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The Role of Different Planting Types in Mitigating Urban Heat Island Effects: A Case Study of Gaziantep, Turkey

Murat YÜCEKAYA[a*], Ahmet Salih GÜNAYDIN[b]

[a]*Faculty of Engineering and Architecture, Department of Landscape Architecture, Nevsehir Haci Bektas Veli University, Nevsehir, TURKEY*

[b]*Faculty of Fine Arts and Design, Department of Landscape Architecture, Inonu University, Malatya, TURKEY*

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Corresponding Author: Murat YÜCEKAYA, E-mail: muratyucekaya@nevsehir.edu.tr
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ABSTRACT

The growth of cities and increase in their structural density lead to several problems. The most important of these is the formation of urban heat islands and the decrease in the bioclimatic comfort levels. This study focuses on the effect of different planting alternatives on bioclimatic comfort. In this context, different planting options with only leafy, only coniferous, leafy and coniferous at half at 4 m, 6 m, and 8 m intervals along with the current planting state of the study area in Gaziantep, Turkey were prepared. These plans were simulated with ENVI-met software. As a result of the study, coniferous plants were observed to have a cooling effect of approximately 2 °C – 2.5 °C compared to the leafy ones. In the simulation results of the map obtained with coniferous mixed plants, it was determined that the cooling effect values of only coniferous and only leafy plants were at almost average. Relative humidity was 15% higher in the plan conducted with coniferous plants compared to leafy plants. It was about 8% higher than leafy ones in mixed planning. There was no significant change in wind speed maps. In the plans with 4 m intervals on average radiation temperature maps, the refreshing effect of the coniferous was more than the leafy. As a result of the study, it was found out that the highest cooling effect was achieved in the planting plan created at 4 m intervals using coniferous plants.

Keywords: ENVI-met, Outdoor thermal comfort, Urban heat island, Planting distance

1. Introduction

It is known that the development of cities has significantly changed the climate. The increase of impermeable surfaces such as roads and structures significantly reduces surface evaporation and increases heat storage. Thus, the temperature increased on the ground surface will be higher than the previous vegetative surface (Ca et al. 1998). Annual average temperature values are 2 - 3°C higher in urban areas than in rural areas (Miraboğlu, 1977). The biggest difference in urban temperatures occurs on clear and still nights. During these times the temperature usually rises around 3-5 °C. Yet, it is still possible to observe an 8-10 °C increase. These temperature increases create the urban heat island (UHI)(Givoni 1998; Karatasou et al. 2006; Bowler et al. 2010).

Daily temperature averages are higher in urban areas with dense constructions compared to regions surrounded by rural areas (Oke 1987; Givoni 1998; Yu & Hien 2006). UHI effect is also increased due to the high heat capacity of impermeable surface materials. These materials absorb heat during the day and release it slowly at night. UHIs' methods of reducing negative energy and environmental impacts have become important research topics in sustainability programs (Wang & Akbari 2014).

Urban islands will affect more urban residents with the increase of urbanization. Therefore, it is reasonable to develop ecological approaches to reduce this effect in areas with thermal stress (Ca et al. 1998). The potential heating and cooling effect of urban green spaces is especially important in hot climates where the urban heat island creates undesirable effects (Potchter et al. 2006). Loss of vegetation cover increases UHI in cities. Increasing vegetation in urban areas will greatly reduce this effect. More comprehensive research is needed to determine the cooling effect levels of vegetation (Armson et al. 2012).

Vegetation has an impact on the climate of urban areas, and its deficiency can be significant cited as one of the main causes of urban heat island formation (Shashua-Bar et al. 2011; Wang & Akbari 2016). The vegetation lowers air temperature by remitting the heat from the sun through shading and evapotranspiration, and by converting the solar radiation into latent heat. Furthermore, the resulting low temperature leads to the reduction of long-wave radiation emitted from the ground and leaves, thus, expose people to a lower radiation load unlike artificial hard surfaces in the environment (Dimoudi and Nikolopoulou 2003).

Vegetation affects thermal energy balance both directly and indirectly in cities. It directly affects the microclimate by lowering the surface temperatures. Besides, it changes the urban climate by reducing the heat transfer in the occupied spaces and thus, the mechanical cooling loads and human-induced heat (Gunawardena et al. 2017). Replacing planted areas with low albedo materials is one of the causes of rising temperatures in urban environments. As a result, it can be considered as one of the main causes of urban heat island effects (Razzaghmanesh et al. 2016).

