Analysing the Impacts of Different Urban Green Areas on Human Thermal Comfort in Bornova, İzmir

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Abstract: This study examines the impact of three different urban green areas with various types of plant cover on human thermal comfort in the Bornova district by measuring some climatic parameters within the parks and their immediate surroundings/built-up areas in a typical hot summer month (July 2017). The measurements were analysed and interpreted according to the Physiological Equivalent Temperature (PET) index and the mean radiant temperature (T_{mrt}) by RayMan software model. The results showed that a green area with good ventilation and a deciduous tree cover with large leafs has a positive effect on human comfort especially during the night. The results also emphasize the importance of wind velocity, plant (tree) cover type and the physical characteristics of the neighbouring area as effective tools for human comfort.

Keywords: human thermal comfort, PET index, T_{mrt}, urban green areas

Introduction

Urban landscapes have been facing some significant problems over the last couple of years including extreme weather events, drought, flooding and changing urban climate (Georgi & Dimitriou, 2010, Coutts *et al.,* 2012). In other words, city dwellers are subjected to changing micro-climatic conditions that make urban environments quite different from surrounding rural areas (Gulyás, 2005). The urban heat island is one of the well-documented phenomenons of climate change. It is associated with increased urban air temperatures compared to the surrounding rural areas. Heat island intensities vary between 1 to 10 degrees (Zoulia *et al.,* 2009). The urban heat island (UHI) is defined as the difference between air temperatures measured in the urban landscapes and those measured in the non-urban surrounding areas (Oke, 1987). The UHI is characterized by increased temperature values, lower relative humidity and moderation of wind velocity that result in unpleasant microclimatic conditions for humans (Potcher *et al.,* 2006). In other words, human thermal comfort is defined as a condition of mind that expresses satisfaction with the surrounding environment. High temperatures and humidity naturally provide discomfort sensations (Abdel-Ghany *et al.,* 2013).

It is important to emphasize that abatement of the urban heat island effect is crucial to improve human health in dense urban settings. For urban heat island mitigation, it is widely acknowledged that increasing vegetation and tree canopy cover have proved to be a promising strategy (Sanusia *et al.,* 2017).

Therefore, urban green areas stand out among the other strategies in heat island mitigation in addition to their crucial roles in providing many other ecosystem services for city dwellers (Hepcan, 2013). Green areas within the urban landscapes can "create a cooling effect, lower temperatures and increase relative humidity" (Oke, 1987). "The cooling effect of urban parks creates a park cool island (PCI)" (Spronken-Smith & Oke, 1998). The potential cooling effect of urban parks is particularly important in hot and humid climates because of the process of cooling by the vegetation (Potcher *et al.,* 2006). In regards to this subject, (Bowler *et al.,* 2010) reviewed some studies and found that urban green areas in the form of parks and individual trees may create a cooling effect. The review also found that both shading and evaporative cooling played a role in lowering urban temperatures (cited in Coutts *et al.,* 2012). It is clear that evapotranspiration of plants influences their micro-environment by increasing the humidity of the dry summer atmosphere that represents more pleasant and thermal comfort (Georgi & Dimitriou, 2010). For instance, Potcher *et al.* (2006) found out that urban parks with high trees with a wide canopy reduced the temperatures by up to 3.5°C and lowered heat stress values.

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Of course, park cooling intensity is determined not only by the characteristics of the green areas but also by the characteristics of neighboring urban surfaces (Coutts *et al.,* 2012). The degree of human or thermal comfort that people experience in open spaces is one of the key determinants, especially in areas with extreme climates. There is a wide range of indices in the literature on this matter, such as THI, PE, TS, PMV, PET, mPET and COMFA (Matzarakis *et al.,* 1999, Ruiz & Correa, 2014, Xuea & Xiao, 2016). Among the outdoor thermal comfort indices, Physiological Equivalent Temperature (PET) is nowadays one of the commonly used evaluation indices (Matzarakis *et al.,* 1999, Xuea & Xiao, 2016) because PET is well suited to the human bio-meteorological evaluation of the thermal component of different climates. Its unit (°C) makes it easily understood as an indicator of thermal stress (Matzarakis *et al.,* 1999).

