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Outdoor thermal comfort conditions during summer in a cold semi-arid climate. A transversal field survey in Central Anatolia (Turkey)

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ABSTRACT

In the present study the outdoor thermal comfort conditions in Konya (Central Anatolia, Turkey) were examined during summer. This is why a transversal field survey was carried out and over 300 questionnaires were filled by randomly chosen participants. Moreover, environmental variables as air temperature, wind speed, relative humidity and globe temperature were constantly measured. This allowed to relate the thermal perception and preference votes given by the interviewees to the morphological and furniture characteristics of the surveyed sites. Then, taking into account at the same time all the obtained data, a regression line between the thermal perception votes and the corresponding PET (Physiological Equivalent Temperature) values was obtained and a neutral PET value of 26.8 °C was calculated. Based on a logistic curve model with the probit function, a preferred PET value of 19.2 °C was determined. On the other hand, the PET comfort range of (21.6)–(32.0) °C was obtained by considering, as thermal comfort interval, the range (−0.5)-(+0.5) of the ASHRAE 7-point scale. Finally, two outdoor thermal comfort indexes were introduced. The first one, called Turkish Outdoor Comfort Index (TOCI), is able to predict the thermal perception of the considered population in hot conditions. In the second case, the Predicted Percentage of Dissatisfied (PPD) relation was modified based on the surveyed data and outdoor sites.

1. Introduction

Outdoor spaces in urban areas vary according to their locations, design features, type of equipment and the way they are used. People living in the city can carry out different activities or relax and socialize in different areas, as parks, squares, pedestrian streets or resting corners. Among all those factors (aesthetic and functional quality) that might affect the preference and the frequency of usage of those spaces, outdoor thermal conditions play a key role.

Microclimate conditions in outdoor spaces are influenced by: regional climate, environment, vegetation and man-made objects. The microclimate is one of the parameters affecting the thermal comfort in outdoor spaces [1]. Other parameters belong to the human category: age, gender, physiological and psychological factors that include past experience, expectations, adaptation, health condition and also behavioural aspects (clothing insulation, metabolic rate, time of exposure) [1,2].

A higher number of the world population living in cities and unfavorable urban developments affected the microclimate and consequently the thermal comfort conditions in outdoor environments as well. In particular, in urban areas the rising temperatures during summer can lead to the Urban Heat Island (UHI) effect, which is a well-known phenomenon in contemporary cities. This phenomenon causes a decrease in the quality of life in developed and developing cities all over the world [3]. The importance of these problems in cities led, on a global scale, to an increase in the number of studies carried out in recent years about urban microclimate. Therefore, thermal comfort in urban environments has become an important research in the field of sustainable urban design [4].

As previously said, the number, variety and frequency of activities

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in open spaces depend on the thermal comfort conditions changing during the day [5]. Outdoor spaces with favorable thermal comfort conditions have a positive impact on the livability of a city and can play an important role in the improvement of its environmental and social life qualities [6,7]. In this way, it is possible to contribute to an increase in the economic activities through a better and more livable urban environment [8]. As a result, these spaces can have a positive effect on the image of the city [9]. Appropriate thermal comfort conditions in outdoor urban spaces can contribute to the prevention of social isolation, thus helping people to socialize [10–12].

Moreover, the presence of outdoor spaces with favorable microclimatic conditions in urban environments can provoke a reduction in the energy consumptions related to air conditioning in indoor spaces, especially during hot summer days [13–15].

The main difficulty, while assessing thermal conditions in outdoor spaces, is that the meteorological variables may be much more diverse than indoor spaces. The spatial and temporal microclimatic variations of meteorological variables are very intense in most cases. In addition, the lack of climate control, the physical and socio-cultural adaptation of the subject and the wide variation in use and users are the most difficult issues to take into account in outdoor thermal comfort studies [16].

On an international scale, the number of studies carried out in recent years in the field of outdoor thermal comfort has been increasing [17]. The research methods in these studies are based on field surveys or computer simulations. Researches have been performed in different climate conditions, highlighting the impact of geographical and cultural factors on the perception of human thermal comfort in outdoor environments. This is why in many studies the thermal comfort range and the deriving neutral value of the used index (e.g. neutral PET) are specifically defined for the examined place. This also gives the possibility to make comparisons among different climate categories and areas. To obtain these specific values, questionnaire surveys and micrometeorological measurements were performed simultaneously in the majority of the studies. It is also possible to see a diversity in the used thermal comfort indexes. The most used one is the PET, followed by other indices as SET, PMV or UTCI [16,18].

Every study was carried out in a different time interval. Some studies were carried out during a day, a season or a whole year. Generally, the study focused on those seasons offering different thermal conditions (e.g. summer and winter) [19,20].

The areas of study are public open or semi open spaces. Among these areas, university campuses have an important role. For example, the study conducted by Xi et al. [21] examines the influence of various types of design elements on the outdoor thermal environment and comfort in a campus located in Guangzhou, China (subtropical climate). In the campus of Putra University (Malaysia), located in a hot and humid tropical climate, the influence of thermal adaptation and psychological parameters on human thermal comfort level in outdoor spaces was demonstrated [22]. In the study realized in the Sapienza University of Rome, the MOCI (Mediterranean Outdoor Comfort Index) and PPD (Predicted Percentage of Dissatisfied) were determined with respect to the Mediterranean population [19]. Wang et al. [23] conducted a study in the outdoor urban green spaces of the University of Groningen (The Netherlands) in spring and summer. They analyzed people thermal perception and preference and specified the combined effects of thermal environmental and personal factors. The results of this research showed that non-physical environmental and subjective factors were more important in perceiving comfort than the actual thermal conditions. In the study conducted by Middel et al. [2] in the Arizona State University, the impact of photovoltaic canopy and tree shade on thermal comfort in a pedestrian mall was analyzed.

Other studies were performed in urban outdoor spaces such as squares and pedestrian streets. These researches have been conducted in various cities all over the world and in different climate categories. Liu et al. [24] carried out a study during summer and winter in the urban public spaces of Changsha city, in China. Lai et al. [25] evaluated the thermal quality of the outdoor spaces in a residential community in Wuhan, central China. Karakounos et al. [26] investigated the quantitative differentiation of urban microclimate through a bioclimatic urban redevelopment. Nikolopoulou and Lykoudis [27] examined in Athens, Greece, the effect of microclimatic conditions on the use of open spaces in an urban Mediterranean environment. Wilson et al. [28] analyzed the thermal perception of different users in public spaces in Manchester and emphasized the importance of socio-economic factors. Kwon and Lee [29] studied the outdoor thermal comfort in a transitional space and specified how this kind of space can improve the thermal comfort of occupants. Li et al. [30] analyzed an outdoor thermal comfort situation in Guangzhou, China, during summer.

For what concerns tools that engineers, architects and urban planners might use during the design process, Tsitoura et al. [31] proposed a complete methodological tool to help in creating "bioclimatic" outdoor urban spaces for the summer season in the Mediterranean climate.

It should be also said that some researches focus on particular cases. For example, some studies want to determine the impact of greenery and vegetation on outdoor thermal comfort [23,32–36]. The impact of urban geometry is also studied [14,37–40]. It can be described through the shape and height of buildings, the distance between buildings, sky view factor [41–43] and all kinds of urban voids formed among buildings (all outdoor spaces including streets, squares, parks etc.).

In Turkey, even if the number of studies on outdoor thermal comfort is still limited, over the past few years this field of scientific study has begun to attract the interest of researchers from various academic disciplines (especially in the field of landscape architecture and geography). These studies were performed in different spatial scales and cities while adopting different methods. Erzurum (eastern Turkey) is the most studied city [44–48] and the climatic data for the calculation of thermal comfort conditions were obtained through the local meteorological stations (except for the studies of Irmak et al. [46] and in part the study of Toy and Yilmaz [45]).