Plants can be used as an effective means to control sunrays. Various forms, textures, and colours of vegetative material offer endless benefits that add beauty to the landscape (Attia & Duchhart 2011). Control of solar radiation, increasing or decreasing temperature and humidity, creating or blocking the wind are the most important effects of plants on the climate (Altunkasa 1987). Areas covered with trees can protect the warm air by creating shade. Besides, grass areas that allow air flows can contribute to convection cooling (Bowler et al. 2010). Deciduous trees provide shade when they are leafy in summer, and allow sun rays to pass when they are leafless in winter, but have little effect on the winter wind. Coniferous trees provide shade in both summer and winter and reduce wind speed in winter (Brown 2010). In different studies, it has been determined that the use of trees and shrubs in urban areas can reduce the peak ambient temperature between 0.2 °C and 5 °C on average, with an average decrease of around 1 °C (Balany et al. 2020). For this reason, it is an important requirement to focus on green space planning at the planning stage (Yucekaya & Uslu 2020). In addition, planting designs in green areas are also considered extremely important in terms of bioclimatic comfort.

This study was conducted in Gaziantep province in Turkey. A public housing garden was identified as the study area. Along with the current planting status of the mass housing, plans were prepared in different combinations with only leafy plants, only coniferous plants, leafy and coniferous plants used in half, and the distance between the plants determined as 4 m, 6 m, and 8 m. This way, how the different plant compositions mentioned would affect the bioclimatic comfort was examined. In different studies, the contribution of plants to the climate has been investigated from different aspects. In this study, the effect of coniferous and leafy plants and the distance between these plants on bioclimatic comfort has been focused on, and in this respect, the study differs from the others.

The study objective is that the determination of planting options can provide optimum bioclimatic comfort conditions in regions with hot dry climate characteristics. Two specific questions were created in line with the main objective. These are i) Are bioclimatic comfort conditions achieved by using only coniferous plants, only leafy plants or both coniferous and leafy plants? ii) How is the bioclimatic comfort status affected when the distance between the plants is 4 m, 6 m, and 8 m? The answers to these questions constituted the analytical framework of the study

2. Material and Methods

Planting plans with only leafy, only coniferous, leafy and coniferous plants in half at 4 m, 6 m and 8 m intervals were created for the purpose. These alternative plans were simulated with ENVI-met software. Climatic findings obtained as a result of simulations were interpreted. The data focused on the determination of the change in the bioclimatic comfort state. It is considered that the study will provide important clues for vegetative designs to be created in hot dry climates.

2.1. Research case

The study was carried out in Gaziantep, Turkey. Gaziantep, located at the junction of the Mediterranean Region and the Southeastern Anatolia Region, lies between 36° 28' and 38° 01' E and 36° 38' and 37° 32' N (Provincial Directorate of Environment & Urbanism 2020). Located at an average altitude of 850 m, the city has a mixture of Mediterranean and continental climate (Sönmez 2012).

The study was conducted in Karatas neighbourhood in Şahinbey district of Gaziantep, the eighth-largest city in Turkey and a cosmopolitan city considering the population movement from Syria in recent years. While choosing the study area, it was considered that it should contain more than one building in the area, and green are size should allow for plant compositions that are intended to be created in the study. Therefore, a mass housing district with approximately 13000 m^2 area in Karatas was identified as the study area (Figure 1).

