Visitors’ subjective estimations on thermal environment in public urban spaces

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Abstract

Our investigations were based on simultaneous questionnaire-surveys and on-site meteorological measurements in recreational urban spaces of Szeged (Hungary). In autumn and spring nearly 1000 visitors were asked about their estimations concerning the thermal environment. Thermal sensation showed stronger and positive relationships with air temperature and solar radiation perception, while the wind velocity and air humidity perception have negative (as well as weaker) impacts. If a parameter was perceived low or weak, then it was usually desired to be higher or stronger. Visitors are most sensitive to the variations of wind and radiant environment. Above the Physiologically Equivalent Temperature PET value of 27°C people usually prefer lower air temperature and less solar radiation.

1. Introduction

Thermal comfort in outdoor settings has received more and more research attention in the last decade (e.g. Spagnolo & de Dear, 2003; Thorsson et al., 2004). If the aim of a study is a survey on whether a public place offers appropriate conditions for the recreation, detailed information needed about the area itself and the thermal conditions evolved there. On the other hand, it is necessary to gather information on the visitors and their subjective assessments. This paper presents the influences of the momentary thermal conditions on the thermal comfort-related subjective reactions of Hungarians. These reactions are expressed by the visitors: (i) thermal sensation, (ii) perceptions of the particular microclimatic parameters (temperature, wind, humidity, solar radiation) and (iii) preferences for any changes of these parameters.

2. Materials and methods

A questionnaire-survey was carried out with simultaneous micrometeorological measurements in two green areas (Ady Square, Honvéd Square) of Szeged during September-October of 2009 and April-May of 2010. Data were collected on 29 weekdays from noon to 3 p.m. (CET, summer time). Szeged (46°N, 20°E, 82 m asl) is situated in south-eastern Hungary and belongs to the Köppen’s Cfb climatic region.

The questionnaires were based on mainly Stathopoulos et al. (2004), Oliveira & Andrade (2007), Lin (2009) and concerned the subjective assessment of the thermal environment. The visitors reported their *thermal sensation vote* (TSV) using a semantic differential scale with 9 main nominal categories: very cold, cold, cool, slightly cool, neutral, slightly warm, warm, hot and very hot. 7-point scales were used for measuring the respondents' *perceptions* about the momentary air temperature, wind velocity, air humidity and solar radiation. The *preference* for better conditions (decrease/no change/increase) was also measured in the cases of the single weather parameters.

Perception reflects what people sense at the moment while preference indicates the desire for ideal conditions (Stathopoulos et al., 2004; Oliveira & Andrade, 2007).

On-site meteorological data have been obtained by a mobile station equipped with Vaisala and Kipp&Zonen sensors in the height 1.1-1.2 m. The station includes a rotatable net radiometer to receive the short and long wave radiation fluxes from upward, downward, and from the four cardinal points of the compass. One-minute averages of air temperature (Ta), relative humidity (RH), wind velocity (v), short and long wave radiation fluxes (K and L) were recorded on a pendrive. The measurements were carried out near the interviewees (same solar exposure). From the individual fluxes the mean radiant temperature (Tmrt [°C]) was calculated (Höppe 1992). The measured Ta, RH, v and the obtained Tmrt were used to calculate the thermal comfort index Physiologically Equivalent Temperature (PET [°C], Mayer & Höppe, 1987).

The non-parametric Sperman's ρ correlation coefficient was computed to reveal inter-relationships among the 967 subjective assessments concerning the thermal environment (thermal sensation, perceptions, preferences). To compare the mean subjective estimations with objective measures the parametric Pearson's R was applied.

3. Results and discussion

Most of the interviews were carried out within a *Ta* range of 24-27°C, although values below 15°C also occurred. Wind speed fall mainly between 0.3-3.3 m/s with a maximum *v* of 6.7 m/s. The *RH* values between 30 and 50% dominated, but some interviews took place at 70-75%. The *Tmrt* incorporate a range of 10-60°C. Regarding the thermal comfort conditions in terms of the *PET* index the slightly warm class (23-29°C) occurred most frequently. This was followed by the neutral (18-23°C) and warm (29-35°C) categories. Fewer interviews were carried out during hot (35-41°C) slightly cool (13-18°C) and cool (8-13°C) thermal conditions.