The studies of Çetin et al. [49] in Kütahya, Çalışkan et al. [50] in Bursa, Topay [51] in Isparta, Tağıl and Ersayın [52] in Balıkesir and Zengin et al. [53] investigated thermal comfort conditions on a regional scale. The study of Çınar et al. [54] was realized in the coastal tourist town of Fethiye (southwest Anatolia), which is characterized by a Mediterranean climate. In this study, the thermal comfort conditions were determined based on the measured meteorological values. On the other hand, Toy et al. [55] performed their study in Şanlıurfa, which is one of the hottest city in Turkey. In this research the climatic data were obtained from meteorological stations.

For what concerns the city of Konya, a study was realized in the city center in 2009 [56]. In this study, outdoor thermal comfort conditions for warm days were evaluated in the most important pedestrian street based on the COMFA method [57]. Moreover, the thermal perception for different points in the pedestrian street was calculated using climatic data from local meteorological stations. From this point of view and with respect to the Turkish area, it should be said that, in the great majority of the researches performed over the past 13 years, the thermal comfort conditions were determined through the climatic data provided by local meteorological stations.

The combined method, which determine the thermal comfort condition while taking into consideration the measurable variables (objective evaluation) and the human perception (subjective evaluation) of the thermal environment has not been realized in the context of Turkey yet. The present study tried to realize, for the first time in the context of Turkey, a study based on this method in a campus area. This is why the goals of this paper are:

- determine the microclimatic and thermal comfort conditions of five outdoor spaces characterized by different environmental characteristics. In this study, the thermal comfort index used was the Physiologically Equivalent Temperature (PET). This index was calculated through the values obtained from the field survey, where a

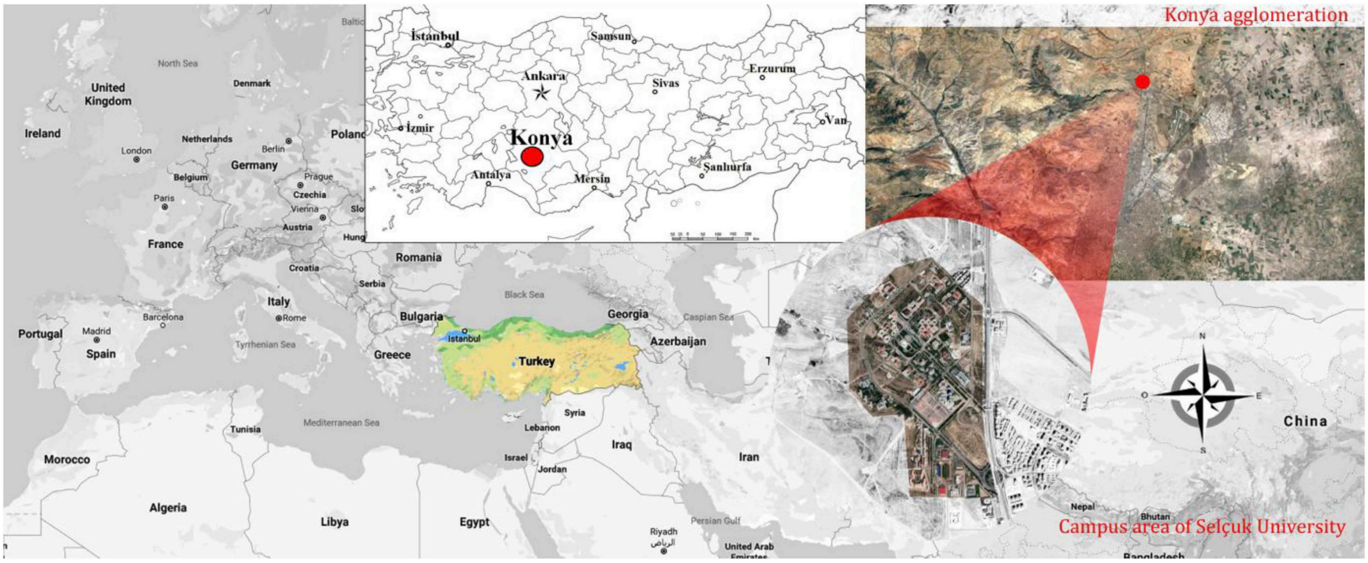


Fig. 1. Geographic location of Konya and the study area.

combined methodology was applied based on the measurement of micro-meteorological variables (objective evaluation) and questionnaire (subjective evaluation of the thermal sensation);
- determine the values of the neutral and preferred PETs and the PET comfort range during summer period in Konya;
- determine the Turkish Outdoor Comfort Index (TOCI), an empirical index able to predict the thermohygrometric perception of the young population in Konya (Central Anatolian Region of Turkey) during the hot season;
- determine the PPD (Predicted Percentage of Dissatisfied) for the Konya (Central Anatolian Region of Turkey) population.

2. Study area and the outdoor spaces for the field survey

The field survey was performed in the campus area of Selçuk University, in the city of Konya (37°52′ N, 32°29′E) (Turkey). Selçuk University campus area is located 18 km north from the city center (Fig. 1). With a population of 1.3 million of inhabitants, Konya is the seventh-most-populous city of Turkey. It is located in the south part of the Central Anatolian region (Fig. 1) and can be considered an important cultural, educational and industrial center. The average altitude is 1016 m in the city center while it is 1140 m in the central part of the campus area.

According to the Köppen-Geiger climate classification, Konya belongs to the Bsk category [58]. It's a cold semi-arid climate. Winter is usually cold and snowy, while summer is hot and dry. Based on the meteorological data obtained from the Turkish State Meteorological Service and Meteorology Regional Directorate of Konya, the average annual value of the air temperature is 11.6 °C [59]. The maximum average temperature is 18 °C and the minimum is 5.3 °C. The hottest months are July (average value: 23.5 °C; maximum average value: 30.1 °C) and August (average value: 23.1 °C; maximum average value: 30.2 °C) whereas January is the coldest month (average value: 0.2 °C; minimum average value: 4.1 °C) (Fig. 2). In the period between 1929 and 2016, the highest measured temperature was 40.6 °C whereas the lowest −28.2 °C. The prevailing wind direction is north-north east (NNE). The annual average value of the wind speed is 1.35 m/s in the city center and 3.6 m/s in the periphery of the city (airport area). Then the relative humidity has an annual average value of 60% and, with an average annual precipitation value of 322.4 mm, the Konya area is considered one of the most arid region in Turkey.

The outdoor spaces were selected in order to cover a certain variety of environmental and spatial characteristics. Open and semi open degree, proximity to buildings, material properties of the surfaces, greenery density, shadowing, wind, topography and sky obstruction were taken into account to choose the outdoor spaces to perform the survey. These places are usually attended and used by people of the campus (Figs. 3 and 4).

Apart from the main pedestrian walkway, which constitutes the most used public place in the campus area, all selected outdoor spaces were near the buildings (faculty, high school, etc.) (Figs. 3 and 4). Moreover, they were organized to be part of the social life.

To be more detailed, the selected outdoor spaces were:

- Outdoor spaces of the School of Civil Aviation: two points were selected (SCA1 and SCA2). The bench of the first point (SCA1) is on a grass-covered ground. This point is close to the School and trees. The ground of the second point (SCA2) is covered by stones, sand and grass.
- At the entrance space of the Faculty of Engineering (FE): designed as an outdoor space with greenery, there are many benches to sit and tables. The ground is covered by stones and sand.
- Small green area near the Informatics Center (IC): the selected point is covered by the foliage of the trees. There is a high density of greenery and the ground is characterized by stones.
- Central Pedestrian Walkway (CPW): the selected point is near a tree and the ground is covered by stones. Even if there is a certain presence of vegetation, mineralized surfaces are dominant. The area is also characterized by many benches.

All the selected outdoor spaces are public. People spend their time to rest, eat and drink, smoke, and meet other people. Fig. 3 shows the position of the aforementioned points in the campus area. The photos of the selected outdoor spaces, the sky view photos, the sky view factor values of the points and the general descriptions are reported in Fig. 4.