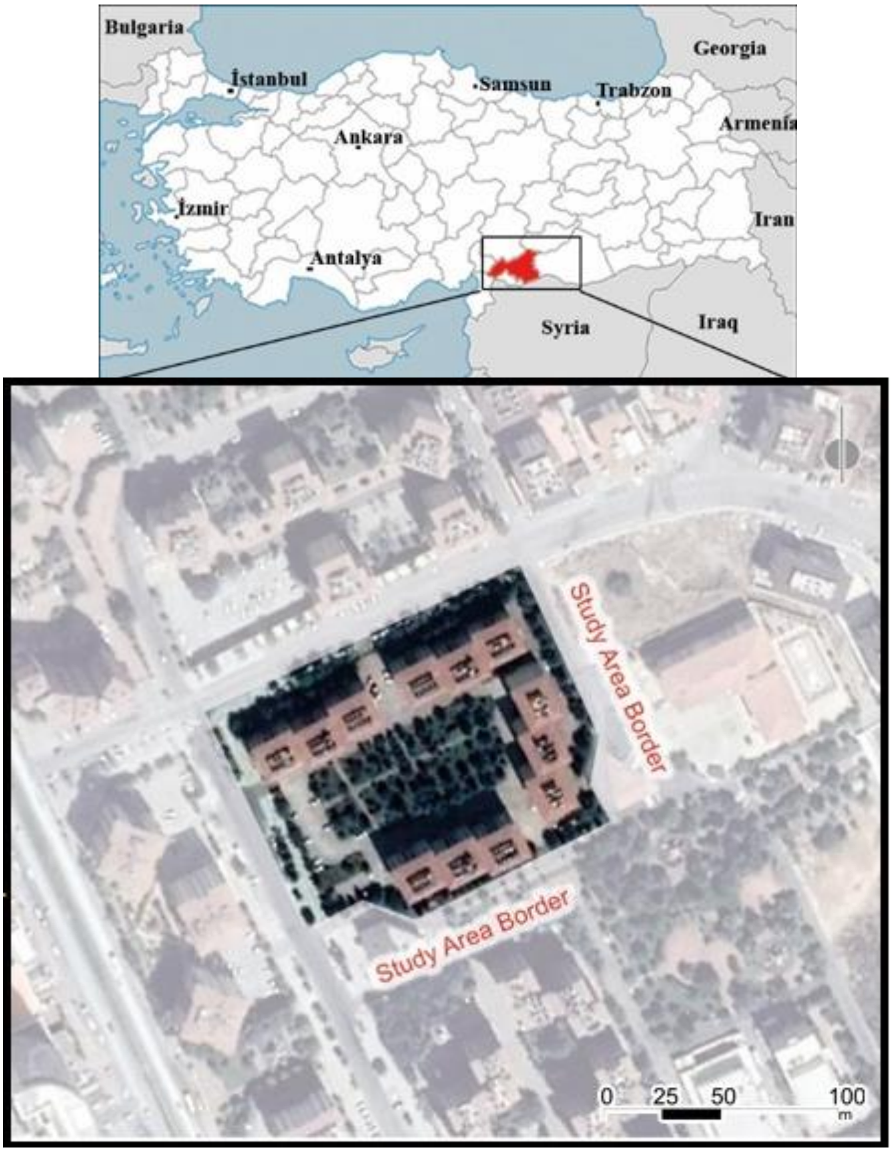

Figure 1- Study Area Location

The existing vegetation of the study area mainly consists of evergreen plants. Coniferous species *Cupressus sempervirens, Cupressus arizonica* and *Pinus brutia* are found in the green areas within the study area. Among these plants, there are *Malus floribunda, Morus alba, Pavlonia tomentosa* and *Acer negundo* as deciduous species.

2.2. ENVI-met

ENVI-met software solves partial differential equations and other steps in the model using the finite difference method. Indirectly, this reduces computational costs and allows the software to be used on normal computers (www.envimet.com).

ENVI-met software allows analysis of the effects of minor changes in urban design (plants, new residential areas, etc.) on microclimate under different medium-sized conditions (Bruse & Fleer 1998). ENVI-met is a holistic, three-dimensional, non-hydrostatic model for the simulation of surface-plant-air interactions. It is designed for microscale with a time frame of 24 to 48 hours with 0.5 to 10 m and 1 to 5 second time stages. This resolution allows us to analyse small-scale interactions between individual buildings, surfaces and plants (www.envi-met.com). The software can simulate air temperature, humidity, wind speed and direction, turbulence, radiation flow, gas and particle distribution and generate maps within this framework. Besides these structural configurations, ENVI-met includes some basic design characteristics. They are as follows; *i)* It simulates an entire climate system, including fluid mechanics, thermodynamics and pollutant distribution. *ii)* It provides the opportunity to create a high resolution model for analysing single buildings. *iii)* Simulates surface-plant-atmosphere processes such as the rate of photosynthesis (Ozkeresteci et al. 2003).

Different studies compared meteorological measurements performed in the field with the ENVI-met simulation software. The simulation results and actual measurement results were compared with the ones from those studies. As a result, it was determined that the ENVI-met software gave results close to the real measurements, and the reliability of the software was proven (Bennet & Ewenz 2013; Elnabawi et al. 2013; Hedquist et al. 2009; Jeon et al. 2010; Lahme & Bruse 2013; Song & Park 2015).

