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RESEARCH

Bioclimatic comfort difference with the effect of urbanisation: the case of Uşak city, Turkey

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Abstract

Rapid human population increase in cities following industrial revolution caused irreversible changes in the physical structure of urban areas by increasing the rate of built-up surface to an unprecedented level. Both the altered physical environment and dense anthropogenic activities in the cities affected also atmospheric environment and climate characteristics in the cities. Today, more than half of the world population lives in cities while nearly 70% is estimated to live in cities by 2050. Turkey's industrialisation and urbanisation process followed a similar way and cities faced a rapid and distorted urbanisation after especially 1950s. Today, over 80% of Turkish population lives in urban areas. Therefore, dwellers in Turkish cities are exposed to unfavourable bioclimatic conditions both due to existent and future urban climatic characteristics and the density of anthropogenic activities. This study is dealt with the effect of urbanisation on bioclimatic comfort conditions in Uşak, a medium-sized Turkish city, between the Aegean and the Central Anatolia regions in the western part of the country, where Mediterranean transitional climate characteristics are dominant and population increases. In the study, 14-year hourly data obtained from two meteorology stations located in urban and rural areas were used to calculate bioclimatic comfort values using PET (Physiological Equivalent Temperature) index and RayMan software. As a result of the study, the urban area was found to be warmer than the rural (2.4 °C, 1.6 °C and 2.2 °C on the average, maximum and minimum PET values). Urban area is exposed to 5.9% and 28.0% more heat stress than rural throughout the year and during the summer period, respectively. As a result of the study, suggestions were made to make landscape designs that take into account the physical geographical conditions for current and future urbanisation movements in order to optimise bioclimatic comfort conditions in cities. In this context, in order to improve the bioclimatic comfort conditions in the city, expanding the areas covered with soil and plants, creating artificial water areas, implementing roof garden applications, vertical and horizontal planting works, and creating wind corridors are some of the suggestions. It is thought that the determined suggestions will contribute to the slowing down of climate change on a global scale, as well as providing bioclimatic comfort in cities.

1 Introduction

Climate is the long-term average conditions of weather at a point on the earth (according to the World Meteorological Organisation 30 years) (Türkeş 2017). Climate has direct effects on the human body and potential and constraining functions for human activities like production, travel and architecture. The relationship between the conditions of the human body (physiological, psychological and health conditions) and atmospheric environment where the human body is exposed to solar radiation, climate elements (e.g. temperature, relative humidity, wind) and pollutants is evaluated within the scope of bioclimate (WMO 1999; Matzarakis et al. 2000; Akman 2011). The atmospheric environment has combined effect on humans outdoors where they express their (dis) satisfaction with the ambient conditions (ANSI/ASHRAE 2004). In the

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heat exchange that occurs as a result of human interaction with the environment, heat transfer from the environment to the body occurs if the temperature of the environment is higher than the temperature of the human body, and heat transfer from the body to the environment occurs if the temperature of the environment is lower than the temperature of the body (Atalay 2010; Lai et al. 2017). When the human body is exposed to cold or heat, it sends signals to the brain and keeps the body temperature in balance with a number of physical reactions. This situation refers to human exposure to hot or cold stresses. Bioclimatic comfort is defined as a situation in which people are not stimulated or stressed by climatic conditions in the environment (Toy 2010; Çağlak 2021). In other words, it is a state of thermally uncomfortable or neutral discomfort between uncomfortable heat and uncomfortable cold (Parsons 2003). Uncomfortable bioclimatic conditions may adversely affect physiological and psychological conditions, work efficiency, cause higher rate of energy consumption, heat strokes and increase in mortality rates (Vanoz et al. 2010; Nastos and Matzarakis 2011; Nastos et al. 2013; Blazejczyk et al. 2018; Schlegel et al. 2020; Çağlak 2021). Urbanisation is among the most influential anthropogenic activities on microclimatic characteristics because it has multifactorial deteriorating effects on atmospheric environment by altering land-use types (from natural surfaces into impervious ones), emitting greenhouse gases and particles which store solar radiation to cause extra heating and producing waste heat from industrial and housing areas and motor vehicle traffic (Demircan and Toy 2019). Climate change and anthropogenic activities are affecting the entire earth, where urban areas are not an exception, being affected by extreme weather conditions and environmental disturbances. Urban expansion and industrial development have negatively affected the local climatic condition due to green space deficiency, soil moisture loss, soil erosion, land subsidence, high runoff and low infiltration rate (Bijay et al. 2022).

Especially in unplanned and over populated urban areas, local climates are hotter, drier, calmer (less windy) and sultrier compared to those prevalent in rural areas (Grimmond 2007). As the size and density of structured urban areas increase, their adverse effects also intensify on humans including their poor thermal and liveability conditions and thus the quality of life especially in hot regions and periods of a year (Öngel and Mergen, 2009; Georgia and Dimitriou 2010). Reduction of bioclimatic comfort conditions can be seen in cities planned by ignoring ecological elements. In this respect, the effect of urbanisation on human thermal comfort conditions is notable since urban environment shows totally different climatic characteristics which impact negatively human thermal comfort conditions causing larger heat stress and uncomfortable areas. In order to create more liveable cities harbouring better planned and managed sites including landscape and recreational areas, there is a requirement to understand the relationships between climatic elements and human thermal environments in especially cities (Dear and Brager 2001; Toy and Yılmaz, 2009). There is an increase in the number of studies conducted over the last years on urban heat islands and their mitigation strategies (Karimi et al. 2022). In mainly warmer regions, where the effect of urbanisation intensifies (in the form of urban heat island UHI) on climatic elements in mostly summer months, studies on human thermal comfort are majorly carried out in the summer period (Spagnolo and Dear 2003; Cheng et al. 2012; Johansson et al. 2018). The release of pollutant gases and particles into the atmosphere due to the use of fossil fuels in cities, more energy consumption in parallel with population density, impermeability of surfaces, insufficiency of moisture sources, loss of rainwater by surface runoff and scarcity of open green areas cause cities to heat up more than rural areas (Karimi et al. 2021). Depending on the factors mentioned above, meteorological parameters may change in cities and different microclimatic areas can be seen in cities. These climatic differences in cities are defined as 'urban heat island' (UHI) (Yüksel and Yılmaz 2008).

Numerous studies reveal that the climate characteristics of cities have changed negatively depending upon the decrease in green areas and soil-covered surfaces in cities (Barış 2005; Çiçek and Doğan 2005; Şimşek and Şengezer 2012; White and Kimmi 2015; Çağlak and Toy 2023). These unfavourable conditions cause cities to have more uncomfortable conditions than the surrounding rural areas. This situation was observed in the central European cities of Szeged (Hungary), Munich (Germany), Warsaw (Poland), Łódź (Poland) and the northern European city Gothenburg (Sweden) (Mayer 1993; Unger 1999; Fortuniak et al. 2006; Blazejczyk et al. 2018). The same situation was observed in the St. Lawrence Lowland (Canada) and Borrow (Alaska) cities which are in the American continent (Oke 1973; Hinkel et al. 2003). Negative comfort conditions were also experienced in Turkish cities due to factors such as unplanned urbanisation, agricultural areas being zoned for construction, destruction of natural areas, industrialisation, waste and increase in fossil fuel consumption with the increasing rural to urban migration movements in Turkey after the 1950s. It has been stated that negative comfort conditions are experienced due to urbanisation in cities such as Erzurum city in the north-east of Turkey (Bulut et al. 2008; Toy and Çağlak 2018), in the cities of Ankara and Eskişehir in the Central Anatolia Region (Çalışkan and Türkoğlu 2014; Toy et al. 2021), in the cities of Samsun and Bolu in the Black Sea Region (Çağlak 2017; Çağlak et al. 2021), and in the cities of Aydın and İzmir in the Aegean Region (Kestane and Ülgen 2013; Tonyaloğlu 2019).