3. Material and methods

Thermal comfort conditions in the selected outdoor spaces were evaluated based on objective measurements and subjective assessments. The objective measurements are related to a micro-meteorological monitoring to collect simultaneously different climatic data (air temperature, globe temperature, wind speed and relative humidity). The obtained data were firstly used to evaluate the microclimatic conditions of the outdoor spaces and then combined with the responses from the questionnaires (subjective assessments) to determine the neutral and

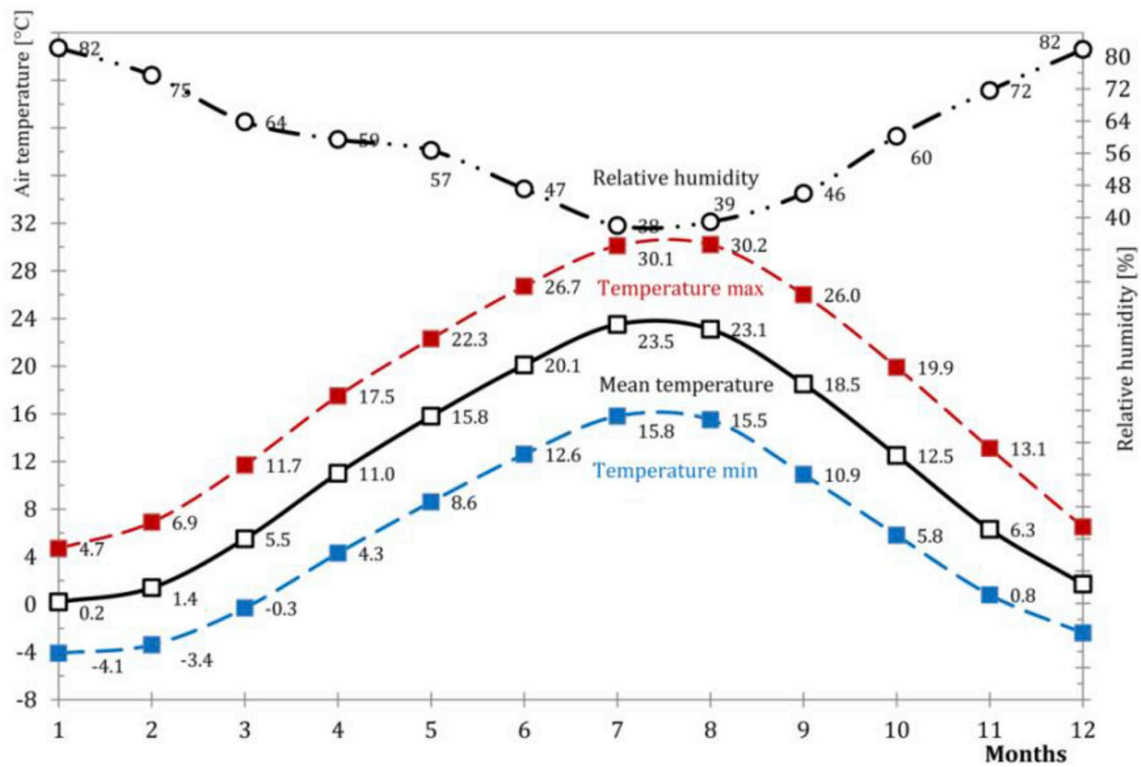


Fig. 2. Temperature and relative humidity in Konya.

preferred PET values and the corresponding thermal comfort range. Indeed, the PET values were calculated based on the measured micro-meteorological data and personal factors using the Rayman software [60]. The value of the neutral PET and comfort range were obtained through a linear regression analysis whereas the preferred PET through a probit analysis. Thereafter the Turkish Outdoor Comfort Index (TOCI) was introduced and the Predicted Percentage of Dissatisfied (PPD) was rearranged. The field survey was conducted for each point from 9:00 a.m. to 6:00 p.m. during summer days from July 31, 2017 to August 9, 2017.

3.1. Micro-meteorological monitoring

The measurements of the climatic variables were carried out with a Delta ohm HD 32.3 instrument. The values of air temperature (T_A), globe temperature (T_{GLOBE}), wind speed (WS) and relative humidity (RH) were recorded automatically every minute at a height of 0.60 m from the ground. This height was defined according to the ISO 7726 [61] for interviewees in sitting position. This is due to the fact that in this study all the interviewees were sitting during the survey. The metrological properties of the probes are reported in Table 1. The micrometeorological measurements of globe temperature, air temperature, wind speed and relative humidity were always performed at a distance of less than 3 m from the interviewee [21].

To determine the mean radiant temperature MRT, Eq. (1) was used:

$$MRT = \left[(T_{GLOBE} + 273.15)^4 + \frac{1.1 \cdot 10^8 \cdot WS^{0.6}}{\varepsilon \cdot D^{0.4}} \cdot (T_{GLOBE} - T_A) \right]^{0.25} - 273.15 \quad (1)$$

where ε and D are the emissivity (0.95) and the diameter of the globe-thermometer.

The measurement process and the instruments complied with the ISO 7726 [61]. Finally, the measuring instruments were tested and calibrated before the field survey.

3.2. The questionnaire survey

People who participated to the survey were randomly selected. Each interviewee was asked to fill a structured questionnaire in accordance with the ISO 10551 [62]. This questionnaire is formed by two parts. The first part asks about personal factors (gender, age, weight, height, activity, time of residency, time of exposure, clothing). The second part wants to determine the thermal perception and preference of the participants with reference to the measured micrometeorological variables. For the evaluation of the thermal perception, the so-called ASHRAE 7-point scale was used. The expression of the thermal perception may vary among different cultures [63]. This is why the questionnaire has been designed to cover all the levels of thermal perception which are known to the local population, without the interviewee having doubts. Therefore, the thermal perception levels were determined as follows: (−3) very cold, (−2) cold, (−1) slightly cold/cool, (0) neutral, (+1) slightly hot, (+2) hot, (+3) very hot. This way to define the thermal perception levels was also reported in the study of Lucchese et al. [64], Hirashima et al. [65,66] and Tebbani and Bouchahm [67]. For the thermal preference, the McIntyre scale (cooler (−1), no change (0) and warmer (+1)) was used.

The clothing insulation I_{CL} was determinated according to the ISO 9920 [68]. In the questionnaire a list of clothing ensembles was reported where the interviewee could choose what was similar to what she/he was wearing. However the thermal clothing insulation was assumed to have the same value ($I_{CL\ INACTIVE}$) determined through the questionnaires in those cases where the activity performed presented a metabolic rate lower than 1.2 met. If the metabolic rate was higher, Eq. (2) was used:

$$I_{CL\ ACTIVE} = I_{CL\ INACTIVE} \cdot (0.6 + 0.4/M) \quad (2)$$

where M is the metabolic rate expressed in met (1 met = 58 W/m^2).

The metabolic rate of the activity performed by the interviewee was determined through the method developed by Bouden and Ghrab [69]. This method takes into consideration the activities performed by the interviewee both in the exact moment of the questionnaire and 0.5 h

Fig. 3. School of civil aviation (A), Faculty of engineering, informatics center and central pedestrian walkway (B).

before. The weights of 0.7 and 0.3 were respectively assigned to these activities and the corresponding metabolic rates M were determined per unit skin area of an average adult (Dubois area = 1.8 m^2) [62].

The time of residency was used as a criteria of exclusion when the value was lower than 6 months. Pregnant women were also excluded. With respect to the sample, 70% of the participants were men, 30% were female. The average age of the participants was 26.7 years old. The vast majority of participants were young people in all the sites. A total of 315 participants was reached in the survey but as previously said, those participants who lived in Konya for less than 6 months were eliminated. So, a total of 296 valid questionnaires was obtained. The required sample size was calculated based on Eq. (3) [70]:

$$n = \frac{x^2 \times N \times p\,(1-p)}{e^2 \times (N-1) + x^2 \times p \times (1-p)} \tag{3}$$

where:

- n is the sample size;
- x^2 is the chi-square for the specified confidence level at 1 degree of freedom;
- N is the size of the target population;
- p is the expected proportion of a population response (it can be set to 0.5 by default which allows for the possible largest sample);
- e is the desired margin error (expressed as a proportion).