2.3. Simulations

The place of vegetation cover was mapped in the study. In the next stage, alternative plans with 4 m, 6 m, and 8 m intervals were prepared (Figure 2).

Figure 2- Study area current status (top left), planting plans with 4 m (top right), 6 m (bottom left), and 8 m (bottom right) intervals

Long-term climate data (temperature (20 years), relative humidity (10 years), soil temperature (10 years), and cloudiness (10 years)) of Gaziantep province obtained from the General Directorate of Meteorology was used in the simulations. These data were used because 20 years of data were obtained for temperature and 10 years for relative humidity, wind speed and soil temperature. The simulations were made for 24 hours on June 21 when the solar radiation is at its highest, and the start time was determined as 06:00 in the morning. In addition, coniferous and leafy plants used in the simulation were similar in terms of their depth of roots (2 m), leaf density (medium intensity), and crown width (5 m). The data fed to the software are given in Table 1.

Table 1- Simulation Conditions

Simulation area	*Gaziantep / Turkey*
Modelling area dimensions	25x30x50
Grid Dimensions	2x2x2
Coordinates	37 ° 04´ North Latitude / 37 ° 23´ East Longitude
Simulation Date	21 June
Simulation Start Time	06:00
Simulation Duration	24 Hours
Temperature	Long Term Mean Temperature Min: 04:00 / 19.25 °C Max: 14:00 / 30.95 °C
Relative Humidity	Long Term Mean Relative Humidity Min: 11:00 / 20% Max: 02:00 / 52%
Wind Speed	Long Term Mean Wind Speed Direction: 245° Wind Speed: 1.1m/s
Soil Temperature	Long Term Soil Temperature Mean Initial Temperature: 24.65 °C
Road/Parking lot	Asphalt
Pedestrian Roads	Gray Concrete Coating
Green Area	10 cm Tall Medium Density Grass
Plants	Cylindric, Small Trunk, Sparse, Small (Plant Height: 5 m) Conic, Small Trunk, Sparse, Small (Plant Height:5 m)

Simulations were performed by defining 4 different interfaces in ENVI-met software. First, the drawings prepared were defined as grids in the Spaces section. Next, the simulation file was created by defining the climatic data of the region in the configwizard section. Then, the simulation process was initiated. Last, the simulated files were visualized in the Leonardo section and thus, climate maps were created.

ENVI-met software is capable of creating climate maps of many different meteorological parameters. The most important climatic variables related to bioclimatic conditions and temperature stress are air temperature, wind speed, relative humidity and average radiation temperature (Gaitani et al. 2007; Türkeş 2010; Walikewitz et al. 2015). Therefore, these 4 meteorological parameters were examined to bring the bioclimatic comfort to the desired levels.

The maps created as a result of simulations were interpreted. Then, how much area the temperature values occupy in the map in all of the air temperature maps was calculated as a percentage. A graph was created with the calculated values, and they were interpreted. Thus, the results of the study were simplified by showing all the air temperature values obtained on a single graphic.

2.4. Analytical framework

In the study, 10 different planting plans were created including;

1. Current status of the study area,
2. Three different combinations where only leafy plants were used at 4 m, 6 m and 8 m intervals,
3. Three different combinations where only coniferous plants were used at 4 m, 6 m and 8 m intervals,
4. Three different combinations where leafy and coniferous plants were used in half at 4 m, 6 m and 8 m intervals

While creating planting plans, main roads, structures, walkways, and other hard surfaces and green area sizes were considered fixed data sets. Variable datasets were distances between plants.

In the next stage of the study, 10 different planting plans were created firstly defined as grids with ENVI-met software.

3. Results and Discussion

At this stage of the study, planting plans that were previously described were created and their climatic simulations were made. A total of 40 maps obtained are given in figure 3. The legends of the maps are given in standard ranges to easily interpret the maps given in figure. Value ranges automatically given by ENVI-met software on air temperature, relative humidity, wind speed and mean radiant temperature maps. These values are the minimum and maximum values on the maps. They do not give any information about what values are on the map and in what proportions. However, it provides a rough framework on how vegetation alternatives affect the climate. Therefore, the values in this table are considered to be important in that they show the minimum and maximum limits.