The aim of the study is to determine the effects of urbanisation on bioclimatic comfort conditions in the city of Uşak, which is exposed to rapid and unplanned urbanisation. The city of Uşak is located in a position that provides the transition from the Central Anatolia Region of Turkey to the Aegean Region. Thanks to its proximity to the capital of the country and important tourism regions, it is in a position to receive migration. Due to these factors, it is important to determine the bioclimatic comfort of the city and recommendations for its sustainability. In the study, 14-year hourly data obtained from two meteorology stations located in urban and rural areas were used to calculate bioclimatic comfort conditions through RayMan software and one of the most commonly used indices, PET (Physiological Equivalent Temperature). In terms of bioclimatic comfort, the difference between urban and rural areas was tried to be revealed.

2 Material and method

Determined as a field of study, the city of Uşak is located at an altitude of 800–1000 m in the Central West Anatolian part of the Aegean Region, on the western edge of the Inner West Anatolian threshold, where the Aegean Region and Central Anatolia are separated from each other, between latitudes 38° 13″ and 38° 56″ and longitudes 28° 48″ and 29° 57″ (Fig. 1). The İzmir-Ankara highway built in 1966 was effective in the development of the city (Bilgen 1999). The textile and leather industry that developed in Uşak after 1970 caused the migration from rural to urban areas to accelerate, resulting in the expansion of the urban area (Yasak 2014). While the total population of Uşak city was 110,255 people in 1980, it became 179,458 people in 2000. In 2022, its total population is 264,540 people and the annual population growth is 14%.The city of Uşak, which has hosted many civilisations throughout the years due to its important location, has a congested urban fabric due to its establishment on a plateau.

Located on the threshold between the Aegean Region and the Central Anatolia region, Usak has a Mediterranean transitional climate between the Mediterranean climate and the Continental climate (Türkeş et al. 2002). According to Köppen-Geiger climate classification Köppen climate classification, which defines five main climatic zones as Tropical (A), Arid (B), Temperate (C), Continental (D) and Polar (E) with various number of subgroups in each main zone represented by lower cases based on dryness (or rainfall) and temperature (Bölük 2016), the study area is located in the zone represented by Csa (Bölük 2016) which means that winters are temperate and summers are very hot and arid (Mediterranean Climate). As can be understood from the classification, the study area is exposed to thermally uncomfortable climate conditions in relatively long summers. Such conditions are expected to increase their unfavourable effects in urban areas and therefore there seems a need to assess the bioclimatic comfort conditions of the city centre.

In the city which is under the influence of the frontal systems coming from Mediterranean basin and the anticyclonic anomalies through the Balkans (Yılmaz 2004), long-term mean annual temperature is 12.5 °C (between the record minimum temperature of − 15.4 °C in January and maximum 40.2 °C in July). Annual rainfall is 557.6 mm and relative humidity is 65%. The average annual wind speed is 1.9 m/s (Table 1).

In the study, 14-year meteorological data (2007–2020) were obtained from the meteorological observation station in the city centre of Uşak (No: 17188) at an altitude of 916 m (i.e. urban station). Meteorological data were obtained from Uşak Meteorology Directorate. The second station is at Uşak Airport (No: 17185) at an altitude of 879 m (i.e. rural station). These two meteorological stations are automatic

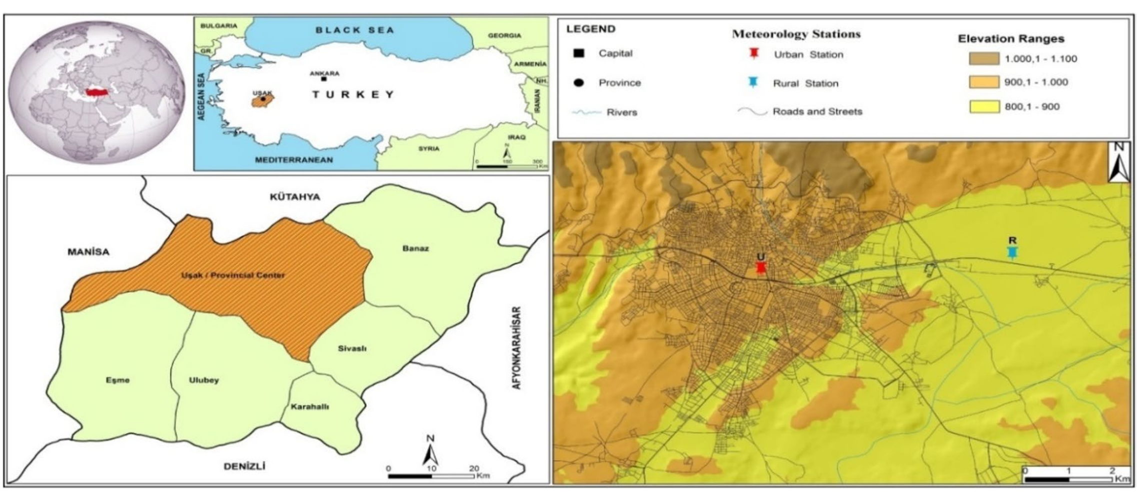

Fig. 1 Location map of the study area

Table 1 Average and extreme values for Uşak

Observation period
1960–2020 (39° 55′ N; 41° 16′ E; 1758 m)

Parameters	Value	Date/Period
Mean temperature	12.5 °C	Annual
Mean relative humidity	65%	Annual
Mean wind speed	1.9 m/s	Annual
Mean total rainfall	557.6 mm	Annual
Mean number of covered with snow	98 days	Annual
Extreme maximum temperature	40.2 °C	11.07.2000
Extreme low temperature	− 15.4 °C	21.01.2000
Highest rainfall in a day	64.3 mm	23.04.2000
Highest snow thickness	35 cm	13.01.2004
Fastest wind speed	26 km/h	16.04.1984

observation stations and record hourly measurements. The distance between the two stations is approximately 6 km (Fig. 2). The urban station is located in the built-up area in the city centre while the rural station is surrounded by open vast plain. The characteristics of the meteorology stations are given in Table 2. In the study, hourly air temperature (Ta; °C), relative humidity (RH; %), wind (Wv; m/s) and cloudiness (octa) data were taken from these two stations.

In order to assess the thermal bioclimatic ambience, the meteorological variables (i.e. air temperature, relative humidity, wind speed and solar radiation) are used together with the human thermo-physiological characteristics (Fanger 1972; VDI 1998). Therefore, among the indices (simple and complex) developed for the determination bioclimatic comfort conditions, those which are more comprehensive and take the features of the human body (e.g. clothing insulation, work load, age) are accepted to evaluate the conditions more elaborately. In this respect, physiologically equivalent temperature (PET) index is among the complex bioclimatic

Fig. 2 Land use characteristics of the meteorology stations used in the study

Table 2 Meteorological stations used in the study and their features

Represent area	Longitude (east)	Latitude (north)	Altitude (m)	Surface
U (urban)	29° 24′	38° 39′	916	Dense structured
R (rural)	29° 28′	38° 40′	879	No structure

comfort indices capable of considering both meteorological elements and human body characteristics and giving understandable and comparable results. PET adopts the approach of human energy balance, where the sum of *M* (metabolic energy production), *W* (energy from physical work), *Rn* (net radiation of the body), *L* (convective heat flow), *QL* (heat flow through the skin), *QSW* (sum of heat flows for heating and humidifying the inspired air), *Qre* (heat flow due to evaporation of sweat) and *S* (storage heat flow for heating or cooling the body mass) is equal to zero. Based on the mentioned equation, PET incorporates required meteorological variables and human body parameters into one bioclimatic value (Matzarakis et al. 2010). PET is among the most widely used four human thermal indices (Potchter et al. 2018), number of which has reached 165 over the past century (de Freitas and Grigorieva 2017).

In the study, the PET (Physiological Equivalent Temperature) index was used, which calculates human bioclimatic comfort depending on the body heat energy balance and meteorological conditions and takes into account all the effects of the thermal environment on humans and the thermophysiological conditions of the human body as separate values (Matzarakis et al. 1999; Gulyas et al. 2006). Calculations were made using the RayMan radiation model (Matzarakis et al. 2007). RayMan model can transfer all the variables which affect bioclimatic comfort by considering the effect of solar radiation (Matzarakis et al. 2007; Toy and Çağlak 2018). A 35-year-old, 175-cm tall, 75-kg, male, healthy individual with 0.9 clo clothing load (wrapping effect of trousers and blouse clothing) and 80-W workload (standing) was considered in the calculation (Matzarakis and Mayer 1996; Matzarakis et al. 1999). The comfort ranges given in Table 3 were considered in the classification of the data obtained. The comfort ranges of the PET index were used in their original form, which is accepted worldwide, for the universality of the study.