With a confidence level of 90% and a margin error of 5%, the sufficient representative sampling number is 270 for Konya.

Finally, sky view factor values (SVF) were determined. Sigma 8 mm f/3.5 EX DG circular fisheye lens was used with Canon EOS 5D Mark II camera to obtain fisheye photos at the selected points. To determine the SVF values from these photos, Sky View Factor Calculator version 1.1 was used [71,72].

3.3. The Physiological Equivalent Temperature (PET)

In this study the preferred and neutral values of the Physiological Equivalent Temperature (PET) [73] and the deriving thermal comfort range were calculated. PET is a thermal comfort index widely used to determine outdoor thermal comfort conditions under different climates [41,73–75] and Matzarakis et al. [76] highlighted how this index is able to evaluate the thermal component of different climates. Moreover, PET also allows to focus on heat-related risks on humans [77] and considers the influence of climatic parameters as air temperature, radiant temperature, air velocity and air humidity from a thermo-physiological point of view, evaluating their effect on the regulatory processes and thermal state of the body [73].

The Physiological Equivalent Temperature (PET) [73] can be defined as the "equivalent to the air temperature that is required to reproduce in a standardised indoor setting and for a standardised person the core and skin temperatures that are observed under the conditions being assessed" [73]. For what concerns the operative variables, PET was determined using a thermal clothing insulation of 0.9 clo and a metabolic rate obtained by adding 80 W to the basal metabolic rate. With respect to the environmental variables, the mean radiant temperature MRT has the same value of the air temperature T_A, the wind speed WS is 0.1 m/s and the water vapour pressure is 12 hPa. Such value implies a relative humidity RH of 50% for an air temperature T_A of 20 °C. Moreover, in order to assess the PET, the equation of the thermal balance introduced by the Munich Energy Balance Model for Individual (MEMI) [78] was used. The first step was the analysis of the thermal conditions of the human body once the values of the environmental variables representing the examined conditions were used in the equation. In the second step the values obtained for the mean skin and core temperature were inserted in the MEMI and the equation of the thermal balance was solved for the air temperature $T_{A.}$

4. Results and discussion

4.1. Microclimatic conditions in the selected outdoor spaces

Table 2 shows the daily average, minimum and maximum values of the measured micrometeorological variables at the selected points. The variables were measured simultaneously from 9.00 a.m. to 6.00 p.m.

To evaluate the microclimatic conditions in the outdoor spaces, the nearest local weather station (Konya airport weather station) was designated as a reference and the recorded daily average air temperature values from 9.00 a.m. to 6.00 p.m. during the survey days were reported in Table 3.

With respect to the points SCA1, SCA2, FE, IC and CPW, the daily average air temperature values ranged from 26.7 to 32,6 °C at the reference weather station.

The lowest average air temperature values obtained from the micrometeorological measurements were registered at the point SCA1 and at the point located in the small park near the Informatics Center building (IC). In the first case the daily average air temperature value was 27.3 °C. In the same day the daily average air temperature value reported by the reference weather station was 26.7 °C, with a difference of 0.6 °C.

At the point IC, the daily average air temperature value was 27.8 °C, with a difference of 1.9 °C with respect to the one registered by the reference weather station (29.7 °C). This is the only point where the average daily temperature is significantly lower than the reference weather station. This decrease can be explained based on the presence of urban greening, low value of SVF and the deriving increase in the

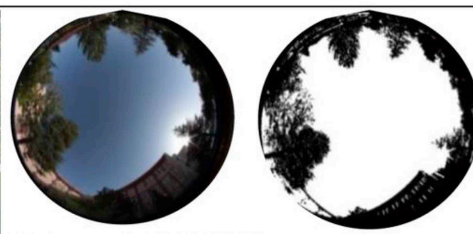
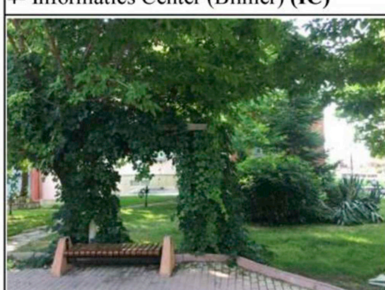
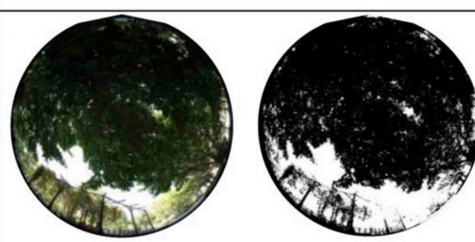
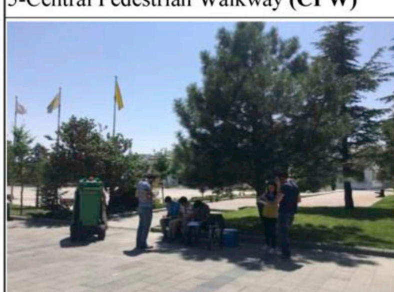
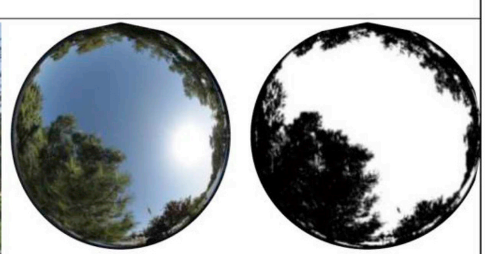
Selçuk University Campus Area Selected outdoor spaces	SVF Values	Density: Greenery	Density: Surrounding building	Ground material	Altitude
1- School of Civil Aviation 1 **(SCA1)** 	 (Holmer et al. 2001): **0.584** (Johnson & Watson 1984): **0.597**	Dense Greenery	Dense	Grass	Altitude: 1156.9m
2- School of Civil Aviation 2 **(SCA2)** 	 (Holmer et al. 2001): **0.921** (Johnson & Watson 1984): **0.935**	Slightly weak	Weak	Grass, sand and stone-1-	Altitude: 1157.7m
3-Faculty of Engineering **(FE)** 	 (Holmer et al. 2001): **0.805** (Johnson & Watson 1984): **0.818**	Slightly dense	Medium	Stone-1- and sand	Altitude: 1140.4m
4- Informatics Center (Bilmer) **(IC)** 	 (Holmer et al. 2001): **0.165** (Johnson & Watson 1984): **0.159**	Very dense greenery	Very weak	stone-1-	Altitude: 1144.9 m
5-Central Pedestrian Walkway **(CPW)** 	 (Holmer et al. 2001): **0.712** (Johnson & Watson 1984): **0.726**	Medium	Very weak	stone-2-	Altitude: 1137.1m

Fig. 4. General aspects, sky view photos, sky view factor values and descriptions of the selected outdoor spaces.

Table 1
Metrological properties of the probes of the measuring instrument.

Climatic variables	Type of probes	Accuracy	Resolution	Range
Air temperature	Combined probe HP3217R, Pt100 with thin film for temperature	Class: 1/3 DIN	0.1 °C	10 °C ÷ 80 °C (−30..+100)
Relative humidity	Combined probe HP3217R, capacitive sensor	± 2% (15 ÷ 90) @20 °C ± 2.5% remaining range	0.1%	5% ÷ 98% (0–100)
Wind speed	AP3203 Omnidirectional hot wire probe, Sensor type: NTC 10kohm	± 0.05 m/s (0 ÷ 1 m/s) ± 0.15 m/s (1 ÷ 5 m/s)	0.01 m/s	0 ÷ 5 m/s
Globe temperature	TP3275 globe thermometer probe (Ø = 150 mm), Sensor type: Pt100	Class: 1/3 DIN	0.1 °C	−10 ÷ 100 °C (−30..+120)

shading of the site during the day.