Unpleasant climatic conditions and less comfortable urban environments associated with the UHI phenomenon are becoming very common in the cities in Turkey regarding the level of urban development over the last decades (Adıgüzel, 2018). Izmir Metropolitan City is no exception in this process. Izmir underwent a significant urbanization over the last couple of decades and lost much of the open-green spaces and natural areas (Hepcan, 2013). The central districts of İzmir, such as Bornova have become more densely urbanized with less urban green spaces and more tall apartment buildings (Hepcan, 2013). Naturally, this process resulted in a serious UHI problem and created uncomfortable microclimatic conditions for humans in the city (Adıgüzel, 2018). The problem is that the topic of UHI and thermal comfort provided by green areas are not widely studied and documented both in Turkey and Izmir. Consequently, there is a considerable gap in this field in the country.

In this study initially it was assumed that green areas within the urban landscape of the Bornova district would create more favorable micro-climatic conditions for human comfort. To test this hypothesis a study was designed to analyze the impact of three different urban green areas on human thermal comfort in Bornova. The study measured some climatic parameters within the parks and their immediate surroundings/built-up areas. The measurements were analyzed and interpreted according to the Physiological Equivalent Temperature or PET index and the mean radiant temperature (T_{mrt}) (Matzarakis *et al.,* 1999; Cohen *et al.,* 2012).

The urban green areas were investigated in a typical hot summer month (July 2017) in order to determine their planting design to provide more desirable climatic conditions for humans in a dense urban setting.

Material and Method
Study Area

The study area which is composed of three urban green spaces (Aşık Veysel Recreation Area, Ege University Housing Campus and The Garden of Olive Research Institute) and built-up areas in their immediate surroundings in the district of Bornova in the İzmir Metropolitan area, located at 38°27'46'' N and 27°14'39'' E (Figure 1). Bornova is situated on an alluvial plain at the east end of İzmir bay and has a semi-arid climate (Mediterranean climate) with hot and dry summers and mild-rainy winters according to "Erinç climate classification". The climatic conditions of Bornova are a result of the different air masses that depend on the façade systems, physical geography factors and urbanization (Doygun, 2012). Precipitation is mostly concentrated in fall and winter. July has been identified as the hottest month by long term temperature measurements. The daily average maximum temperatures are around 34°C and daily minimum temperatures are around 21°C. The wind regime is influenced by the topographic conditions and the annual average wind velocity is 3.5 m/s (Karadaş, 2012).

In order to serve the purpose of this study, three urban green areas with different characteristics and vegetation patterns in the Bornova district were selected. All study areas are surrounded by high-density built-up areas (Figure 1).

The Ege University Housing Campus (Park 1; 54.000 m^2): covered by medium-sized and medium-density shading trees (mainly *Pinus pinea* and *Pinus brutia*) and located in a residential neighbourhood on the eastern part of the Bornova district. Approximately 48% of the area is covered with trees while nearly 41% is covered with grass and 3% is covered with impermeable surfaces.

Aşık Veysel Recreation Area (Park 2; 21.000 m^2): covered by grass, deciduous and evergreen trees, partly shaded, surrounded by high-density residential areas and highway connections and located

in a residential neighbourhood at the northwest of the city. 19.72% of the area is covered with trees, 26.76 % is covered with grass and 31.24% is covered with impermeable surfaces.

