 10,1 | 11,1 | 11,5 |
| 100% grass cover S3 | | | | -1,5 | -2,2 | -2,9 | 0,2 | 3,0 | 4,6 | 5,3 | 6,1 | 6,2 | 3,0 | 6,1 | 7,6 | 8,5 | 9,6 | 9,9 |
| 100% grass cover S4 | | | | | -0,7 | -1,4 | 1,7 | 4,5 | 6,1 | 6,7 | 7,6 | 7,7 | 4,5 | 7,6 | 9,1 | 10,0 | 11,1 | 11,4 |
| 100% grass cover S5 | | | | | | -0,7 | 2,4 | 5,2 | 6,8 | 7,5 | 8,3 | 8,4 | 5,2 | 8,3 | 9,8 | 10,7 | 11,8 | 12,1 |
| 100% grass cover S6 | | | | | | | 3,1 | 5,9 | 7,5 | 8,2 | 9,0 | 9,1 | 5,9 | 9,0 | 10,5 | 11,4 | 12,5 | 12,8 |
| 50% tree cover S1 | | | | | | | | 2,8 | 4,4 | 5,1 | 5,9 | 6,0 | 2,9 | 5,9 | 7,5 | 8,3 | 9,4 | 9,7 |
| 50% tree cover S2 | | | | | | | | | 1,6 | 2,3 | 3,1 | 3,2 | 0,1 | 3,1 | 4,7 | 5,6 | 6,6 | 6,9 |
| 50% tree cover S3 | | | | | | | | | | 0,7 | 1,5 | 1,6 | -1,5 | 1,5 | 3,1 | 4,0 | 5,0 | 5,3 |
| 50% tree cover S4 | | | | | | | | | | | 0,8 | 0,9 | -2,2 | 0,8 | 2,4 | 3,3 | 4,3 | 4,7 |
| 50% tree cover S5 | | | | | | | | | | | | 0,1 | -3,1 | 0,0 | 1,6 | 2,5 | 3,5 | 3,8 |
| 50% tree cover S6 | | | | | | | | | | | | | -3,2 | -0,1 | 1,4 | 2,3 | 3,4 | 3,7 |
| 100% tree cover S1 | | | | | | | | | | | | | | 3,1 | 4,6 | 5,5 | 6,6 | 6,9 |
| 100% tree cover S2 | | | | | | | | | | | | | | | 1,5 | 2,4 | 3,5 | 3,8 |
| 100% tree cover S3 | | | | | | | | | | | | | | | | 0,9 | 2,0 | 2,3 |
| 100% tree cover S4 | | | | | | | | | | | | | | | | | 1,1 | 1,4 |
| 100% tree cover S5 | | | | | | | | | | | | | | | | | | 0,3 |
| 100% tree cover S6 | | | | | | | | | | | | | | | | | | |

**Fig. 3:** Tukey-HSD comparison matrix for all scenarios, where the blue and red grids show the significantly different ($p < 0.05$) mean pets.

The results of the scenarios are interpreted according to the grade of the physiological stress (Table 1). While the S1 and S6 classes had a grade of '*extreme heat stress*', S2 to S5 had *'strong heat stress' grades* in the 100% grass cover simulation. However, S1, S2, S3, and S4 classes had *'strong heat stress' grades* in the 100% tree cover density and they rose to grade one physiological stress. S5 and S6 classes rose to grade two, i. e., the *'moderate heat stress'*. This shows that the area size is an important factor as the tree cover density to determine the suitable PET value for thermal comfort.

**Mean PET values obtained ENVI-met based on settlements parcel for three scenarios**

**Mean PET differences of tree cover densities on urban spaces**




100% Grass cover

100% Tree cover – 50% Tree cover

50% Tree cover

100% Tree cover – 100% Grass cover

100% Tree cover

50% Tree cover – 100% Grass cover

**Fig. 4:** ENVI-met modelling results: Mean-PET for Çukurova district

# 4 Conclusion

The expansion of urban area causes a decrease in green spaces, an increase in impermeable surfaces, and an increase in temperature from rural areas to urban areas. Thus, the urban heat island effect increases in an urban area where the outdoor thermal comfort has adversely been affected from UHI. Previous studies highlighted that the best way to improve thermal comfort is to increase the shade ratio. Plant existence is one of the main factors positively affecting the PET value and outdoor thermal comfort. According to this information, our study aims to statistically compare PET changes in urban green areas based on the area size of green spaces and three tree cover density scenarios. The general results and suggestions of the study can be listed as follows,

***Design strategies:*** Green spaces with large area size and high tree cover density have lower PET values and are the most suitable areas in terms of thermal comfort due to their high shade ratio. However, it is impossible for all urban green spaces with 100% tree cover in a city. Although this situation provides a high shading area, it decreases wind speed, high specific humidity, and high PET value. Consequently, the suitable tree cover density can be determined according to the characteristics of each urban green space including area size with more detailed resolution. Before implementing the decisions on the development of green spaces in a city, the optimum tree cover density and tree species for outdoor thermal comfort of different seasons should be determined in the study areas.

***Planning strategies:*** The climate of green spaces is directly affected by the settlement located nearby. We determined that, especially, small green spaces located at the east side of a high-rise building have lower PET values in any scenario because of the shading effects of these structures. On the other hand, inevitably, large green spaces with 100% grass cover adjacent to on the east side of high-rise settlements have higher PET values.

The microclimatic analysis of urban areas is difficult due to a large number of variables. In this study, the area size is as important as the tree cover density. However, the expanding area size is the most difficult characteristic of urban green spaces in the planned city. Therefore, it should be preferred to high tree cover density for green spaces with unsuitable thermal stress. Green areas contributing to the urban microclimate should also be located in the right place with the proper plan decisions. Consequently, the study results can be useful for city planners and decision-makers in developing appropriate spatial planning strategies in terms of urban climate design.

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