PET values are calculated hourly using hourly meteorological data. Then, its distribution throughout the year is shown in graphs at 10-day intervals. The colours in the graphs indicate thermal sensation levels. Monthly PET value differences are shown in tables and figures. In addition, the percentages of comfort ranges are also shown in figures.

3 Results

In this study, 14 years of hourly data from two meteorological stations in Uşak city and countryside was used to calculate bioclimatic comfort conditions using RayMan software and PET (Physiological Equivalent Temperature), one of the most widely used indices. In this context, the bioclimatic comfort conditions of the urban and rural stations in the study area are described in detail as average, minimum and maximum, divided into 10-day intervals from the first to the last day of the year.

3.1 Mean conditions

While ‘very cold’ and ‘cold’ stresses are seen from December to mid-February at the city station in winter, ‘very cold’ and ‘cold’ stresses are seen from mid-November to mid-March at the rural station. Besides, ‘extreme cold’ stress with freezing effects is also perceived in the rural station. Although ‘warm’ stress is dominant in the urban station during the summer season, ‘hot’ stress is also experienced. On the other hand, ‘slightly warm’ stress is dominant in summer at the rural station. While ‘comfortable’ conditions are perceived in May and October at the urban station, they are perceived from mid-May to mid-June and from mid-September to mid-October at the rural station. While ‘slightly cool’ and ‘cool’ stresses are seen at the urban station in the spring and

Table 3 Thermal sensation and stress ranges (edited from Matzarakis et al. 1999; Höppe 1999; Toy 2010; Çağlak 2021)

PET (°C)	ThermalSensation	Level of ThermalStress	Colors
< -4	Extreme Cold	FreezingColdStress	
-3.9 – 4.0	VeryCold	Extreme ColdStress	
4.1–8.0	Cold	StrongColdStress	
8.1–13.0	Cool	ModerateColdStress	
13.1–18.0	SlightlyCool	SlightlyColdStress	
18.1–23.0	**Comfortable**	**No ThermalStress**	
23.1–29.0	SlightlyWarm	SlightlyHeatStress	
29.1–35.0	Warm	ModerateHeatStress	
35.1–41.0	Hot	StrongHeatStress	
>41.0	Very Hot	Extreme HeatStress	

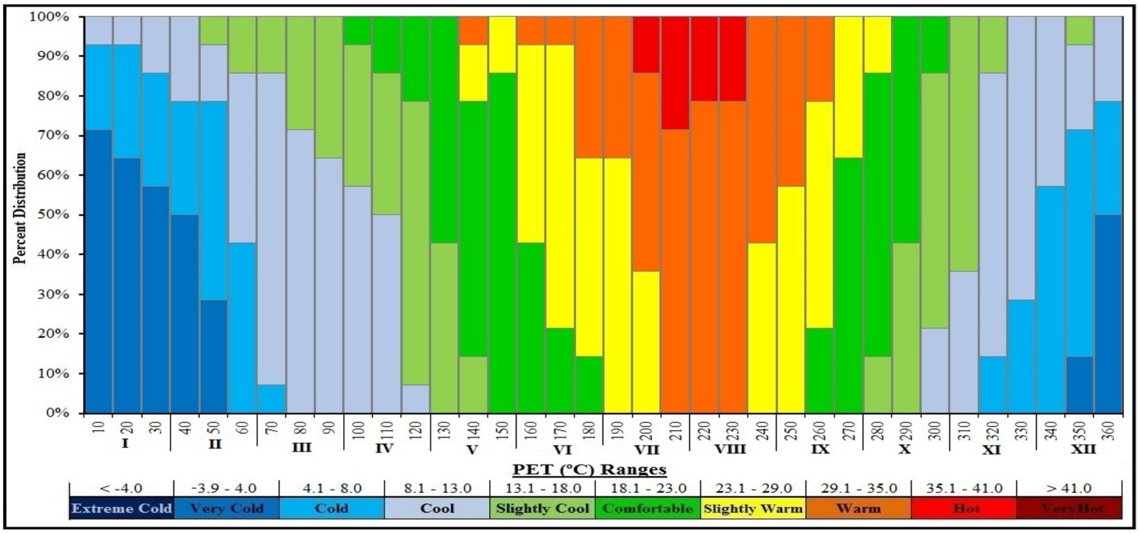

Fig. 3 Distribution of the average bioclimatic comfort conditions of the urban station

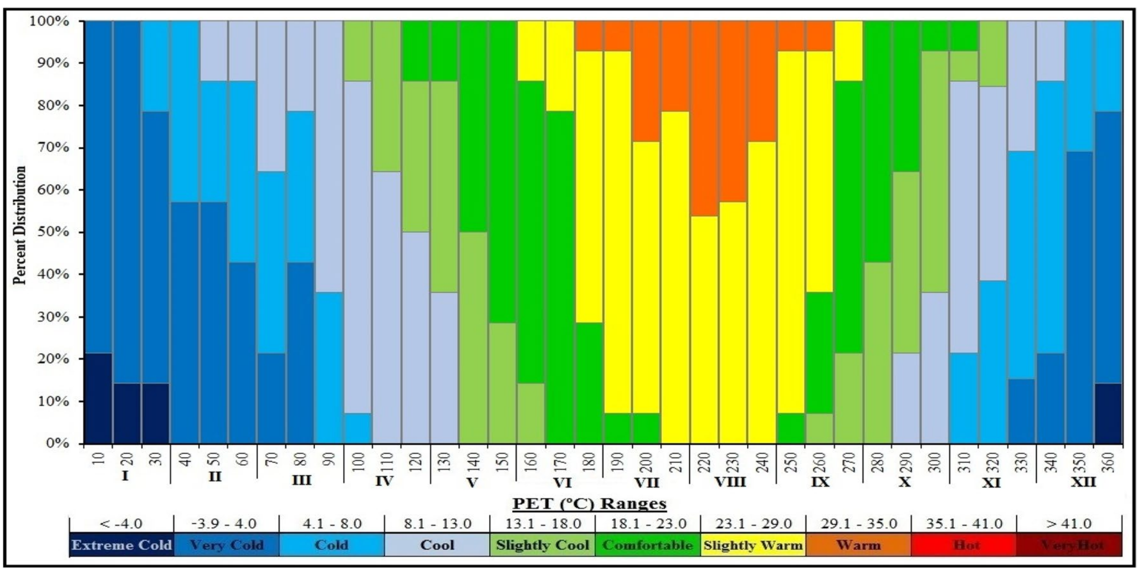

Fig. 4 Distribution of the average bioclimatic comfort conditions of the rural station

autumn seasons, which are the transitional seasons, 'cold' stresses are also seen at the rural station (Figs. 3 and 4).

When the percentage distributions of average bioclimatic comfort conditions are examined for urban station, 'very cold' stress is experienced in 9.3% of the year, 'cold' range by 10.9%, 'cool' stress by 20.0%, slightly cool by 14.1% and comfortable 15.5%, 'slightly warm' by 14.1%, 'warm' stresses by 13.7% and 'hot' stresses by 2.4% (Fig. 5). In rural stations, 1.8% of the year is 'extreme cold', 16.9% is 'very cold', 13.7% is 'cold', 16.7% is 'cool', 11.7%, slightly cool 15.3% 'comfortable' conditions are experienced in 15.3%, 'slightly warm' in 18.5% and 'warm' in 5.4% (Fig. 6).

The city station has an annual PET value of 2.3 °C higher than the rural station according to the average of PET values. The greatest difference between the city station and the rural station was in March (3.5 °C), and the least difference was observed in September and October (1.7 °C) (Table 4; Fig. 7).