To better understand the microclimate conditions in the examined sites, other climatic variables and physical factors (ground cover material, SVF …) related to the site should be taken into consideration. The daily average value of the mean radiant temperature at the point IC was 30.7 °C, which is the lowest value among the measured points. The daily average wind speed also was the lowest (0.6 m/s) whereas the daily average relative humidity was the highest (43.5%). Then the foliage of the trees covers the sky and the SVF value results to be equal to 0.165, thus reducing the penetration of direct solar radiation. The trees also obstruct the Informatics Center building, which is close to the selected point, and this reduces the amount of radiation reflected by building coatings.

If the point SCA1 is considered, the value of the mean radiant temperature was the second lowest (47.8 °C). The ground was covered with grass and the sky was partially obstructed by the foliage of the trees, leading to a SVF value of 0.58.

The third lowest average air temperature value was measured at the point SCA2. In this case the registered value was 30 °C, while the daily average air temperature reported by the reference weather station was 27.8 °C. The average air temperature at the point SCA2 was higher than the one related to the reference weather station (difference: 2.2 °C). However, it should be also highlighted how the average value of the mean radiant temperature and the SVF were the highest (61.9 °C and 0.92 respectively). In particular, the SVF value increases the exposure of the point to the direct solar radiation during daytime. The average relative humidity value was 29.4% (the second lowest among the points) and the average wind speed was 1.9 m/s. The greening in the site was low and stone, grass and sand composed the ground cover material.

A higher average air temperature value (30.7 °C) was registered at the point FE and, compared to the reference weather station, an increase of 2 °C was reported. The average mean radiant temperature and SVF values were the second highest among the points (52.4 °C and 0.81). Then the average relative humidity was 35.6% and the average wind speed was 1.2 m/s. The greening in the site was quite dense and stone and sand characterized the ground cover material.

The survey at the point CPW was performed during one of the hottest summer days (maximum temperature at the reference weather station: 36 °C). This gave the possibility to survey data in this site in extreme thermal conditions. The average value of the air temperature was 33.6 °C, 1 °C higher than the value measured by the reference weather station. The average mean radiant temperature value was 51.5 °C, the average relative humidity was 23.9% and the average wind speed was 1.8 m/s.

Table 3
Daily average air temperature values recorded by the reference weather station during the survey days.

Day	Outdoor spaces (Points)	Daily average air temperature (Local weather station, Konya Airport)
31-07-2017	SCA1	26,7 °C
01-08-2017	SCA2	27,8 °C
03-08-2017	FE	28,7 °C
07-08-2017	IC	29,7 °C
09-08-2017	CPW	32,6 °C

Based on the reported results, it could be stated that the IC point had the best conditions from a micrometeorological point of view whereas the points SCA2 and FE were the most unfavorable. On the other hand, the values reported at the point CPW were also affected by the extreme thermal conditions characterizing the surveyed day.

4.2. Thermal comfort conditions in study areas

A certain variety of thermal perception votes across the selected sites was registered due to the values assumed by the environmental variables, the properties of the physical environment (materials, greenery, SVF …) and the personal factors related to the users. Fig. 5 shows the distribution of the thermal perception votes and Fig. 6 shows the distribution of the thermal preference votes.

The highest percentage of neutral votes was obtained in the small green area near the computer center (Point IC) (31.3%). In this outdoor space, the percentage of "slightly cold/cool" (−1) votes was 27% and the one of the "slightly hot" (+1) votes was 31.3%. Only 1% of the votes was in the "cold" (−2) category. The percentage of "very hot" (+3) and "hot" (+2) votes were low (5.2% and 4.2% respectively). Compared to the other points in the campus area, the "hot" (+2) votes were the lowest. Moreover, 42.7% of the users preferred no change in the thermal environment, whereas 55% preferred a cooler configuration. Only 2.1% of the users preferred to be in a warmer thermal environment. Therefore, according to the obtained votes, the point IC reported a pleasant thermal environment. This could be due to the presence of urban greening which led to a SVF value of 0.165 and to control the direct solar radiation.

On the other hand, in the points SCA1 and SCA2 a certain influence of the wind speed was registered. This is due to its altitude, which was

Table 2
Values of the measured micrometeorological variables at the selected points.

	T_A (°C)			MRT (°C)			RH (%)			WS (m/s)		
	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.
SCA1	27.3	31.5	20.4	47.8	85.0	16.8	26.8	45.1	18.2	2.5	5.5	0.2
SCA2	30.0	34.7	23.9	61.9	83.6	29.5	29.4	47.3	19.3	1.9	3.8	0.3
FE	30.7	35.9	27.2	52.4	92.7	32.1	35.6	47.5	26.5	1.2	4.5	0.2
IC	27.8	30.4	24.1	30.7	36.0	25.3	43.5	55.9	28.4	0.6	1.9	0.0
CPW	33.6	36.9	28.6	51.5	83.9	34.0	23.9	32.8	17.3	1.8	6.7	0.3

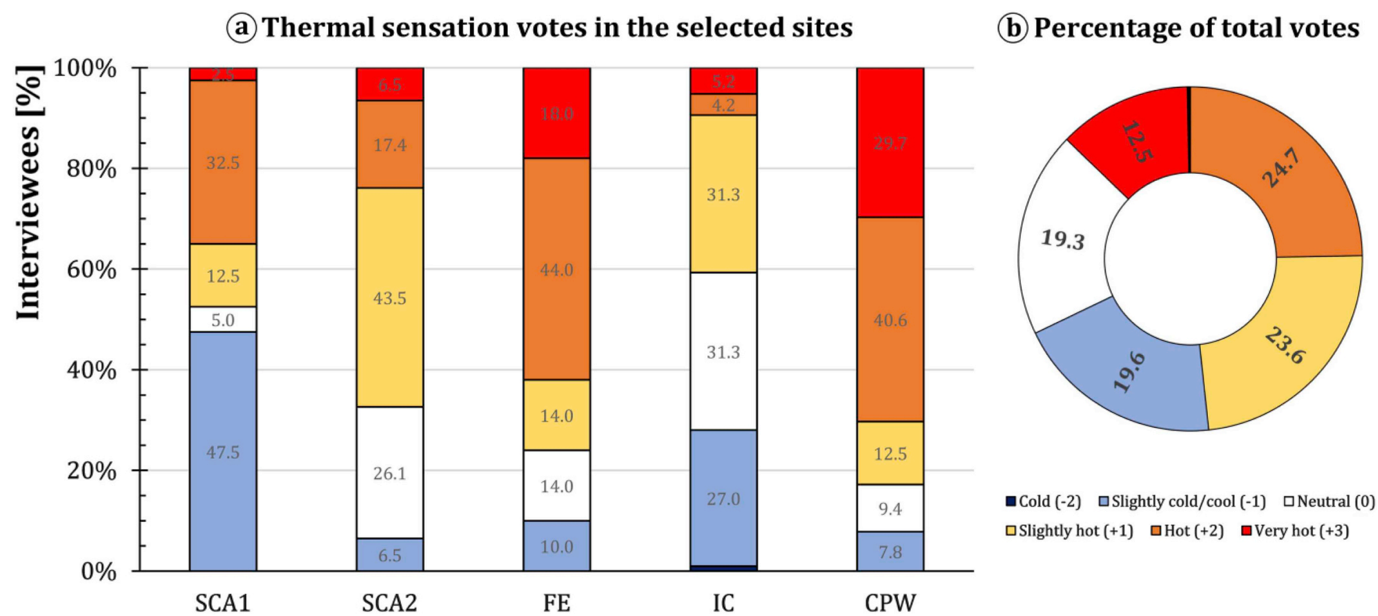


Fig. 5. Distribution of the thermal perception votes: thermal perception votes in the selected outdoor spaces (a) and overall thermal sensation votes including all study areas in the university campus (b).