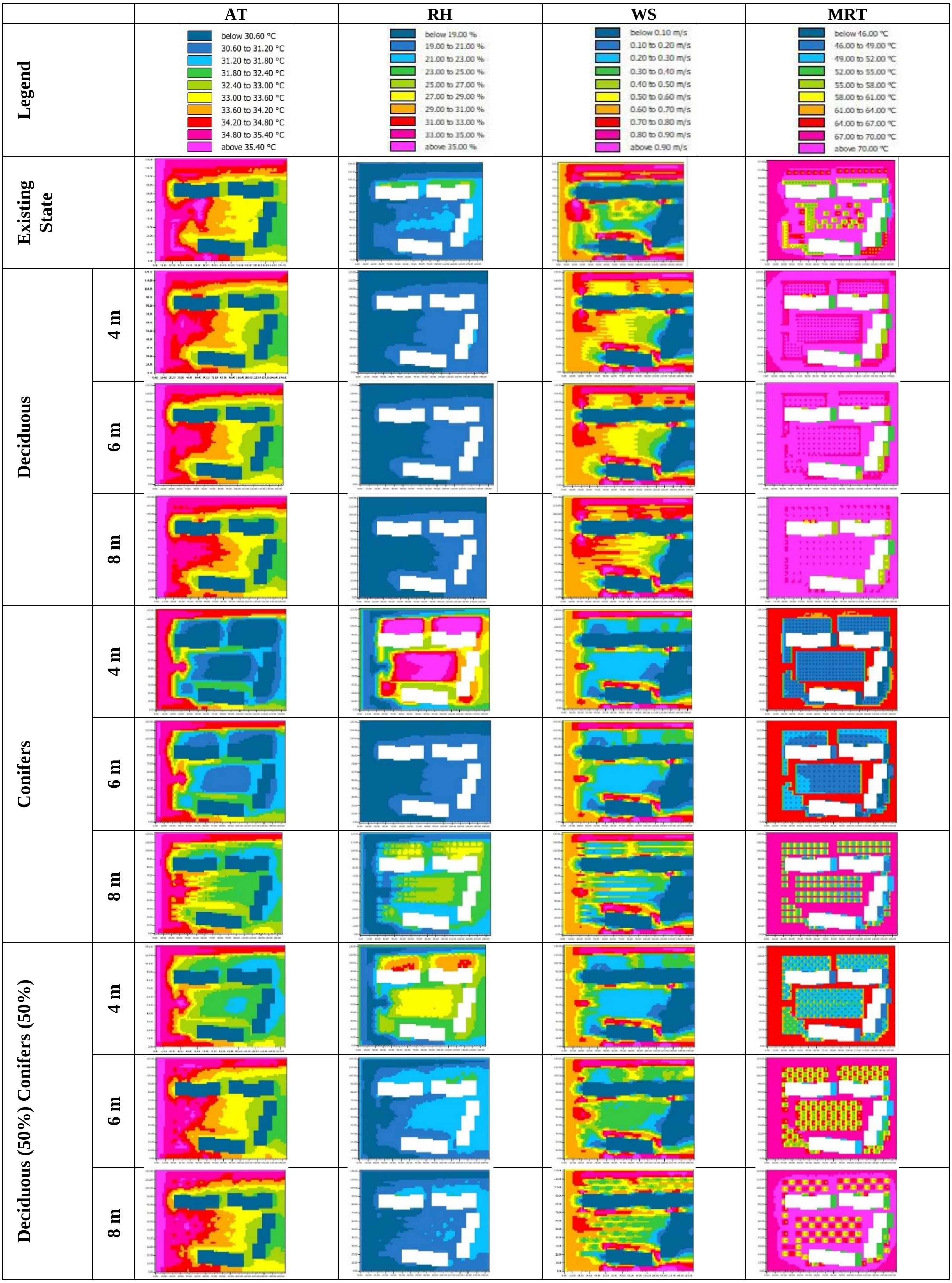

Figure 3- Analysis results (AT: Air Temperature, RH: Relative Humidity, WS: Wind Speed, MRT: Mean Radiant Temperature)

3.1. Air temperature

Coniferous plants showed approximately 2 °C – 2.5 °C more cooling effect than leafy ones. In the simulation results of the map obtained with coniferous mixed plants, it was found out that the cooling effect values of only coniferous and only leafy plants were almost average. There are no major differences between the current situation and the simulation results of only leafy ones. When the minimum and maximum values mentioned in the maps are examined, it is observed that while there is no big change in the minimum-maximum air temperature values in the maps with 4-6-8 m intervals, there is also a decrease in the temperature values as the intervals of coniferous plants decrease. A partial decrease was observed in the simulations of coniferous and leafy.