3.2 Maximum conditions

According to maximum comfort conditions, while 'cold' stress is seen in January in the city station in winter and 'cool' stress is seen in other months (November and

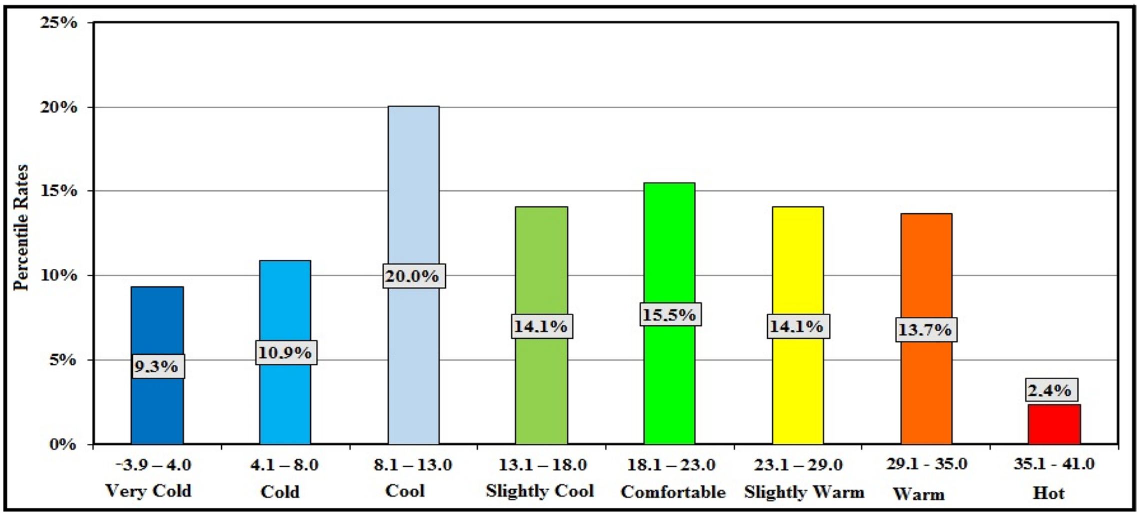

Fig. 5 Percentages of average bioclimatic comfort conditions of urban station

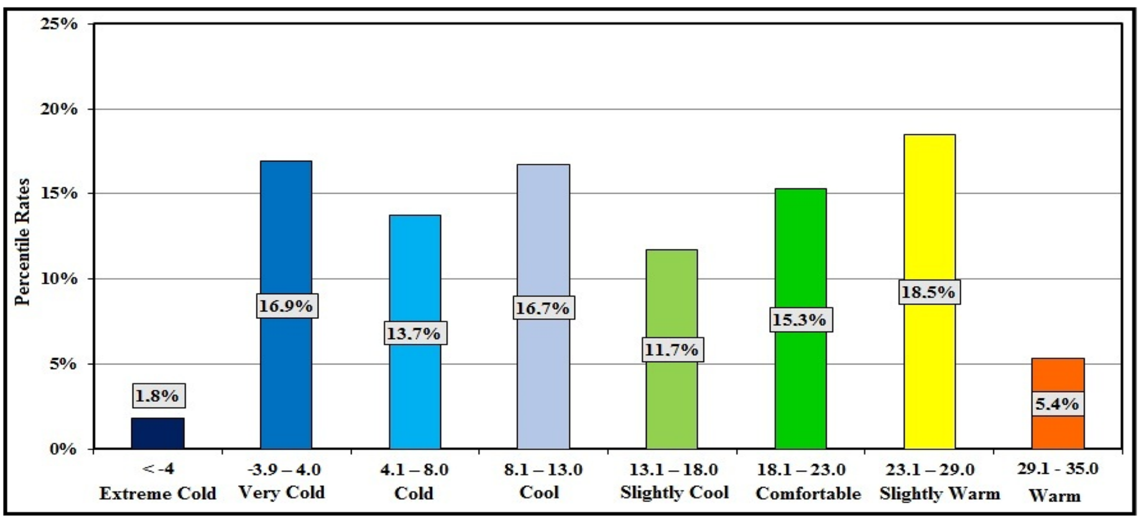

Fig. 6 Percentages of average bioclimatic comfort conditions of rural station

Table 4 Average PET values and differences of urban and rural stations (°C)

	1	2	3	4	5	6	7	8	9	10	11	12	Yearly
Urban	2.3	5.7	10.4	14.4	19.8	25.1	30	30.9	25.3	17.8	10.7	5.5	16.5
Rural	– 0.2	3.2	6.9	12.3	17.6	23	27.4	28.5	23.5	16.1	9	3.1	14.2
Δ (*U*−*R*)	2.5	2.5	3.5	2.1	2.2	2.1	2.6	2.4	1.8	1.7	1.7	2.4	2.3

December), ‘very cold’ and ‘cold’ stresses are seen in the rural station during the winter. Along with the ‘hot’ stress being dominant in the summer season in urban areas, ‘very hot’ stress is also experienced. On the other hand, ‘warm’ stress is dominant in summer at the rural station, but it also perceives ‘hot’ stress. While ‘comfortable’ conditions are perceived at the end of April and the beginning of October at the urban station, they are perceived from mid-April to mid-May at the rural station. While ‘slightly cool’ stresses are seen at the urban station in the spring and autumn seasons, which are the transitional seasons, ‘cold’ stresses are also seen at the rural station (Figs. 8 and 9).

When the percentage distributions of maximum bioclimatic comfort conditions are examined; at the urban station, ‘very cold’ stress is experienced 1.2% of the year, ‘cold’ 8.1% of the year, ‘cool’ 18.8% of the year,

