ASSESSMENT OF THERMAL SENSATION OF RESIDENTS IN THE SOUTHERN GREAT PLAIN, HUNGARY

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ABSTRACT. Assessment of thermal sensation of residents in the Southern Great Plain, Hungary. This study examines the subjective thermal sensation characteristics of people living in Szeged, in the Southern Hungarian Great Plain. Micrometeorological measurements were conducted with two mobile stations in six urban public spaces during 70 days from spring to autumn in 2011 and 2012. Simultaneously, 6080 visitors were asked to assess their actual subjective thermal sensation. The collected climatic variables (air temperature, relative humidity, wind velocity, and mean radiant temperature) were assigned to the respondents individually, taking the actual spatial position of the subjects and the meteorological stations, as well as the degree of their solar exposure into account. From the linked basic parameters the Physiologically Equivalent Temperature (PET) index was calculated to quantify the overall thermal conditions. This study presents the characteristics of the visitors' Thermal Sensation Votes (TSV) as well as their relationships with the measured or calculated objective variables. The results confirmed that PET has the strongest influence on the thermal sensation. Based on the TSV–PET regression function, the widely used European PET thermal sensation classes were rescaled in order to express more closely the thermal perception characteristics of the people living under the climatic conditions of the Southern Hungarian Great Plain. The results indicate significant shifts in the PET class boundaries, emphasizing the role of thermal adaptation of people living in distinct climates.

Keywords: subjective thermal sensation, field survey, physiologically equivalent temperature, thermal comfort classes

1. INTRODUCTION

In urbanized areas an increasing number of citizens are influenced by the thermal conditions of outdoor urban environments. However, people dwelling in different geographical regions with various background climates are on distinct levels of physiological acclimatization and they tolerate the extreme thermal conditions differently. Moreover, people belonging to different cultures or having various attitudes may evaluate the thermal conditions of the urban spaces quite differently, even in similar thermal conditions (Knez and Thorsson, 2006, 2008). Their subjective assessments and the applied forms and intensities of their

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behavioural responses given to a thermal environment can also be considerably different, depending on expectations, thermal experiences, and actual emotional state (Nikolopoulou and Steemers, 2003; Knez et al., 2009).

Several studies confirmed that due to the different adaptation levels, the thermal sensation or stress classes of a thermal comfort index derived in one region may not be applicable in another region. Therefore, new thermal sensation scales have been developed based on simultaneously conducted onsite microclimate measurements and questionnaire surveys on the visitors' instantaneous subjective assessments of their thermal environment (e.g. thermal sensation) (Lin and Matzarakis, 2008; Kántor et al., 2012; Cohen et al., 2013).

This study aims to characterize the subjectively assessed thermal sensation of the residents living in the Southern Hungarian Great Plain and aims to reveal the influence of the objective measures of the thermal environment on the citizens' actual thermal sensation. The results are based on simultaneous microclimate measurements and onsite questionnaire surveys conducted in Szeged, Hungary. In order to reflect the real thermal perceptions of the residents in this region, we modify the boundaries of thermal sensation classes of a widely applied thermal comfort index, namely the Physiologically Equivalent Temperature [PET (°C)] (Matzarakis and Mayer, 1996; Höppe, 1999), which class boundaries were derived originally for Western and Central European conditions.

2. STUDY AREA

Szeged is the regional and educational centre of the Southern Great Plain Region located in the south-eastern part of Hungary (46°N, 20°E, 82 m above sea level),with a population of 160,000 and an urbanized area of about 40 km^2. According to Köppen's climatic classification, the city belongs to region Cfb (temperate warm climate with uniform annual distribution of precipitation). The investigated open public spaces are different in size, design, and functions, too (Fig. 1). They include three recreational squares (Dugonics, Széchenyi, and Szent István), two playgrounds (on the Honvéd Square and on the Retek Street), and a pedestrian area (Kárász Street with the adjoining Klauzál Square) (Fig. 1).