17 m higher than the one of the center of the campus, and the average wind speed values were 2.5 m/s and 1.9 m/s at the points SCA1 and SCA2 respectively.

The percentage of neutral votes was the lowest (5%) at point SCA1 and, during the surveyed summer day, 47.5% of the participants judged the environment as slightly cold/cool (+1). Only 2.5% of the interviewees voted "very hot" (+3), the lowest percentage among the selected points, and 55% of the users voted "no change" from the thermal preference point of view. This reveals that people did not feel any great discomfort from the cool environment in a summer day. The shading effect deriving from the trees (SVF = 0.58), the wind speed values and the grass were the factors which increased the thermal comfort conditions in this outdoor space.

Considering the percentage of neutral votes (26.1%), the point SCA2 was the second in terms of thermal comfort. However, the highest percentage of "slightly hot" (+1) votes was reported. Then 28.3% of the participants in the survey wanted "no change" in the thermal conditions, while 69.6% wanted a cooler environment. Only 2.2% of the subjects preferred to be in a warmer configuration.

The lowest percentages of neutral votes were reported at the points FE and CPW (14% and 9.5% respectively) and, with reference to the point FE, the total percentage of "hot" (+2) and "very hot" (+3) votes was 62%. This shows unfavorable thermal comfort conditions and a possible reason could lie in the fact that the site was not sufficiently shaded during the day (SVF = 0,81). The materials characterizing the ground are stone and sand, thus leading to an average mean radiant temperature value of 52.4 °C. Indeed, the present urban greening is not able to mitigate the thermal environment and the average wind speed value was not very high (1.2 m/s). Moreover, 78% of the participants preferred to be in cooler thermal conditions at the point FE.

At the point CPW the percentage of "hot" (+2) votes was 40.6% and the one of "very hot" (+3) votes was 29.7%. These results demonstrated that the site had very unfavorable thermal conditions. This could be related to the stone-covered ground and to the deriving solar reflections. Indeed, the benches characterizing the site are parallel to the main pedestrian axis. It should be also said that in the site a certain insufficiency of shadows provided by the trees (SVF = 0.71) was reported. This is one of the reason why a high percentage (81.3%) of

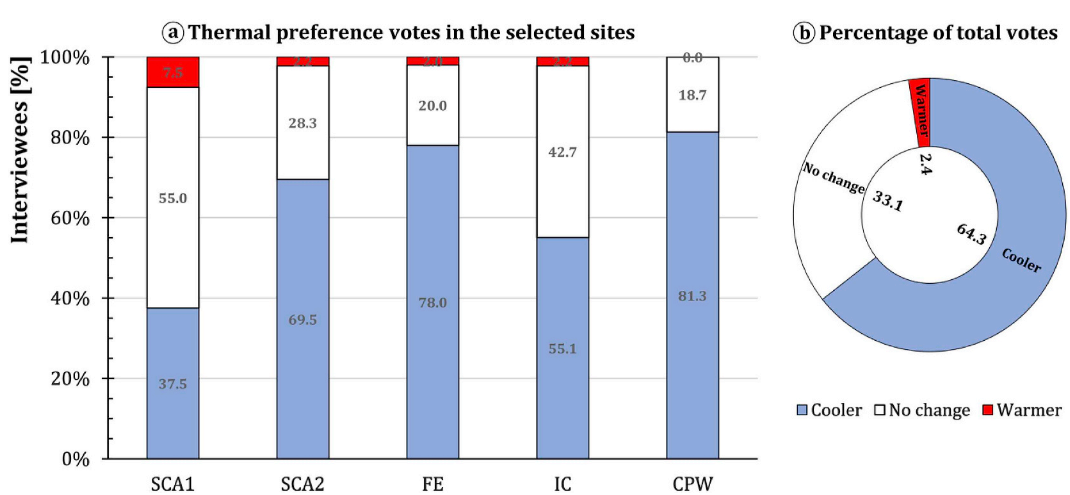


Fig. 6. Distribution of thermal preference votes: thermal preference votes in the selected outdoor spaces (a) and overall thermal preference votes including all study areas in the university campus (b).

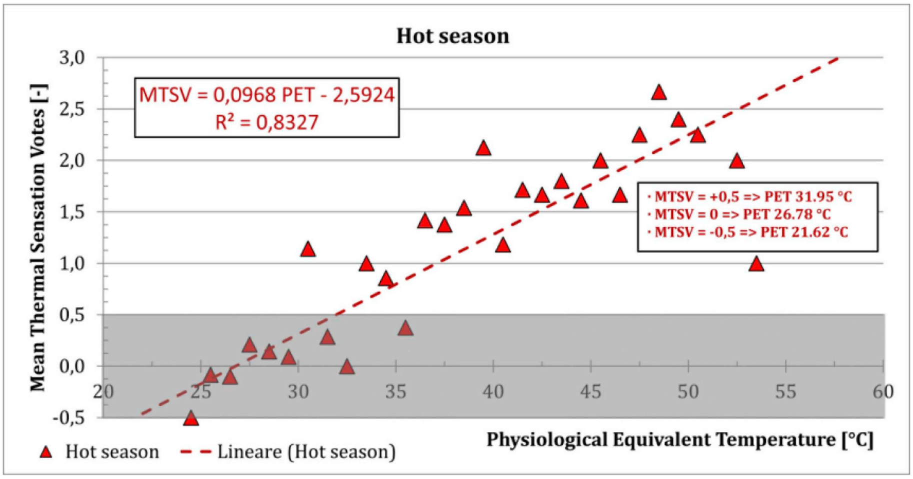


Fig. 7. Correlation between the binned mean thermal sensation votes (MTSVs) and PET during summer, identification of the neutral PET and PET comfort range.

participants preferred to be in cooler thermal conditions.

From a general point of view, the highest percentage of votes (24.7%) was reported by the thermal perception "Hot" (+2) while 64.3% of the participants preferred a cooler thermal environment. These significant percentages show how the great majority of people do not tolerate the thermal stress deriving from the outdoor conditions during summer in Konya. Finally, 33.1% of the people voted "no change" with respect to the thermal preference and only 2.4% preferred to be in a warmer thermal environment (Fig. 6).

4.3. Neutral and preferred PETs, PET comfort range and Turkish Outdoor Comfort Index (TOCI)

The analysis was further developed to determine neutral and preferred PET values, the corresponding range of thermal comfort and an index (Turkish Outdoor Comfort Index (TOCI)) able to provide information concerning the thermohygrometric perception of the population living in central Anatolia. The results obtained concern summer season. Fig. 7 shows the connection between the binned Mean Thermal Sensation Votes (MTSVs) related to the thermal perception reported by the interviewees and the corresponding values of Physiological Equivalent Temperature (PET). The graph was determined considering intervals of Physiological Equivalent Temperature (PET) of 1 °C. For example, a Mean Thermal Sensation Vote (MTSV) of 1.14 was reported with a corresponding PET value of 30.5 °C since it is the average value of the thermal perception votes given by those subjects who were exposed to thermal conditions ranging between 30 and 31 °C (in terms of PET).

Different studies used linear regressions to analyse the ASHRAE scale-based sensation votes [79–81] and Fig. 7 gives the possibility to determine the value of the neutral PET during the hot season [82–84]. According to Fanger and Lin [82,85,86], the neutral PET represents that microclimatic condition where people do not feel neither warm nor cold. Its value was about 26.8 °C and it was obtained setting a Mean Thermal Sensation Vote (MTSV) of 0 in Eq. (4):

$$MTSV = -2.5924 + 0.0968 \cdot PET \quad R^2 = 0.8327 \tag{4}$$

Such neutral value of the PET was affected by factors as acclimatization, adaptation and thermal expectation. Hence it is possible that it is proportional to those temperatures which usually characterize the city examined. It is important to notice that, with respect to Tempe (Arizona) [2], the neutral PET revealed was 28.6 °C. Cairo (Egypt) [87] is also an interesting case, where for the cold season a neutral PET value of 26.5 °C was determined. This value was 0.3 °C lower than the value determined in the present study for the hot season and this can be considered a consequence of the subtropical desert climate of the considered city, mild even during winter.