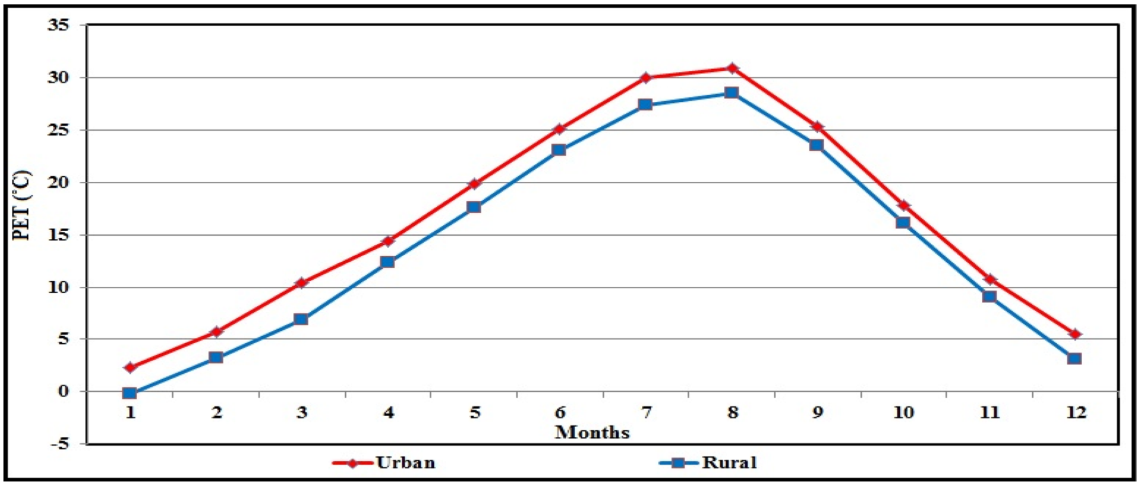

Fig. 7 Distribution of monthly average PET values of urban and rural stations

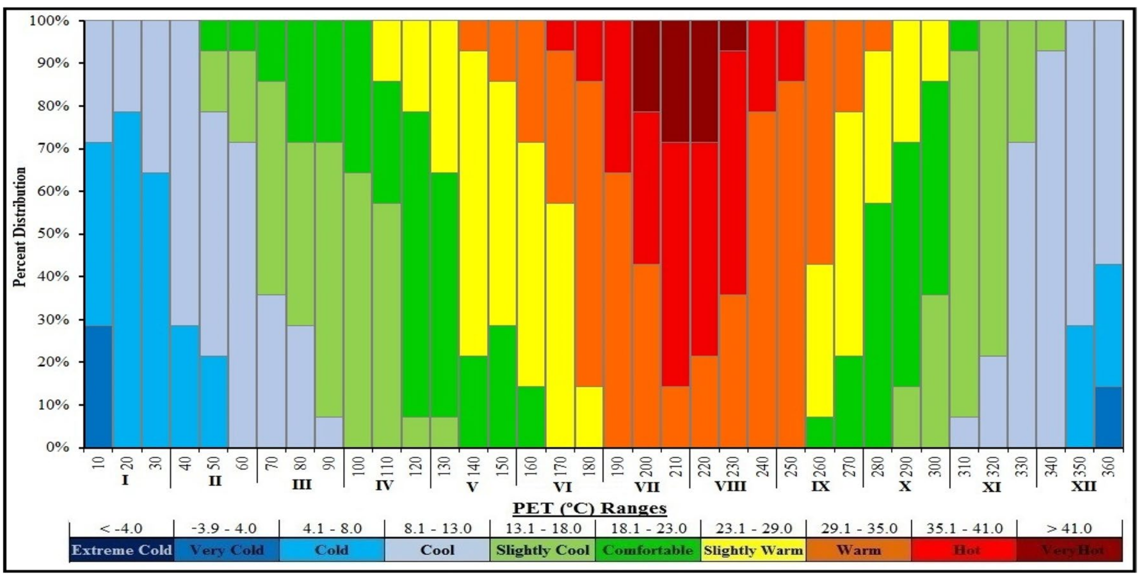

Fig. 8 Distribution of the maximum bioclimatic comfort conditions of the urban station

'slightly cool' 16.1% of the year, 'comfortable' conditions 15.1% of the year, 'slightly warm' stresses 13.9%, 'warm' stresses 16.3%, 'hot' stresses 8.1% and 'very hot' 2.4% of the year (Fig. 10). At the rural station, on the other hand, 'very cold' stress is experienced 4.6% of the year, 'cold' 12.1% of the year, 'cool' 6.3% of the year, 'slightly cool' 16.7%, 'comfortable' conditions 13.1% of the year, 'slightly warm' stresses 15.3%, 'warm' stresses 16.9 and 'hot' stresses 5.2% of the year (Fig. 11).

The urban station has an annual PET value of 1.6 °C higher than the rural station according to the average of PET values. The greatest difference between the urban station and the rural station was in July (3.0 °C), and the least difference was observed in November (0.8 °C) (Table 5; Fig. 12).

3.3 Minimum conditions

According to the minimum comfort conditions, at the urban station, 'very cold' and 'cold' stresses are observed from November to mid-March; at the rural station, 'extremer cold' stresses are observed from mid-December to mid-February and 'very cold' and 'cold' stresses from mid-February to the end of April and from November to mid-December. While 'slightly warm' stress dominates the summer season in July and August at the urban station, 'warm' stress is

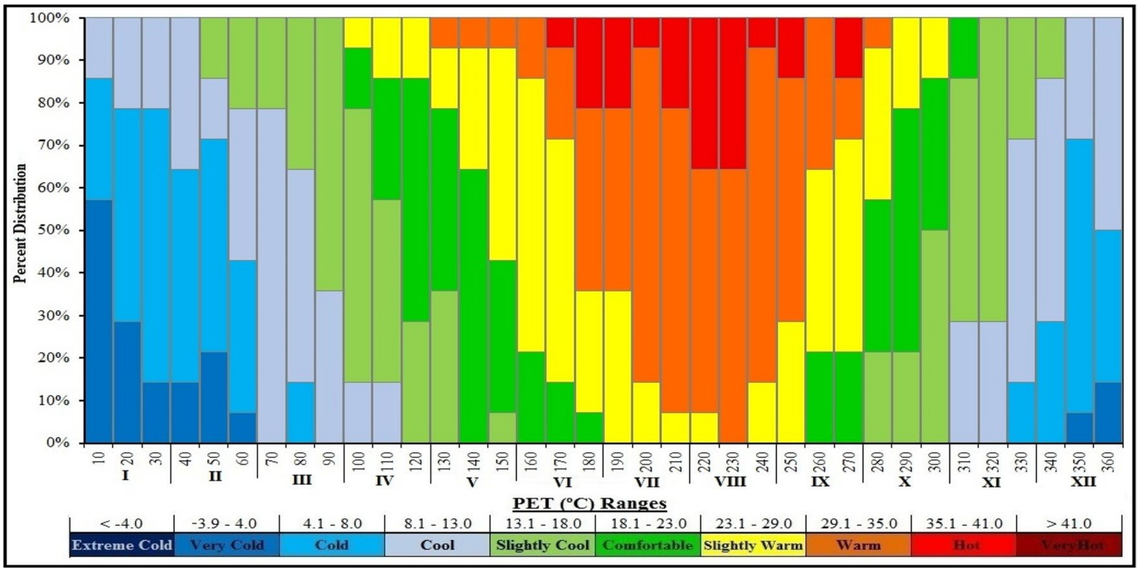

Fig. 9 Distribution of the maximum bioclimatic comfort conditions of the rural station

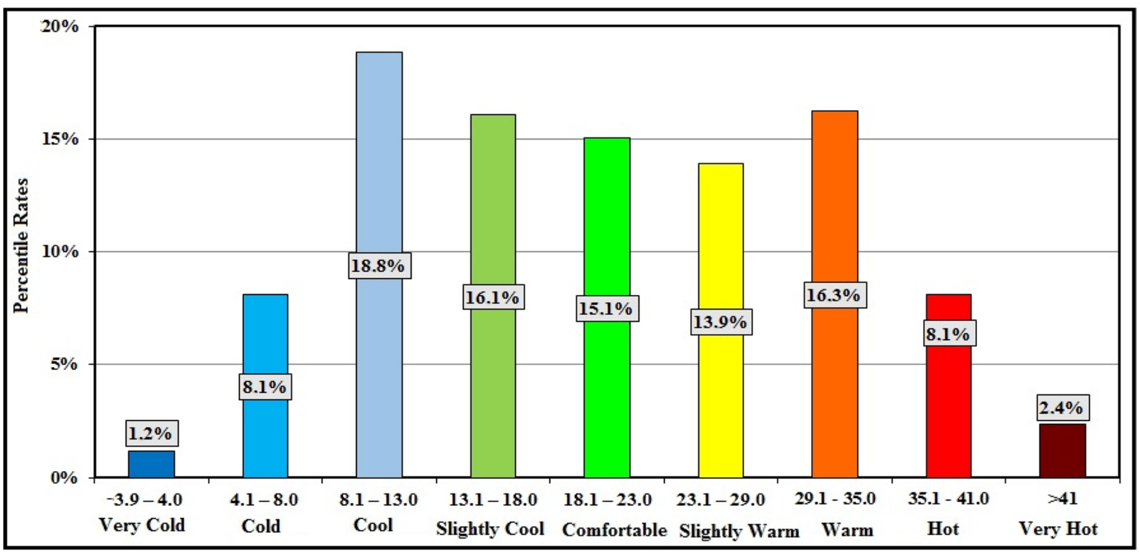

Fig. 10 Percentages of maximum bioclimatic comfort conditions of urban station

also perceived. At the urban station, during summer 'comfortable' conditions and 'slightly warm' stress take effect. 'Comfortable' conditions are experienced at the urban station in June and September, and from end of May to the beginning of September (Figs. 13 and 14).

When the percentage distributions of minimum bioclimatic comfort conditions are examined; at the urban station, 'extreme cold' stress is experienced 4.0% of the year, 'very cold' 16.7 of the year, 'cold' 13.1% of the year, 'cool' 12.9 of the year, 'slightly cool' 14.1% of the year, 'comfortable' conditions 16.9% of the year, 'slightly warm' stresses 15.3% and 'warm' stresses 7.1% of the year (Fig. 15). In rural stations, 'extreme cold' stresses are experienced 12.1% of the year, 'very cold' stresses 25% of the year, 'cold' stresses 10.5% of the year, 'cool' stresses 12.9% of the year, 'slightly cool' stresses 14.5% of the year and 'comfortable' conditions are experienced in 16.1% of the year, 'slightly warm' stresses are experienced in 8.5% and 'warm' stresses are experienced in 0.4% of the year (Fig. 16).