3. METHODS

In order to reveal the relationships between the subjective thermal sensation of local people and the objective (measured or calculated) variables in the six urban spaces, simultaneous measurements with two mobile automatic urban-microclimatological stations and questionnaire surveys on the momentary subjective assessments of the visitors were conducted. The data were collected in the framework of a long-term urban bioclimatic project during the springs, summers, and autumns in 2011 and 2012. The survey was carried out from 10 a.m. to 6 p.m. for a total of 70 days.

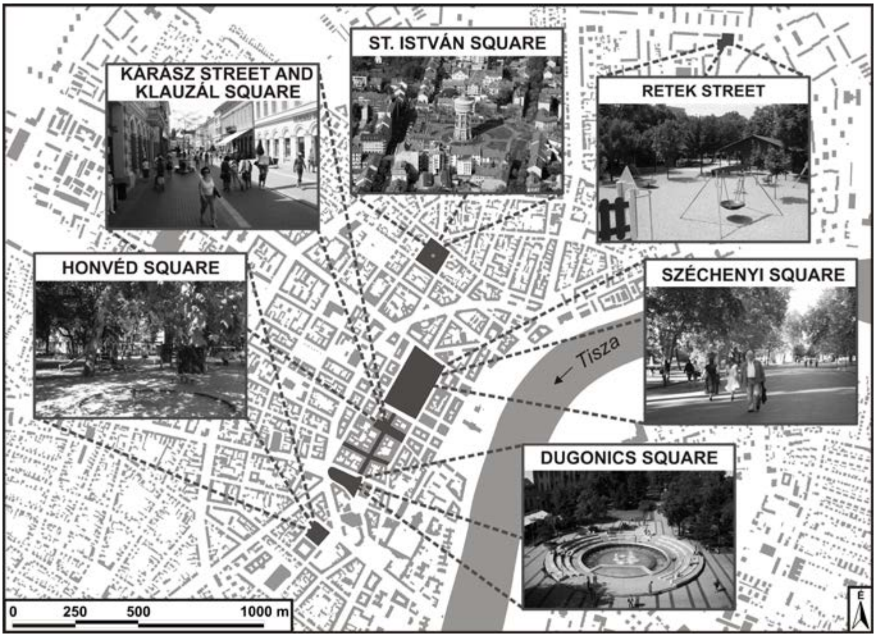

Fig. 1. The investigated public spaces in Szeged

The meteorological stations collected one-minute averages of air temperature [T_a(°C)], relative humidity [RH (%)], and wind velocity [v (ms^{-1})] with sensors parts of Weather TransmitterWXT520 (Vaisala), at a height in accordance with the thermal comfort measurement guidelines (1.1–1.2 m). Furthermore, rotatable CNR net radiometers (Kipp & Zonen) mounted also on the stations enabled to receive short- and long-wave radiation flux densities from six perpendicular directions of the environment. Based on the six-directional method suggested by the VDI 3787 (VDI, 1998), Mean Radiant Temperature [T_{mrt} (°C)] values were calculated. This parameter summarizes the thermal effect of all short- and long-wave radiation fluxes in one, temperature-unit value (Fanger, 1972).

During the spring of 2011 the measurements were performed simultaneously in two significantly different thermal environments, i.e. in the well-shaded Széchenyi Square and in an open (sunny) point of the Dugonics Square. From the summer of 2011 one of the meteorological stations was exposed continuously to the sun while the other was located in the shade in the same area. The only exception was the poorly shaded Szent István Squarewhere both stations were exposed to the sun.

As a subjective variable expressing the thermal sensation of visitors, we utilized the so-called Thermal Sensation Vote (TSV) to compare with the objective data. The interviewees were asked to indicate their subjective thermal sensation on a semantic differential scale with 9 main thermal perception classes ranging from very cold to very hot. This scale allows marking votes with a precision of one decimal (Fig. 2).