The most frequent *TSV* was the slightly warm category, followed by the warm and neutral votes. Regarding the estimated climate factors *perception* values of 0 and +1 were the most frequent (parameters was perceived slightly strong or slightly high) and extreme perception votes (-3 or +3) hardly occurred. Asking about the *preference* for any changes the responses were mainly 0 (satisfaction with the prevailing conditions).

90% of the visitors perceived the *air temperature* as more or less high (0, +1 and +2 votes dominated) and most of them felt it suitable or wanted higher temperatures (0 and +1 preference votes). In the case of *wind speed* the perception values have almost the same numbers (20-25%) in the categories from -2 to +1. The overall subjective assessment reflects that the air was calm – moderate, and according to the preference votes who would like to some changes those wanted lower wind speed. *Air humidity* can be judged subjectively the least: the ratio of the middle (0) votes is the highest among the investigated climate parameters for both perception (45%) and preference (75%). In the case of the *solar radiation* positive perception votes dominate (0, +1 and +2) and most of the people longed for more sunshine (+1).

In favour of the more clear evaluation the percentage distribution of the preference votes by perception categories were also investigated for every climate parameters (Fig. 1). According to the expectations as the higher or stronger was felt a parameter the more people desired it to be lower or weaker. All of the presented relationships are significant (α<0.001); the Spearman ρ rank-correlation coefficients between perception and preference votes in the cases of all parameters are relatively large: ρ=-0.482, -0.415, -0.365 and -0.457 for air temperature, wind, humidity and solar radiation, respectively. Figs. 1a and 1d show that visitors prefer high temperature and strong solar radiation, as apart from the extreme +3 votes, for every perception category either they did not want the change or they wanted a positive change of the given parameter. In the cases of wind and humidity the calm and dry conditions were clearly desirable (Figs. 1b and 1c).

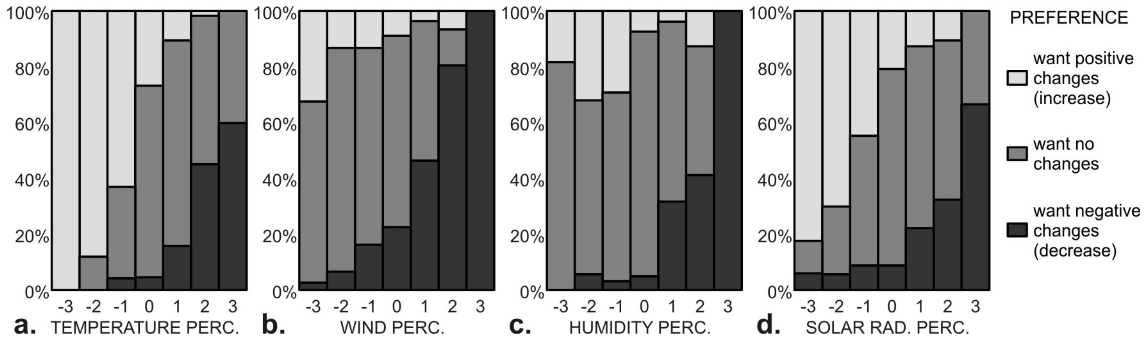

Fig. 1: Relationships between perception and preference votes

The next two figure-series show the relationships between the thermal sensation and the evaluations regarding the particular climate parameters. TSV has the strongest correlation with the perception of air temperature and solar radiation (ρ=0.558 and 0.502). That is the perception votes increased (temperature felt higher and solar radiation stronger) the ratio of the higher TSV-s also increased gradually (Fig. 2). In the case of wind and humidity perceptions the relationships are not so unequivocal: the coefficients are smaller, moreover their signs are negative (ρ=-0.182 and -0.163).