The Garden of Olive Research Institute (Park 3; 15.000 m²): covered by dense medium-sized Olive trees along with a few deciduous and evergreen trees, mostly without shade and located in a residential neighbourhood at the southwest of the city. 34.76% of the area is covered with trees, 18.46% is covered with lawn areas and 27.79% is covered with impermeable surfaces.
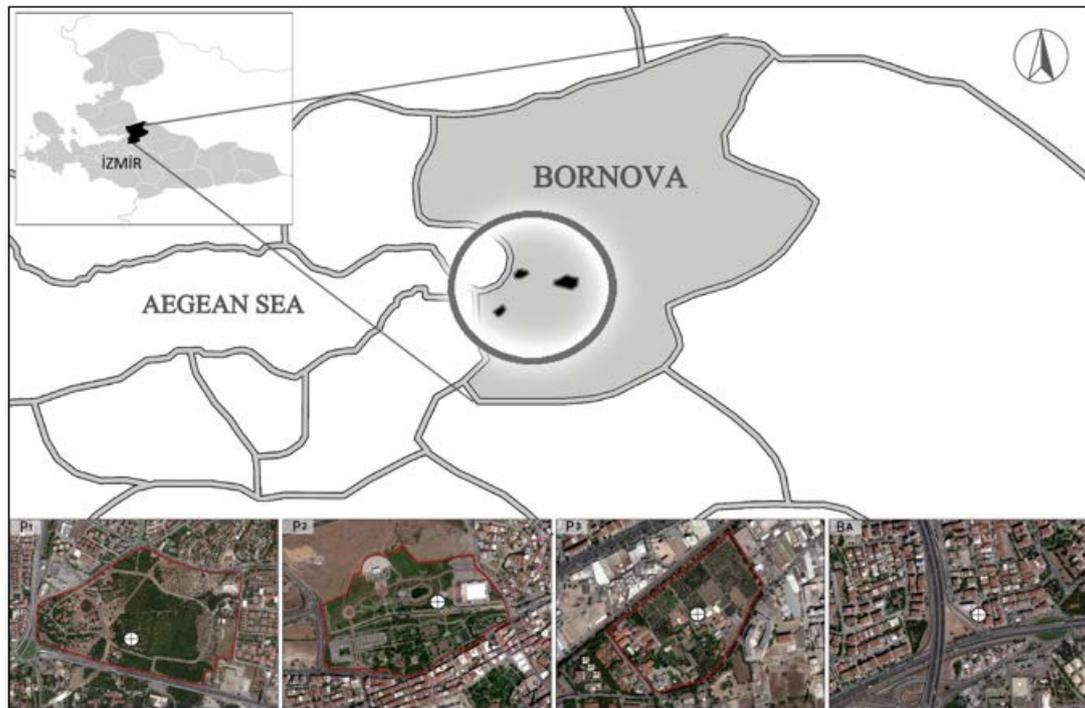

Figure 1. Location of the Bornova district and study areas

Method

The method of this study is composed of two parts; (1) the setting up of fixed meteorological stations and collecting data and (2) calculating and analysing of the human thermal comfort conditions by the data collected from the stations according to the Physiological Equivalent Temperature or PET index and the mean radiant temperature (T_{mrt}) (Matzarakis *et al.,* 1999; Cohen *et al*., 2012).

Measurement and data collection

Four fixed (Aero Skywatch) automatic meteorological stations were established in the study area (in each green area and in the built-up area in their immediate surroundings). The meteorological stations measured temperature, relative humidity and wind velocity at a height of 2 m. In each station meteorological data were measured every 10 minutes with a daily average of 144 data is recorded by the electronic data logger. The mean for July was calculated from the data compiled. The study was conducted in July in 2017, during typical summer weather conditions; clear skies, high temperatures and high relative humidity.

Data analysis

In this process the PC modelling program RayMan was used (Matzarakis *et al.,* 2000, Matzarakis, 2002). RayMan allows the calculations of the radiation flux within urban structures on the basis of parameters (air temperature, air humidity, degree of cloud cover, time of day and year, albedo of the surrounding surfaces and their solid-angle proportions) (Matzarakis *et al.,* 2000, Matzarakis, 2002). The model requires the following constants; body surface area which was standardized to 1.9 m², which represents a human who is 1.75 m tall and has a body weight of 75 kg (Höppe, 1999) and internal heat production: 80W, heat transfer resistance of the clothing: 0.9 clo (according to Matzarakis & Mayer 1997). The main advantage of the RayMan is that it facilitates the reliable determination of the microclimatological modifications of different urban environments (Gulyás,

2005). Matzarakis & Mayer (1997), divided the physiological equivalent temperature into nine grades to represent different levels of human comfort (Table 1).