The urban station has an annual PET value of 2.2 °C higher than the rural station according to the average of PET values. The greatest difference between the urban station and the rural station was in March (3.0 °C), and the least difference was observed in February (1.4 °C) (Table 6; Fig. 17).

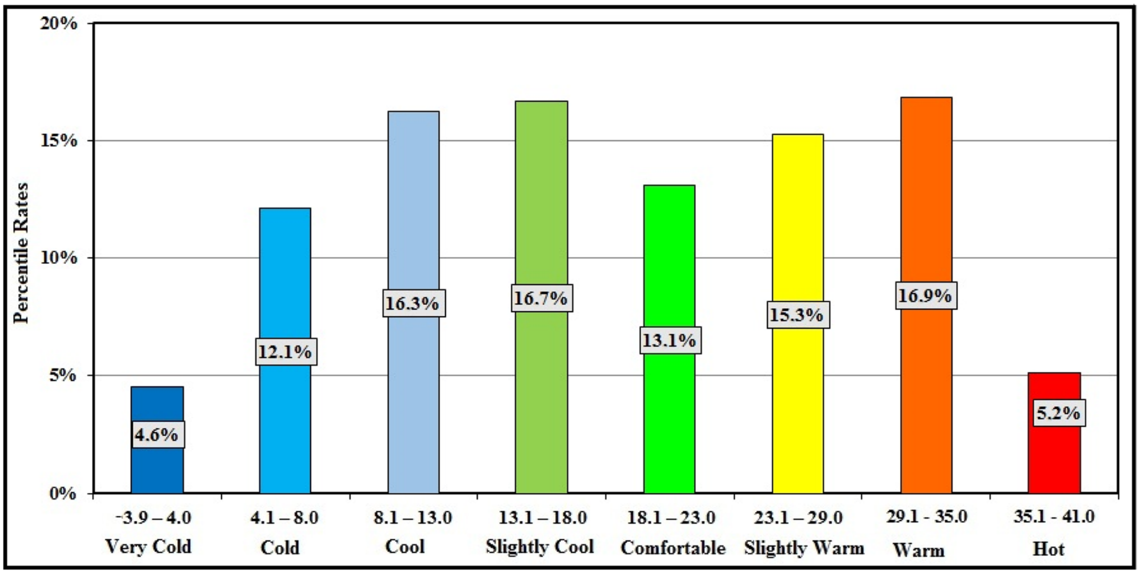

Fig. 11 Percentages of maximum bioclimatic comfort conditions of rural station

Table 5 Maximum PET values and differences of urban and rural stations (°C)

	1	2	3	4	5	6	7	8	9	10	11	12	Yearly
Urban	6.5	9.9	14.8	19.1	23.8	29.3	35.2	35	29.2	21.4	14.3	9.3	20.7
Rural	5.2	7.8	12.2	17.7	22	27.8	32.2	33	28.3	20.3	13.5	8.2	19.0
Δ (*U*–*R*)	1.3	2.1	2.6	1.4	1.8	1.5	3.0	2.0	0.9	1.1	0.8	1.1	1.6

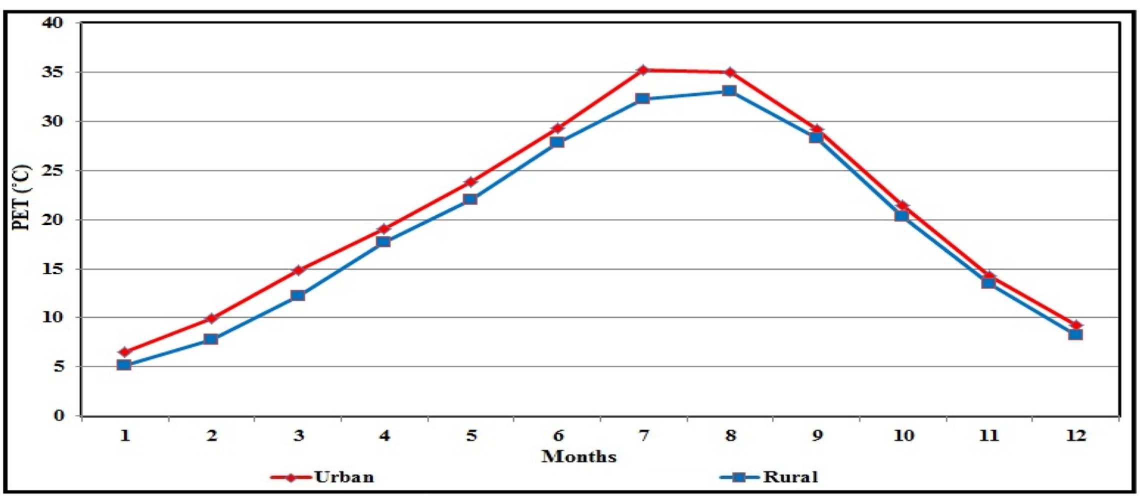

Fig. 12 Distribution of monthly maximum PET values of urban and rural stations

4 Discussion and conclusion

People are affected by the combined effects of climatic elements outdoor like temperature, relative humidity, wind velocity and solar radiation (Çağlak et al. 2023). This effect is perceived as thermal comfort and outlines the ambiences where people express their satisfactory conditions with the atmospheric environment (ANSI/ASHRAE Standard 55 from 1966 to 2015). Thermally comfortable conditions express the environment or time period where people feel no discomfort about the thermal conditions or

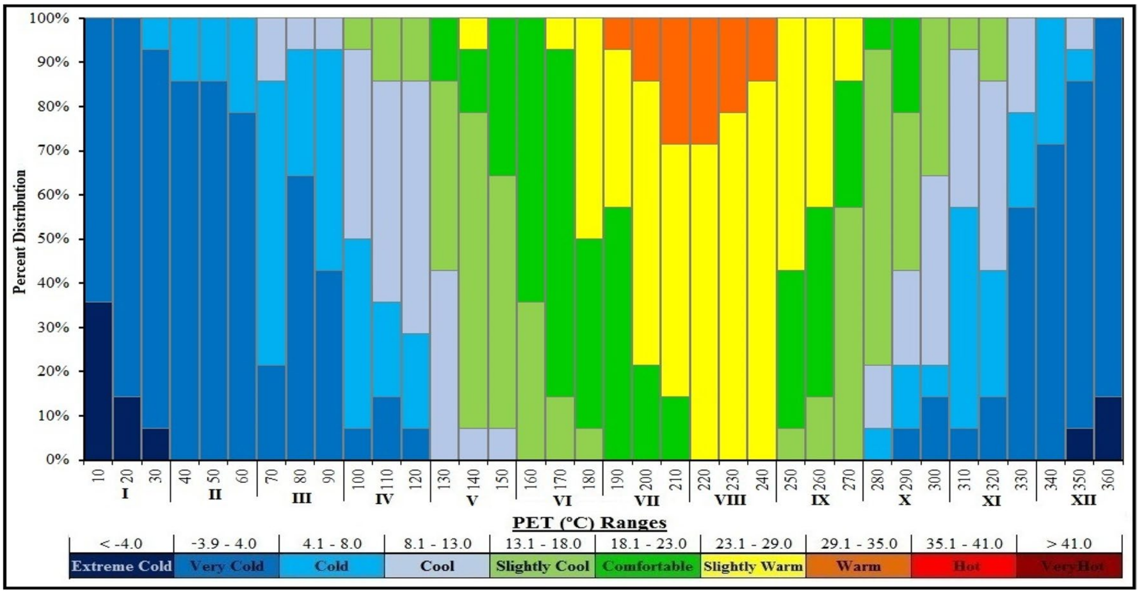

Fig. 13 Distribution of the minimum bioclimatic comfort conditions of the urban station