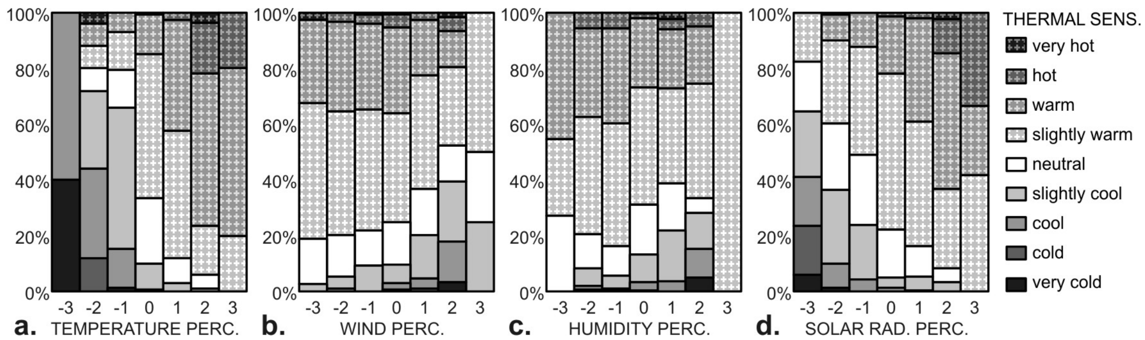

Fig. 2: Relationships between the thermal sensation and perception votes

As expected the connections between the TSV and preference votes have opposite directions compared to the TSV-perception relationships (Fig. 3). Accordingly, coefficients for preferences of air temperature and solar radiation are negative (ρ=-0.417 and -0.356), while for preferences of wind and humidity the connections are positive (ρ=0.283 or 0.090).

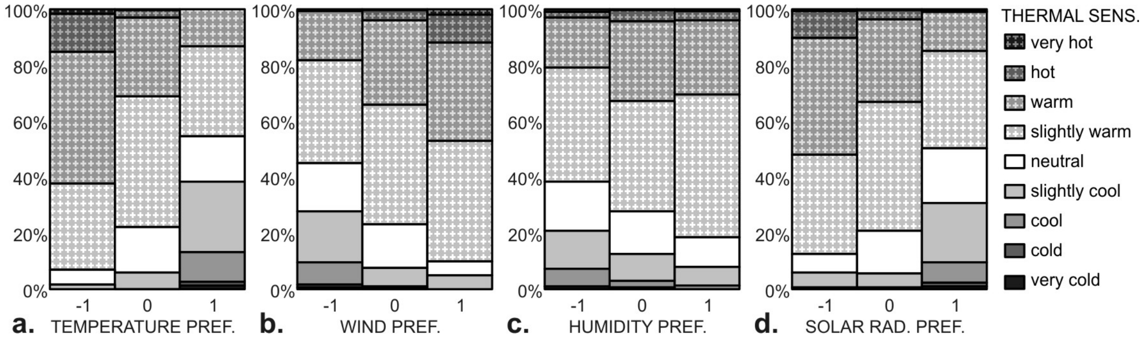

Fig. 3: Relationships between the thermal sensation and preference votes

We explored also how sensible the visitors are at the *perception of the particular objective parameters*. Even in the case of the same environmental conditions subjective perceptions may differ remarkably, thus perception values were averaged and plotted against the objective variables (Fig. 4). Temperature perceptions were averaged for each 0.5°C Ta bin, resulting N=32 discrete values (Fig. 4a). The interval-widths were 0.1m/s v for wind (N=47), 1% RH for humidity (N=44) and 1°C Tmrt for solar radiation (N=47) perceptions (Figs. 4b-d). The slopes of the fitted lines indicate the sensitivity of respondents against the objective variables. The lowest slope value was found in the case of humidity and the largest at solar radiation, as the obtained mean perception values are in the narrowest range in the former case (from -1 to +1) and in the wider range in the latter case (from -2.5 to +2.5). The fitted regression lines give the best determination coefficients in the cases of Tmrt – solar radiation and v – wind perceptions: R^2= 0.834 and 0.684, respectively.