Table 1. Relation of PET, thermal perception and Grade of Physiological stress (Matzarakis & Mayer 1997)

PET ºC	Thermal perception	Grade of physiological stress
<4	Very cold	Extreme cold stress
4 to 8	Cold	Strong cold stress
8 to 13	Cool	Moderate cold stress
13 to 18	Slightly cool	Slight cold stress
18 to 23	Comfortable	No thermal stress
23 to 29	Slightly warm	Slight heat stress
29 to 35	Warm	Moderate heat stress
35 to 41	Hot	Strong heat stress
>41	Very hot	Extreme heat stress

Matzarakis *et al.,* (2000) defined T_{mrt} as "the uniform temperature of a surrounding surface emitting black-body radiation (emission coefficient $€ = 1$)". T_{mrt} is "the temperature of surfaces surrounding a person and also a measure of the radiant heat exchange between a person and his surrounding" (Potcher *et al.,* 2006).

Findings and Discussion

The findings showed that every green area developed different micro-climatic conditions for human thermal comfort during the measurement period. It is probably because they are quite different in terms of land cover characteristics, plant cover type and wind velocity during the measurement period. It is also worth mentioning that the characteristics of the neighbouring urban surfaces of the studied green areas were different. Surrounding urban surfaces are very important because Coutts *et al.* (2012) emphasized the importance of the surrounding urban landscape and stated that PCI intensity is determined not only by the characteristics of the park, but also by the characteristics of neighbouring urban surfaces. To be able to explain the reasoning behind the different performances of the green areas in this study in terms of thermal comfort, the PET and T_{mrt} values of each green area are being looked at in detail as follows;

Park 1 is the largest green area in this study with a very dense cover of coniferous trees with nearly half of the area covered by trees. In the area, the measured wind velocity was extremely weak with 0.1 m/s during the studied period. The wind velocity dies down here due to very dense tree cover and naturally the heat is trapped inside the area. It is the mostly likely reason why the highest PET values of 40.6 ºC were calculated in this green area between 13.00 and 17.00. Contrary to the findings of this study, Cohen *et al.* (2012) found that an urban park with a dense canopy of trees has maximum cooling effect during the summer in the daytime in Tel Aviv, Israel. But, what made the difference here is the wind velocity because even the lowest wind velocity recorded in the parks in Tel Aviv was still remarkably higher than the one recorded in park 1. Matzarakis & Mayer (1997) stated that the most influential climatic variable impacting PET on hot summer days with low wind speed is T_{mrt} (cited in Matzarakis *et al.,* 1999). As a matter of fact, the T_{mrt} values were high as well, reaching 48.8ºC in this period in the study. However, it is important to add that T_{mrt} values were lower than other study sites. The lowest PET values (22.2-23.7ºC) in this park were calculated between 02.00 and 06.00 in line with the T_{mrt} values that increased suddenly with sunrise and decreased after sunset (Figure 3).

It is interesting to note that the more comfortable PET values were calculated in park 2 during the measurement period even though just 20% of the area is covered by trees. Park 2 is one of the biggest urban parks in the district of Bornova. It is surrounded by high density residential areas at the North and East. It also includes a stream that creates a natural wind corridor that corresponds with the dominant local wind direction in the area. The wind velocity is 4.0 m/s, which is the highest compared to other study sites. Likewise, Yang *et al.* (2016), suggested that the presence of water surfaces plays an important role in the cooling effect. In addition, "neutral (comfortable)" comfort range was noted longer than in other sites (from 21.00 to 08.00). The lowest PET values or the most comfortable conditions with 17.7-18.1ºC were calculated between 03.00 and 06.00. It is worth mentioning that

most of the trees in the area are wide canopy trees with large leaf surfaces. According to Potcher *et al.* (2006) an urban park that contains high trees with a wide canopy has the maximum cooling effect during the daytime and reduces temperatures by up to 3.5°C (Potcher *et al.,* 2006). It is interesting to mention that very high T_{mrt} values such as 55.7°C were calculated in park 2. This seems to be contradictory with the statement of Matzarakis *et al.* (1999). But, it may be explained with the higher wind velocity recorded in the park during the day.