3.2. Relative humidity

The relative humidity is 15% higher in the plan made with coniferous plants compared to leafy ones. It was about 8% higher than leafy ones in mixed planning.

The minimum and maximum values were almost the same in 4-6-8 m simulations of leafy plants. While the minimum values did not change in coniferous simulations, there was a 5% difference between the moisture rates as the intervals decrease. While the simulations with 6-8 m intervals did not change much in mixed plans, a 7% increase in relative humidity was observed when the intervals were reduced to 4 m.

3.3. Wind Speed

Wind speed in coniferous and mixed plans was almost the same. It was approximately 0.2 m/s higher in leafy plans. Since there was no regular vegetation in the current situation, the wind speed also showed an uneven distribution.

There was no remarkable decrease or increase between minimum and maximum values in wind speed maps in any simulations.

3.4. Mean Radiant Temperature

The refreshing effect of the coniferous was about 18 °C higher than the leafy with plans at 4 m intervals. The high cooling effect of coniferous plants is clearly seen on the current situation map. In this map, the regions with coniferous plants have an 8 °C – 10 °C more cooling effect than leafy ones. The cooling effect is about 6 °C less than the coniferous in the mixed planting plan.

While there was no remarkable change in 4-6-8 m simulations of leafy plants, there were approximately 4 differences in the minimum and maximum values of simulations with 4 m intervals in the coniferous plants. The same situation with coniferous simulations applies to mixed plant simulations.

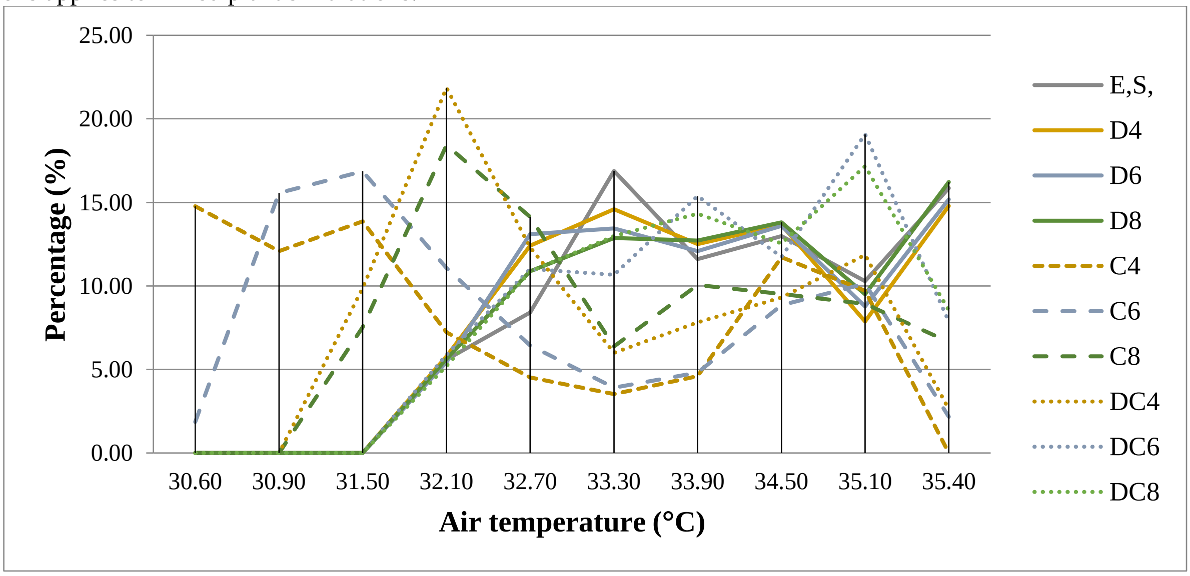

Figure 4- Air Temperature percentage distribution graph

(E.S: Existing State, D4: Deciduous 4 m interval, D6: Deciduous 6 m interval, D8: Deciduous 8 m interval C4: Conifer 4 m interval, C6: Conifer 6 m interval, C8: Conifer 8 m interval, DC4: Deciduous/Conifer 4 m interval, DC6: Deciduous/Conifer 6 m interval, DC8: Deciduous/Conifer 8 m interval)

The area covered by each temperature value in the map was calculated by measuring the percentage in the air temperature maps obtained as a result of the study. The obtained values were turned into a graph (Figure 4). It is seen in the graph that coniferous planting with 4 m intervals has high rates at low temperatures and low rates at high temperatures. Thus, it can be said that it creates the best cooling effect among all alternatives.