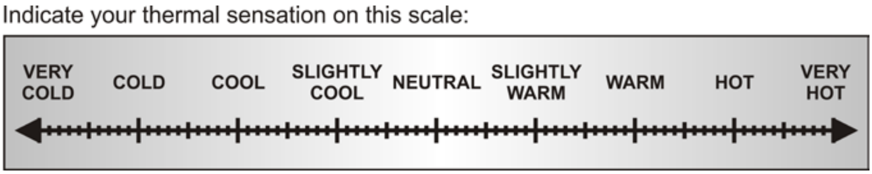

Fig. 2. The 9-point thermal sensation scale applied in the questionnaire survey

It is important to note that when filling the questionnaires, the exact times when the subjects assessed their thermal sensation were recorded. This made it possible to link the adequate one-minute objective meteorological data (T_a, RH, v, and T_{mrt}) to the questionnaires. The spatial positions of the interviewees and the meteorological stations were marked on maps of the survey data, as well as their solar exposure (‘on the sun’, ‘in penumbra’, or ‘in the shade’) was recorded in the questionnaires. Taking these factors into consideration, we attached the appropriate combination of the basic meteorological parameters with the following procedure.

Air temperature, relative humidity, and mean radiant temperature were assigned to individuals in accordance with the solar exposure of the stations and the respondents, for example data of the sunny station belonged to people located on the sun. In the case of people in penumbra, the average T_a, RH, and T_{mrt} data of the two stations were used. The wind velocity was attached based on the proximity of people to the stations viewed on the maps, i.e. the v data of the nearest station was connected. This was the case with all four parameters in overcast sky conditions because it was impossible to determine the visitors’ solar exposure.

In order to express the overall thermal effect of the basic meteorological parameters affecting human thermal sensation (T_a, RH, v, and T_{mrt}), the thermal comfort index PET was calculated using the RayMan model (Matzarakis et al., 2007, 2010). This index was calculated only after the data attachment procedure described above. In that way every individuals got a specific PET value which reflected their actual thermal environment.

After filtering out some obviously incorrect data, 6080 coupled (subjective-objective) datasets were used in the subsequent analyses. Regression analyses were performed to reveal the separate (T_a, RH, v, and T_{mrt}) and the overall (PET) influence of the thermal environment on the subjective thermal sensation (TSV). Based on the PET–TSV relationship, new boundaries of PET thermal sensation classes were derived, which are applicable for the thermal assessment in the Southern Hungarian Great Plain.

4. RESULTS

At first, we investigate the distributional characteristics of the subjective thermal sensation votes of the interviewees (Fig. 3). During the times of the interviews ‘slightly warm’ and ‘warm’ classes were selected the most frequently (31.2% and 21.9%, respectively), which can be attributed to the investigated seasons (from spring to autumn). The proportion of ‘neutral’ and ‘slightly cool’ votes were also high, however the frequencies of extreme votes were negligible (Fig. 3).

As a following step, mean thermal sensation votes were calculated and plotted against the measured or calculated objective variables (T_a, RH, v, T_{mrt}, and PET). In the case of the T_a, the TSV values were averaged for each 0.5°C bin (resulting in *N*=63 discrete values). For RH, v, T_{mrt}, and PET the corresponding interval widths were set to 1% (*N*=69), 0.1 ms^{-1}(*N*=35), 1° C (*N*=68), and 1° C (*N*=46), respectively.

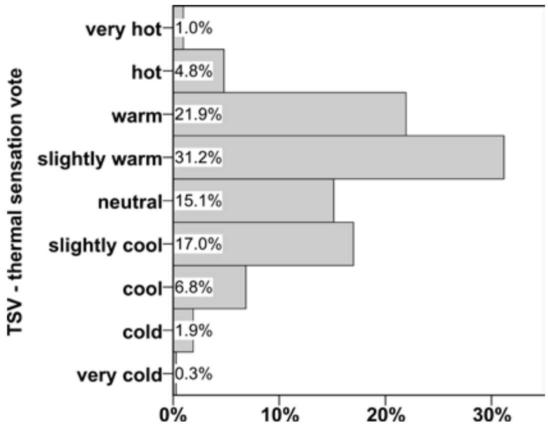

Fig. 3. Subjective assessment of the thermal environment according to the thermal sensation votes (TSV) of visitors (N=6080)

In the case of all thermal parameters, quadratic fit was better compared to the linear regression, resulting in higher determination coefficients (Fig. 4). According to the quadratic regression, strong positive relationships were found in the cases of T_a and T_{mrt} with R^2=0.947 and 0.848, respectively. Between TSV and v, the connection was only slightly weaker (R^2=0.835). In this case, the figure revealed negative tendency, thus stronger wind results in a shift toward cooler domain on the thermal sensation scale. The relative humidity also contributes to the formation of the thermal sensation similarly to the wind speed, however we can find the weakest relationship in this case (R^2=0.750) (Fig. 4).