Park 3 is the Garden of Olive Research Institute. It represents a totally different type of a green area in Bornova. It is mainly covered by olive trees with very few other landscape plants and lawn areas. Since olive trees are kept very well-trimmed all year around and have a wide open canopy for better harvesting, shading of direct solar radiation by tree crowns is not as high and effective as the other types of trees. Consequently, between 13.00 and 17.00, the highest PET values of 40.8°C were recorded in this park and that indicated a heat load of greater intensity for humans within the area as stated by Matzarakis *et al.* (1999). This also suggests strong heat stress conditions for humans in the park (Table 1). High PET values were accompanied by high T_{mrt} values that reached 53°C in the park (Figure 3). That is consistent with the strong influence of T_{mrt} over PET scores. Cohen *et al.* (2012) stated that T_{mrt} is more dominant at exposed urban sites than compared to shady urban parks, which is the case in park 3 that suffers from the lack of shady natural conditions. Additionally, dominance of lawn areas in park 3 is another variable that negatively contributed to higher PET values and less comfortable conditions for humans. According to Potcher *et al.,* (2006) parks for instance, with grass and only a few low trees were found to be warmer than the surrounding built-up areas and other park types, especially during the day, and have a negative effect on human climatic comfort. The measured wind velocity in the park 3 was somewhat high with 3.2 m/s in the studied period. This may explain why relatively similar PET scores with park 1 were obtained in this park during the day and night.

It is important to look at all the study areas together in order to come up with a more comprehensive picture. During the early hours of the morning (between 07.00-08.00), the PET values were comfortable in only Park 2, while in Park 1 and Park 3 the PET values were defined as slightly heat stress (between 23°C and 29°C). It is fair to say that along with increasing solar radiation, the comfort levels have decreased in all areas. Between 09.00 and 12.00 the highest PET values (between 29°C and 35°C) were calculated in Park 1. In addition, the comfort level in Park 2 and in Park 3 was somewhat similar (Figure 2).

Between 13.00 and 16.00, the PET values in all parks indicate a hot situation (between 35 and 41°C), while in the built-up area the PET values were one level higher (>41°C). The Pet values decreased in all areas with sunset. Before midnight (from 21.00 to 24.00), Park 2 and Park 3 were more comfortable than Park 1. In addition, the PET values in built-up areas were defined as slightly heat stress (between 23°C and 29°C). The lowest Pet values in this period were calculated in Park 2 (Figure 2). After midnight (between 03.00 and 06.00), the Pet values were comfortable in all stations (between 18°C and 23°C).
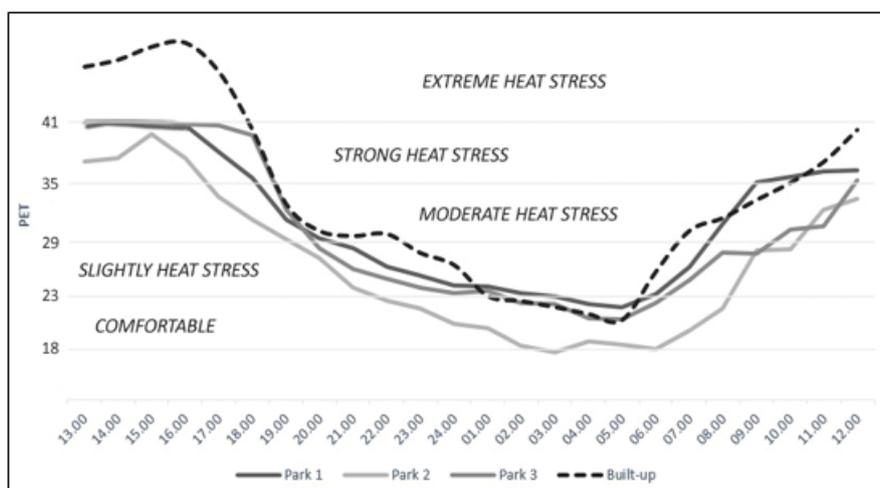