It is seen that the current situation and leafy planting alternatives create values close to each other. It can also be said that leafy vegetation creates the least cooling effect in the graph. As a result, it can be easily stated that the plants used are more important than the plant ranges.

It is observed that the cooling effect is more powerful especially in the close surroundings of the plants. In other words, there is a specific Cooling Effect Radius (CER) for each plant. There is approximately 1 °C difference in the asphalt areas with only coniferous plants compared to the areas with only leafy plants. Thus, it is necessary to build central refugees and correct planting options on the roads and pedestrian crossings to create a cooling effect, especially on asphalt surfaces. Thus, the plant CER is kept at an optimum level, and a cooling effect can be created in all areas possible.

When the plant intervals with coniferous plants are considered, it is observed that as plant intervals decrease, the temperature drops at 0.6 °C. Interval differences in leafy plants do not lead to a big change in temperature. There was about 0.6 °C differences at 4 - 6 m intervals in mixed planting. However, there was no significant change between 6 - 8 m intervals. Within the maps produced, the optimum cooling effect was provided by the planning with the coniferous plants at 4 m intervals. The cooling effect of this alternative planning was found to be approximately 2.5 °C higher than the current state of the area.

In their study, Wang and Akbari found out that significant decreases in temperature values can be seen with increasing tree size because larger shading areas in summer can reduce solar energy absorption (Wang & Akbari, 2016). This finding coincides with the finding that the cooling effect increases as the plant density increases.

Almost the same maps were obtained from the simulations of the leafy at 4 m interval and mixed plants at 8 m interval. Although the number of plants in the first case was twice that of the second case, the fact that the maps show similar characteristics in both cases can be seen as a clear indication that the refreshing effect of coniferous plants is much more than that of leafy plants.

With the intensification of the vegetation, the wind could not be canalized into the area and there was a decrease in wind speed. Coniferous plants appear to play a greater role than leafy plants in this decline. However, these decreases in wind speed were not at significant intervals.

It is seen that the humidity rate was high especially in the regions with plants but it was not much high in the other regions. It is seen that there was not a big change in relative humidity values in the simulation of only leafy plants, but in simulations with coniferous plants, the relative humidity rate increased as the plant intervals narrowed.

In the study, it was found out that the presence and density of green areas and keeping plant intervals low is an important factor in improving the climate. This finding is compatible with the findings by Chatzidimitriou & Yannas (2004), Yu & Hien (2006), Petralli et al. (2009), Latini et al. (2010), Yang et al. (2011), Ng et al. (2012), Papangelis et al. (2012), Srivanit & Hokao (2013), Yahia & Johansson (2014) which state that bioclimatic comfort will rise to higher levels as the density of vegetation is increased.

4. Conclusions

This study was designed to determine the effects of bioclimatic comfort by differentiating vegetation design in the mass housing area where different dwellings are located. As a result of the study, it was found out that the highest cooling effect was achieved in the planting plan made at 4 m intervals using coniferous plants.

While preparing planting plans in landscape architecture studies, plant intervals are determined according to the maximum crown width that each plant can reach. The findings here suggest that it may be appropriate to reduce the plant intervals when necessary to improve climatic comfort conditions. It will be a correct approach to use coniferous plants especially in median barrier plantings and to place them close to each other as much as possible.

This study concludes that residential gardens can partially minimize the negative effects of intensive housing on urban areas. This way, the bioclimatic comfort level can be increased to maximum levels only if house gardens are larger than certain standards. Thus, all actors including decision-makers and practitioners who play a role in urban design stages have a great responsibility.

Urban planning is a complex and multidisciplinary process that requires more and more actors to be in contact with each other. Higher data requirements, different methods, accepted assumptions and limitations in planning processes should be carefully considered by the planners. Indicators evaluating bioclimatic comfort status represent very useful tools for planners and can provide sound foundations for local to develop policies that can create more liveable and healthy urban environments.

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