The mean TSV shows the strongest correlation with the PET index which expresses the overall effects of the thermal environment. In the case of linear regression, the determination coefficient is 0.953, however the quadratic function describes the relationship better: R^2=0.976 (Fig. 5a). By substituting TSV=0 value in the fitted regression function we are able to determine the so-called neutral temperature, i.e. the temperature at which the visitors feel neither cool nor warm (Nikolopoulou and Lykoudis, 2006). The neutral temperature for Hungarian subjects seems to be 17.8°C in terms of PET (Fig. 5b), which is slightly lower than that indicated by the conventional European PET scale on which the class of 18–23°C corresponds to the neutral zone (Matzarakis and Mayer, 1996).

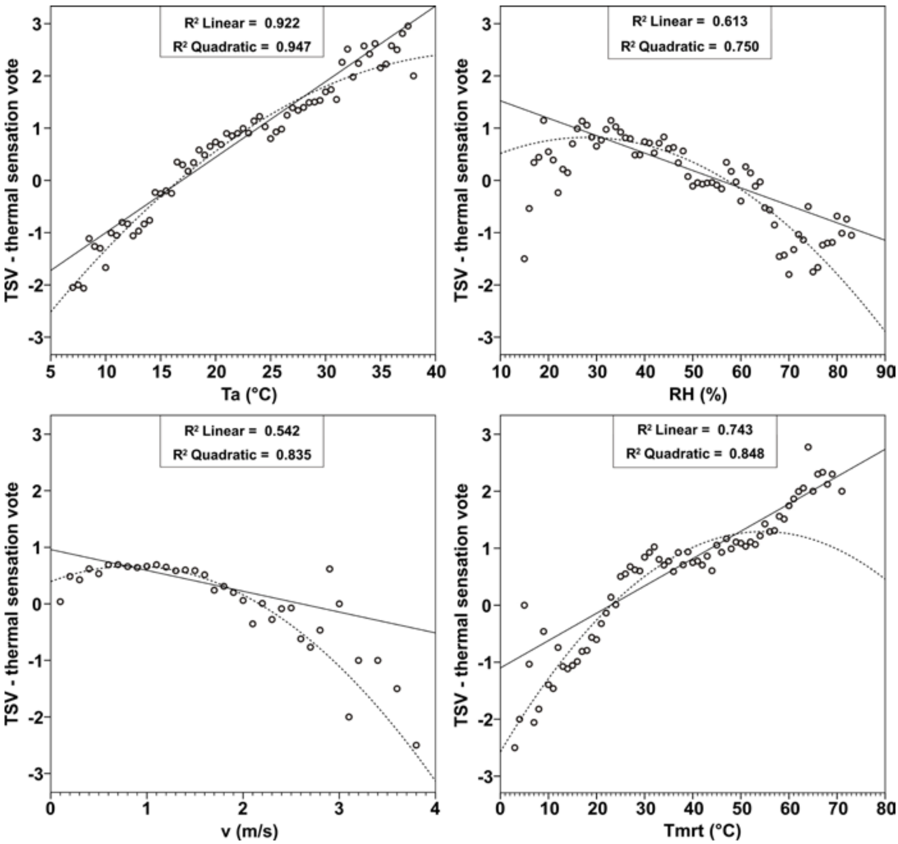

Fig. 4.Changes of the mean thermal sensation votes of visitors (TSV) depending on different objective parameters (T_a: air temperature, RH: relative humidity, v: wind velocity, T_{mrt}: mean radiant temperature)