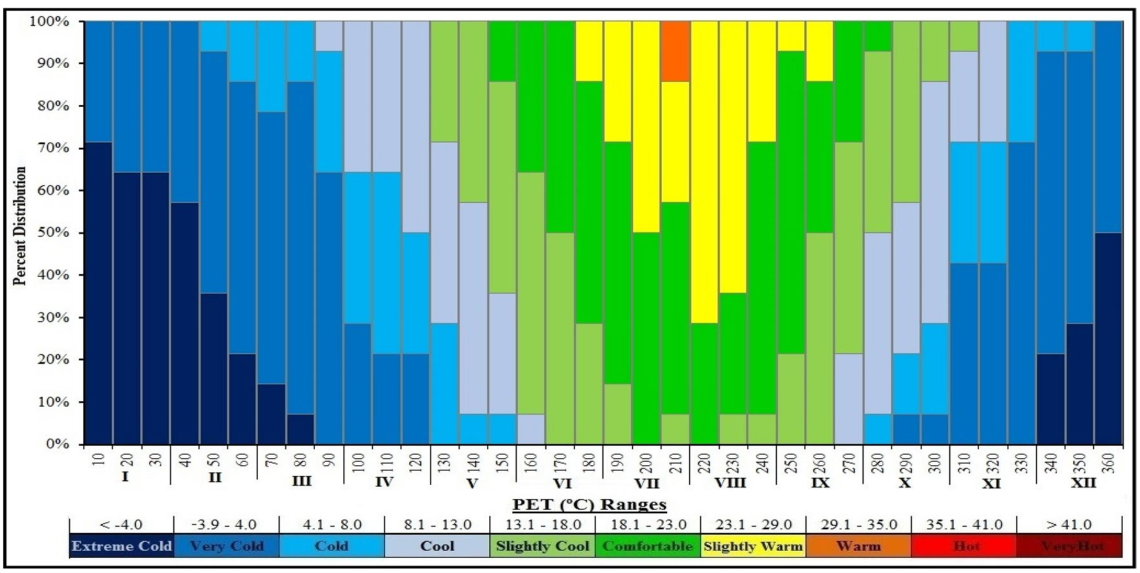

Fig. 14 Distribution of the minimum bioclimatic comfort conditions of the rural station

need no action for the adaptation of their body temperature in the surrounding environment (Lai et al. 2017; Çağlak 2021; Çağlak et al. 2023). Under unfavourable thermal conditions, people can experience various health problems like fatigue or chronicle diseases or lose work performance (Nastos et al. 2013; Blazejczyk et al. 2018; Konefal et al. 2020; Çağlak 2023).

This study examines how the urbanisation affects the bioclimatic comfort conditions in Uşak which is a medium-sized Turkish city on the threshold between Turkey's Aegean Region and Central Anatolia region that experiences Mediterranean Transition Climate. As a result of the study, it has been found that the bioclimatic comfort conditions in the urban area vary in comparison to the rural area depending on the anthropogenic factors such as asphalting, concreting, increase in impermeable surfaces, destruction of natural areas, heavy and high construction. It is known that the mentioned factors create a heat layer in cities Bulgan and Yılmaz (2017). According to the bioclimatic comfort conditions calculated from the climate data between 2007 and

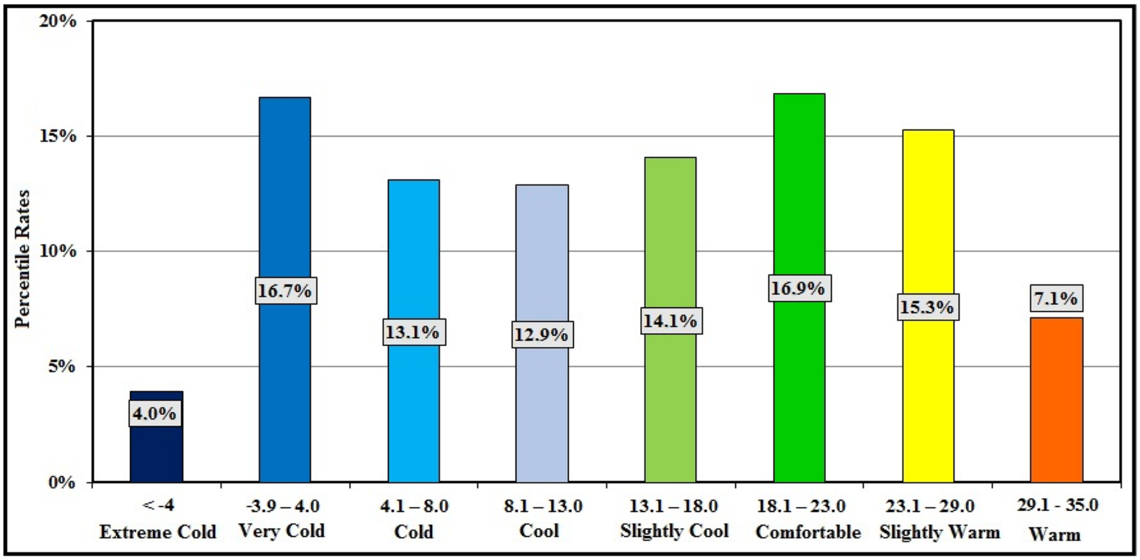

Fig. 15 Percentages of minimum bioclimatic comfort conditions of urban station

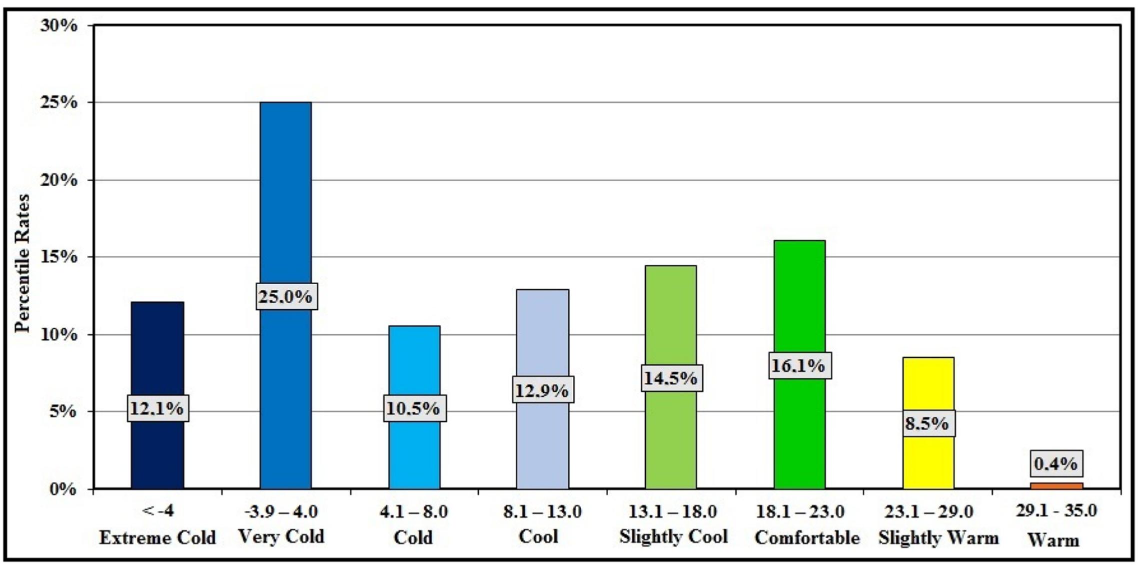

Fig. 16 Percentages of minimum bioclimatic comfort conditions of rural station

Table 6 Minimum PET values and differences of urban and rural stations (°C)

	1	2	3	4	5	6	7	8	9	10	11	12	Yearly
Urban	– 3.3	– 1.1	3.9	8.9	15.7	20.5	25	26.6	21	12.9	6.4	– 0.2	11.4
Rural	– 5.1	– 2.5	1.7	6.6	12.7	18.4	22.5	23.7	18.5	11.1	4.4	– 2.1	9.2
Δ (*U*–*R*)	1.8	1.4	2.2	2.3	3.0	2.1	2.5	2.9	2.5	1.8	2.0	1.9	2.2

2020 (14 years), the urban station has an annual PET value of 2.3 °C on average higher than the rural station, 1.6 °C on average maximum and 2.2 °C on average minimum. The greatest difference between the urban station and the rural station was in March (3.5 °C), and the least difference was observed in September and October (1.7 °C). The greatest difference on average minimum was observed in July (3.0 °C), and the least difference in November (0.8 °C).