Personal expectations and acclimatization also affect the assessment of the PET comfort range which involves those PET values corresponding to tolerable thermal stresses. According to Kruger et al. [88], it was determined by setting the values of the Mean Thermal Sensation Vote (MTSV) to 0.5 and −0.5 respectively in Eq. (4). Those values were chosen because this study used the ASHRAE 7-point scale. The analysis revealed how the population living in central Anatolia consider as acceptable those conditions characterizing the PET values ranging between 21.6 and 32.0 °C. Such range is wider in those cities presenting a higher annual temperature swing. For example it ranges from 19.1 to 38.1 °C in Tempe (Arizona) [2], a city which reports an average value of the maximum temperatures of about 40 °C in August and an average value of the minimum temperatures of about 3 °C in December.

It is also interesting to determine the preferred value of the PET (Fig. 8). In particular, this value is able to identify the microclimatic configuration that people tend to prefer because they do not feel neither hot nor cold [82,85,86]. It was determined through the feedback provided by the subjects when they were asked about their thermal preference based on the McIntyre scale (cooler (−1), no change (0) and warmer (+1)). Moreover, as occurred during the assessment of the neutral PET, the analysis was carried out based on bins of 1 °C and a logistic curve model characterized by a probit function was used.

The value of the preferred PET, of about 19.2 °C, was identified as the intersection between the curves "wanting cooler" and "wanting warmer" and it can be noticed a decrease of 7.6 °C with respect to the neutral PET. The obtained value is even more significant if compared to what was determined in previous studies. Lin [82] estimated in Taichung City (Taiwan) the aforementioned difference in 1.1 °C whereas Salata et al. [19] reported in Rome (Italy) a difference of 2.1 °C. Results similar to those found in the present study were then determined by Middel et al. [2] through a seasonal field study in Tempe (Arizona). Indeed, they reported 7.8 °C as the difference between neutral and preferred PET value.

It must be specified though that the values determined for the neutral PET, the preferred PET and the corresponding comfort range can be used as testing values. Once the outdoor area is planned, some predictive simulations can be performed through software meant for studying the microclimate as ENVI-met [89,90]. Those simulations can determine the deriving values of the micrometeorological variables and assess, once the activity performed by a possible subject is set, the corresponding PET values. It should be also specified that the PET is an index determined through tests performed while taking as a sample the northern European population. Hence some variations between the thermal perception predicted and the one revealed (with respect to the young population of Konya) might occur due to the behavioural, social

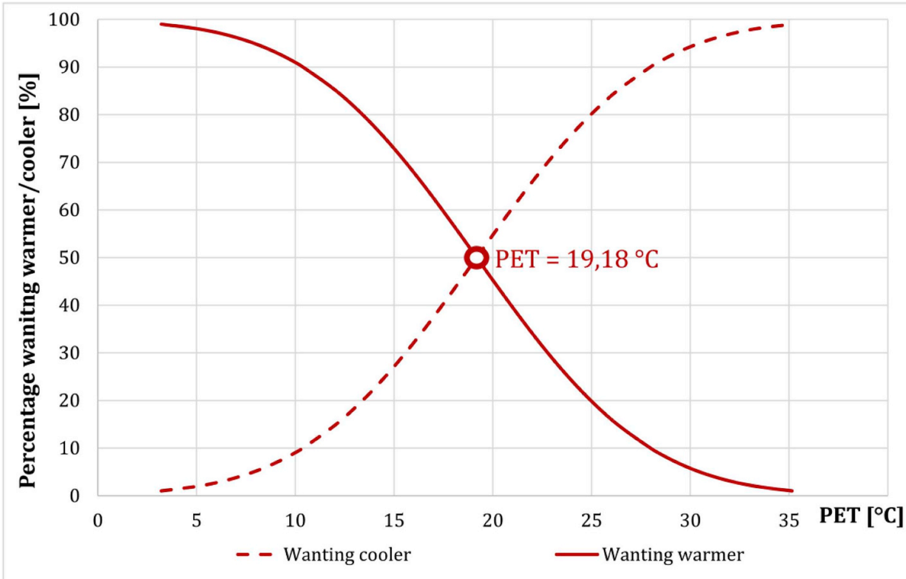


Fig. 8. Assessment of the preferred PET during the hot season.

and physiological adaptations.

This is why the present study introduced, as a predictive tool, an index able to evaluate the thermal perception of this population. Therefore, through the questionnaires and thanks to the simultaneous measurement of the micrometeorological variables, the Turkish Outdoor Comfort Index (TOCI) was obtained.

In particular, the data provided by the interviewees about their thermal perception were previously related to the corresponding micrometeorological and operative variables as air temperature, mean radiant temperature, wind speed, relative humidity, time of exposure, age, clothing thermal insulation, metabolic rate and Body Mass Index (BMI) [91]. Such analysis wanted to preliminarily examine the multicollinearity, and according to Marquardt [92], those variables characterized by a VIF (Variance Inflationary Factor) value higher than 10 were not evaluated for the study of possible prediction models. For this reason, the relative humidity and time of exposure were excluded. The other 7 variables were then analyzed together with the values characterizing the thermal perception of the studied population based on a Best Subsets Analysis. It gave the possibility to compare the performances of all the 127 possible developed models through the adjusted R^2 and C_P statistics. The first one is useful because it takes into consideration, besides the range of the sample examined, the number of explicative variables inserted in the model. The C_P statistics quantifies the difference between the estimated regression model and the real one: hence it is possible to take into consideration those models presenting a value which is lower or equal to v + 1, where v is the number of variables characterizing the model examined.

In this specific case the most performing model is the one with the following independent variables: air temperature, mean radiant temperature, wind speed, age, clothing thermal insulation and metabolic rate (Table 4).

The adjusted R^2 is 0.39, the R^2 is 0.40 and the Pearson coefficient is 0.63. Eq. (5) reports the relation characterizing the Turkish Outdoor Comfort Index (TOCI) for the hot season.

$$TOCI_{HOT\ SEASON} = -4.142 - 0.210 \cdot WS - 0.005 \cdot Age + 0.037 \cdot MRT + 0.095 \cdot T_A + 0.316 \cdot I_{CL} + 0.014 \cdot M \quad (5)$$

However, it must be taken into consideration that the TOCI is able to predict the mean value of the votes that subjects who are part of the young population living in Konya might give to judge the thermal environment. Hence it might be important know the number, or percentage, of people that, being exposed to the same environmental conditions, are not satisfied. This is why this study also rearrange the Predicted Percentage of Dissatisfied (PPD), introduced by the ISO 7730 [93] for the evaluation of the thermal comfort in an indoor environment. PET bins of 1 °C were taken in consideration and the percentage of interviewees who judged the thermohygrometric environment with the thermal perception votes of +2, +3, −2 and −3 was calculated. According to the ASHRAE 7-point scale, those values represent the thermal stress due to hot temperatures (positive) and cold temperatures (negative) respectively. Fig. 9 reports those percentages based on the values of the Mean Thermal Sensation Votes (MTSVs).

Hence the Predicted Percentage of Dissatisfied (PPD) (Eq. (6)) was determined:

$$PPD = 100 - 89.74\ EXP(-0.10\ TOCI^4 - 0.20\ TOCI^2) \quad (6)$$

While examining Fig. 9 it can be noticed how, in the area corresponding to the thermal comfort, the curve of the PPD experimentally obtained in the present study leads to a higher number of unsatisfied people with respect to the one related to the ISO 7730 [93]. Indeed, the

Table 4
Results related to the development of the Turkish Outdoor Comfort Index (TOCI) for the hot season.