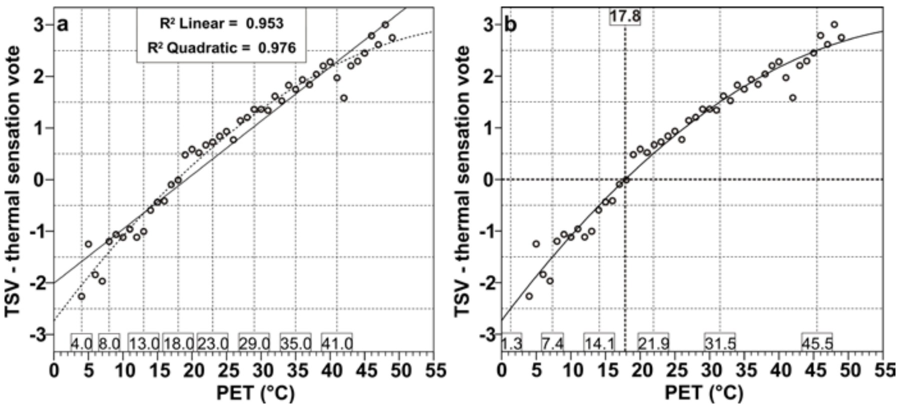

Fig. 5. Relationship between mean thermal sensation vote (TSV) and physiologically equivalent temperature [PET (°C)] according to linear and quadratic regressions. Dashed lines indicate the original (a) and modified (b) PET thermal sensation scale, while the dashed line indicates the neutral temperature for the Hungarians.

Based on the fitted PET–TSV quadratic equation, new PET class boundaries were derived. Figs. 5 and 6 illustrate both the original and the modified classes. The new ‘neutral’ and the cold categories shifted toward lower PET values compared to the original scale, indicating that the Hungarians feel themselves less uncomfortably in cooler thermal conditions compared to the European subjects. The new ‘slightly warm’ domain overlaps with the original interval but it became twice as wide, and thus the ‘warm’ and especially the ‘hot’ domain moved toward higher values (Figs. 5 and 6). This indicates a decreased sensitivity of the Hungarians against the hot thermal conditions experienced outdoors.

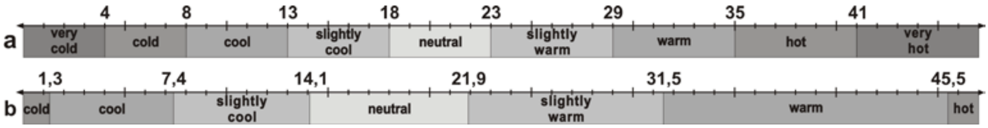

Fig. 6. The PET thermal sensation scale (°C) of Western and Central European people (Matzarakis and Mayer, 1996) (a) and the modified class boundaries for residents in the Southern Hungarian Great Plain (b)

5. CONCLUSIONS

Subjective thermal sensation of citizens in the Southern Great Plain Region of Hungary visiting outdoor public spaces and its relationship with objective climatic variables were analysed. We attached the measured climatic parameters to the subjective data individually, depending on the position of the meteorological stations and the respondents, as well as on their solar exposition.

The results of regression analysis supported that the PET index expressing the overall thermal effect of the thermal environment has the strongest influence on the visitors’ thermal sensation. Besides PET, air temperature and mean radiant temperature also has a strong and clear positive relationship with TSV. In the case of all investigated parameters, the quadratic regression resulted in better determination coefficients compared to the linear one.

The subjective thermal assessments of people can be highly different depending on the investigated geographical region with its special climatic conditions to which the local residents have been adapted. Therefore, we rescaled the well-known European PET thermal sensation classes according to the quadratic regression relationship between TSV and PET in order to reflect more properly the Hungarians’ thermal perceptions outdoors. The results indicate that neutral PET (at which the average TSV is equal to 0) of the Hungarians is lower than that suggested by the conventional scale. We found considerable shifts in the thermal sensation domains: while the ‘neutral’ and the cold classes shifted to lower PET values, the ‘warm’ and ‘hot’ domains moved toward higher ones. The extremely wide warm classes indicate a reduced ability of the Hungarians to distinguish the distinct levels of thermal stress in warmer environment. This can be very dangerous in hot conditions as they tend to assess these conditions less warm, spending too much time in extremely stressful conditions.

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