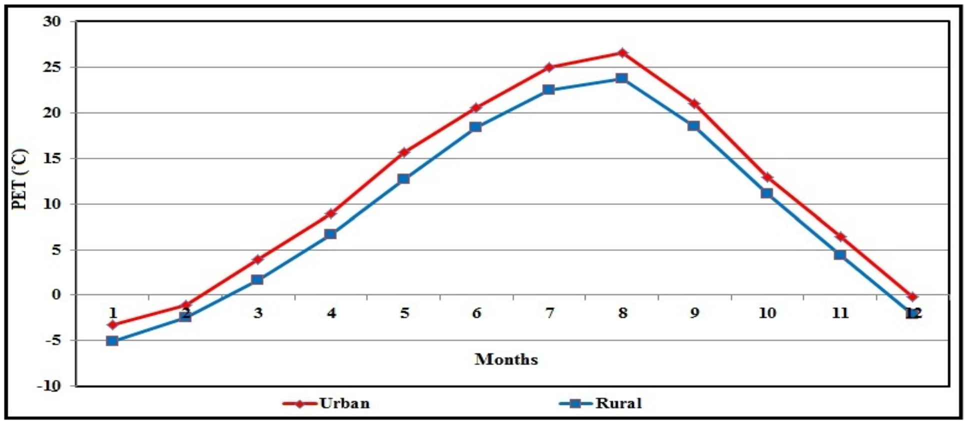

Fig. 17 Distribution of monthly minimum PET values of urban and rural stations

The greatest difference on average minimum was observed in May (3.0 °C), and the least difference in February (1.4 °C). In percentage distributions, on the other hand, while colder and cooler stresses are perceived more often at the rural station, warmer stresses are seen more often at the urban station. Especially in the summer season, while 'slightly warm' stress dominates at the rural station, 'warm' and 'hot' stresses at the city station, according to the average values; and while the 'warm' stress is effective at the rural station, the 'hot' and 'very hot' stresses at the urban station according to the average maximum values; and 'comfortable' conditions are perceived at the rural station, while 'slightly warm' and 'warm' stresses are experienced at the urban station according to the average minimums.

As a result of the study, it was seen that the urban area reflects unfavourable negative bioclimatic comfort conditions compared to the rural area. Extremely sweltering heats are effective in urban areas especially in summer. The fact that the comfort conditions worsen depending on anthropogenic factors in urban area where the majority of the population live can be seen in other studies conducted both in Turkey and all around the world. When the results of the study are compared to those conducted in different parts of the world, it can be seen that similar results are obtained (Table 7).

Table 7 Comparison of PET differences in urban and rural areas with examples

Researchers	Study area	Observation period	Urban–rural differences
Oke 1973	St. Lawrence Lowland (Canada)	1969–1971	0.27–1.91 °C
Karl et al. 1988	At 1219 station in continental ABD	1901–1984	0.1 °C
Unger 1999	Szeged (Hungary)	1978–1980	2.5 °C
Svensson and Eliasson 2002	Gothenburg (Sweden)	1998–1999	4.0–8.0 °C
Hinkel et al. 2003	Borrow (Alaska)	2001–2002	2.2 °C
Peterson 2003	289 stations in the USA	19989–1991	No difference
Fortuniak et al. 2006	Łódź (Poland)	1997–2002	Max 8.0 °C
Bonacquisti et al. 2006	Roma (Italy)	1991–1999	2.0–5.0 °C
Bulut et al. 2008	Erzurum (Turkey)	2003–2004	1.7 °C
Gulyas et al. 2010	Szeged (Southern Hungary)	1999–2008	2.9 °C
Bulgan 2014	Erzurum (Turkey)	2012	0.3–2.8 °C
Çalışkan and Türkoğlu 2014	Ankara (Turkey)	1975–2013	0.5–2.6 °C
Vitt et al. 2015	Szeged (Hungary)	2000–2011	1.0 °C
Blazejczyk et al. 2016	Warsaw (Poland)	2013	1.5–2.5 °C
Çağlak 2017	Samsun (Turkey)	2000–2015	0.3–1.7 °C
Bulgan and Yılmaz 2017	Erzurum (Turkey)	2012	1.1–4.3 °C
Toy and Çağlak 2018	Erzurum (Turkey)	2014	2.8 °C
Toy et al. 2021	Eskişehir (Turkey)	2007–2017	~ 2.5 °C
Tonyaloğlu 2019	Aydın (Turkey)	2005–2015	~ 3.6 °C
Çağlak et al. 2021	Bolu (Turkey)	2010–2020	6–11 °C

Similar to the findings in the literature, the study also shows that cities negatively affect bioclimatic comfort conditions depending on anthropogenic factors. UN estimates that 60% of the world population will live in cities until 2030 and that the majority of the population growth will take place in the cities of the developing countries (Balogun et al. 2010). The urbanisation trend has been accelerating in Turkish cities for the last 50 years. Rapid and unplanned urbanisation carried out by ignoring the nature and the existence and sustainability of the natural element causes loss in the cities in terms of ecologic, economic and aesthetic ways and also negatively effects the human health and biodiversity. It is recommended that the holistic perspective of geography and ecological-based approaches of environment, architecture and planning sciences should be prioritised in urban planning. Thanks to the climate-responsive urban designs which will be performed with interdisciplinary approaches and with the priority of sustainability and protection of nature, the climate-related comforts of individuals can be maintained at the highest level.

It is known that the bioclimatic comfort in a city depends on the use of open spaces in the urban land. In this context, improvements in the microclimate conditions of the cities can be provided by opening wind corridors in existing urban areas, creating water surfaces and increasing green areas with vertical or horizontal planting works. Recreation areas including city forests and trees and water bodies can be built in city centres. Thanks to these recreation areas, the areas covered with earth and plants can be increased and individuals can be encouraged to spend time in comfortable outdoors spaces. This can contribute to bioclimatic comfort by reducing the energy consumption caused by heating and cooling in buildings.

It is a well-known fact that climate change will negatively affect the living environments, working environments and health of millions of people (Costello et al. 2009). It is thought that urban planning that will be carried out by considering climatic factors will contribute to the increase of air quality in cities, the health and welfare of urban people, bioclimatic comfort conditions, the climatic conditions of cities on a microscale and the prevention of global climate change on a macroscale.

Considering the flat land structure and sunshine duration of the research area, urban agriculture application areas can be included, and artificial water areas and urban forests can be created. Roof gardens can be included in existing and future buildings. In order to reduce the effect of urban heat island effect, wind maps can be created by analysing the wind direction in the city. Measures can be taken to activate or inhibit the wind. Wind corridors can be created in the construction. Insulation measures can be used to reduce the need for heating and cooling in dwellings originating from the continental climate. Road afforestation can be increased in the city. Increasing the share of planting areas in the grey building areas to be constructed can be encouraged by local administrations. The results of the study are considered to provide a scientific basis for the studies to be carried out for creating a climate sensitive city model and climate action.

This study contributes to the related literature as a case by showing the bioclimatic comfort conditions in a medium-sized city centre with no heavy industrial activities in west part of Turkey representing Mediterranean type climate features. There is a need for the future studies where more elaborated data measurement and analyses should be performed by setting a special type of urban meteorological observation network.

Author contributions The main manuscript text was written by Metin A. E. and Toy S. All figures were prepared by Çağlak S. All authors reviewed the article.

Data availability The data used in the article were obtained from the Turkish Meteorology General Directorate. All data for this study are available within the manuscript.

Declarations

Consent for publication The authors of the article make sure that everyone agrees to submit the article and is aware of the submission.

Ethics approval and consent to participate Not applicable, because this article does not contain any studies with human or animal subjects. The data of this research were not prepared through a questionnaire.

Competing interests The authors declare no competing interests.

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