	Coefficient	Standard Error	t Stat	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	−4.142	0.805	−5.144	−5.727	−2.558	−5.727	−2.558
M	0.014	0.008	1.650	−0.003	0.030	−0.003	0.030
Age	−0.005	0.007	−0.743	−0.019	0.009	−0.019	0.009
I_{CL}	0.316	0.592	0.534	−0.849	1.481	−0.849	1.481
MRT	0.037	0.005	7.799	0.027	0.046	0.027	0.046
T_A	0.095	0.020	4.728	0.055	0.134	0.055	0.134
WS	−0.210	0.051	−4.114	−0.310	−0.109	−0.310	−0.109

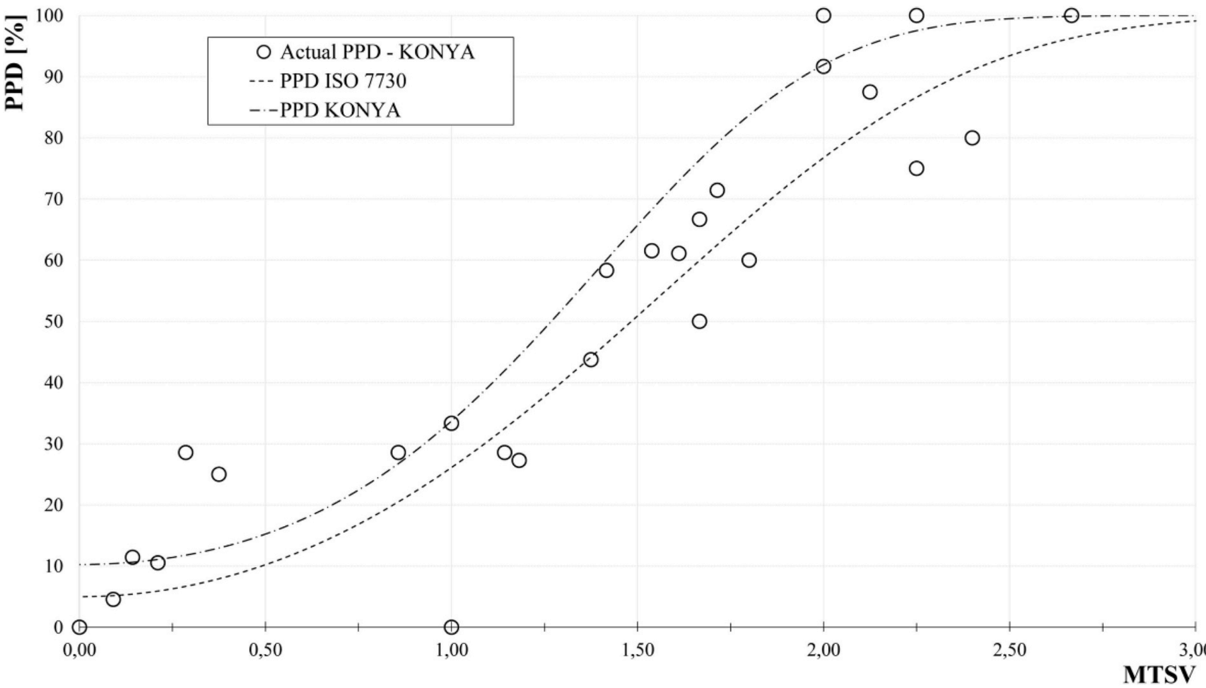


Fig. 9. Predicted Percentage of Dissatisfied (PPD) for the population living in central Anatolia.

values of the micrometeorological variables vary more in outdoor spaces rather than in enclosed spaces, with a corresponding higher variation in the votes provided by the interviewees for what concerns their thermal perception. On the other hand, for Mean Thermal Sensation Votes (MTSVs) representing a higher thermohygrometric stress, the difference between the curve of the PPD complying with the ISO 7730 and the one obtained in the present study decreases. In this case a possible explanation might be that a subject, when in outdoor spaces, has a higher level of tolerance towards environmental conditions because he/she knows that cannot totally control the micrometeorological variables.

5. Conclusions

In this study the thermohygrometric conditions in the campus of Selçuk University (Konya, Turkey) were evaluated.

An experimental field survey was carried out in July and August (2017) and the sample examined was formed by 315 subjects (the number of the valid questionnaires was 296). Each subject was asked to fill in a questionnaire which was previously organized complying with the ISO 10551. During the survey the experimental values of micrometeorological variables as air temperature, relative humidity, wind speed and global radiation were also measured. This is why it was possible to connect each subject to the corresponding values of the mentioned variables. Such values were then combined, with reference to each subject, with the values of the operative variables which were determined through the questionnaires. This also allowed to link each interviewee to the deriving value of the Physiological Equivalent Temperature (PET).

For what concerns the results, a regression line between the binned Mean Thermal Sensation Votes (MTSVs) provided by the subjects and the corresponding PET values was obtained. To be more specific, the mean value of the votes given by the interviewees when asked to judge their thermohygrometric perception was assessed based on PET intervals of 1 °C. Then setting the Mean Thermal Sensation Vote (MTSV) to 0, the value of 26.8 °C was determined for the Physiological Equivalent Temperature (PET). On the other hand, by setting the Mean Thermal Sensation Vote (MTSV) equal to $+0.5$ and -0.5, it was possible to assess the PET comfort range whose values ranged from 21.6 °C to 32.0 °C.

In the areas selected for the survey, 54% of the PET values calculated for each interviewee were above the upper limit of the neutral PET range (PET $>$ 32 °C). The total of thermal perception votes above the neutral value (TSV $\geq +1$) was 60.8%. In total 64.3% of the participants preferred cooler conditions. Only 33% found the thermal conditions of the selected outdoor spaces comfortable. These results confirm that the majority of people in the daytime do not appreciate and tolerate PET values higher than 32 °C. It is in the small green area well shaded during the day (point IC) that the highest percentage (31.3%) of thermal perception votes equal to 0 (neutral thermal comfort condition) was reported. This shows the importance of greening to reduce summer heat and make outdoor spaces livable.

The results of the values provided by the subjects about their thermal perception were then examined through a probit analysis. Hence the curves concerning the percentage of those subjects who would like a microclimatic configuration with warmer temperatures and the percentage of those who would like a microclimatic configuration with colder temperatures were determined. The intersection between those two reveals the PET preferred value of about 19.2 °C. A decrease higher than 7 °C with respect to the neutral value of the PET was then noticed and the focus was on those phenomena linked to acclimatization and adaptation.

This is why the present study introduced an index meant for the prediction of the thermohygrometric perception of the population living in Konya. It was called Turkish Outdoor Comfort Index (TOCI) and it was determined through statistical elaborations based on the evaluation of multicollinearity and VIF (Variance Inflationary Factor) followed by a Best Subsets Analysis. The Best Subsets Analysis permitted the comparison of the performances of 127 possible predictive models while using as independent variables metabolic rate, age, thermal clothing insulation, air temperature, mean radiant temperature and wind speed.

The mentioned index is able to predict the mean value among the data that a large group of young subjects living in Konya might provide if asked to judge a thermohygrometric environment. This is why the authors decided to determine the relation of the Predicted Percentage of

Dissatisfied (PPD) for this population with respect to outdoor spaces.

The relations of the Turkish Outdoor Comfort Index (TOCI) and Predicted Percentage of Dissatisfied (PPD) might be used by architects, engineers and urban designers while planning an outdoor space because they can help them while choosing the materials characterizing the urban area and adopting the proper mitigation strategies. On the hand the values of the neutral PET, preferred PET and PET comfort range can be useful in the verification.

A possible limitation of the study could be found in the fact that the survey was carried out in a campus area and the surveyed sample is characterized by young subjects. Moreover, in this first study the hot season was surveyed. For this reason, future developments of the research will extend the survey to the cold season and to other cities of the same area or climate category to widen the sample.

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