Figure 2. Hourly heat stress values according to the PET index in the different park types and in their surrounding built-up area during the measurement period (July 2017)
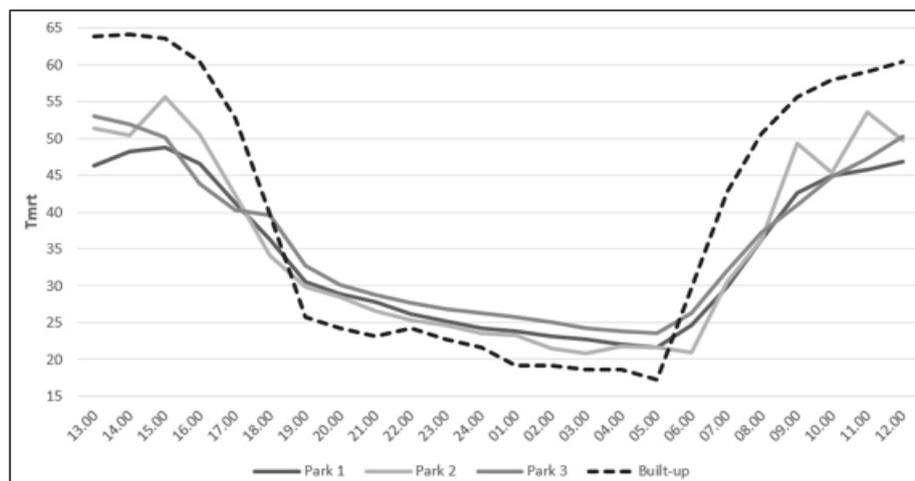
Figure 3. Hourly changes of T_{mrt} values in the different park types and in their surrounding built-up area during the measurement period (July 2017)

Conclusions

The hypothesis of this study was that green areas within the urban landscape of the Bornova district would create more favourable conditions for human comfort. This initial assumption was tested and somewhat confirmed in the present study using PET and T_{mrt} indexes because PET is very well suited to the human bio-meteorological evaluation of the thermal component of different climates (Matzarakis *et al.,* 1999).

Overall findings showed that a green area (park 2 for instance) with good ventilation and deciduous tree cover with large leafs has a positive effect on human comfort during most hours of the night. The results emphasized the importance of wind velocity, plant (tree) cover type and the characteristics of neighbouring areas as effective tools for human comfort and well-being.

Although the cooling process is quite complex and affected by the species of plants, water coverage, and surrounding features (Yang *et al.,* 2016), from the physical planning perspective, the most important intervention to be made is to increase the number of large urban green areas and spread them throughout the city evenly, and provide linkages between them by green/cooling corridors. When it comes to the design of urban green areas that provide more desirable climatic conditions for humans in a dense urban setting, this boils down to five key measurements; **1**) high and wide-canopied trees with large leafs should be dominant and cover large areas in the urban parks, **2**) water bodies should be created and/or kept in their natural states in the park areas, **3**) wind corridors should be designed towards dominant wind direction, **4**) height of the buildings around the urban green areas should be limited to improve wind velocity and their configuration should be arranged accordingly, and **5**) more pervious surfaces, such as porous asphalt in the built-up areas should be created for infiltration and transpiration. In addition to the above mentioned factors it should also be remembered that the cooling effect caused by plants is much higher in the summer than in the winter. Finally, deciduous trees are the most suitable type for green open spaces in the hot and humid Mediterranean climate (Cohen *et al.,* 2012).

In conclusion, climate sensitive urban design (CSUD) or nature-based solutions embedded in urban design could be the ultimate solution to cover all the aforementioned issues in a sustainable way (Coutts *et al.*, 2012).

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