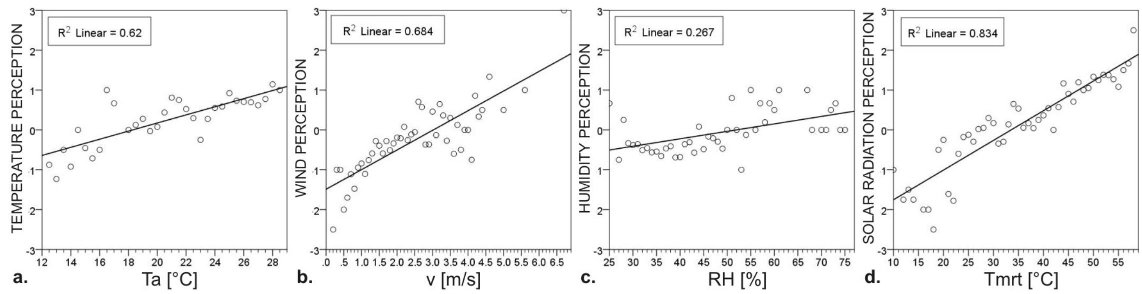

Fig. 4: Mean perception votes vs. corresponding meteorological parameters

As a next step we investigate how the mean *preference votes* varied as a function of the *corresponding objective parameters* (Fig. 5). As expected there are negative relationships between them. The Ta – temperature preference connection is the strongest (R^2=0.723) followed by the Tmrt – solar radiation preference (R^2=0.665), v – wind preference (R^2=0.594) and finally, the RH – humidity preference (R^2= 0.204). According to the determination coefficients the correlation of Ta with the corresponding preference vote occurs stronger than with the perception (R^2=0.723 and R^2=0.620, respectively), while the Tmrt, v and RH are in a stronger connection with the visitors' perception votes than with their preferences.

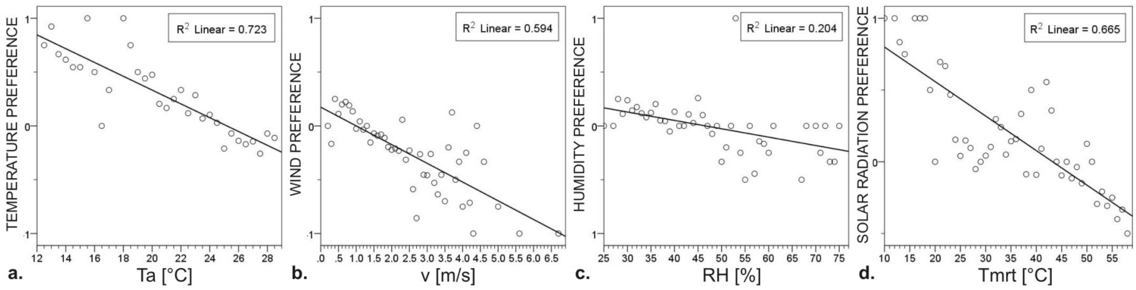

Fig. 5: Mean preference votes vs. corresponding meteorological parameters

We examined also whether the connections of the *subjective evaluations (perceptions and preferences)* with the corresponding meteorological parameters are stronger than with *PET* expressing the combined effect of the climatic factors on the thermal sensation. Therefore we compiled a row of diagrams (Fig. 6) with PET values on the x axis (1°C bin, N=31) instead of Ta, v, RH and Tmrt.

The relationships with PET are stronger in almost every case than with the corresponding objective parameters. Exceptions are only the perceptions of wind and solar radiation which have lower R^2 values with PET (Figs. 6b and 6d) than with the v and Tmrt values (Figs. 4b and 4d). At wind and humidity the relations have different signs: at the increase of the PET values the people's perception-votes become lower, while the preference-votes higher. According to the fitted regression lines, people prefer for lower air temperature and less sun from PET = 27°C (Figs. 6e and 6h), which value is in the category of slight heat stress or slightly warm thermal sensation (based on the PET-scale referring to Central-Europeans). Visitors wished more air movement from PET = 30.5°C and wanted the decrease of humidity below PET = 22.5°C (Figs. 6f and 6g).

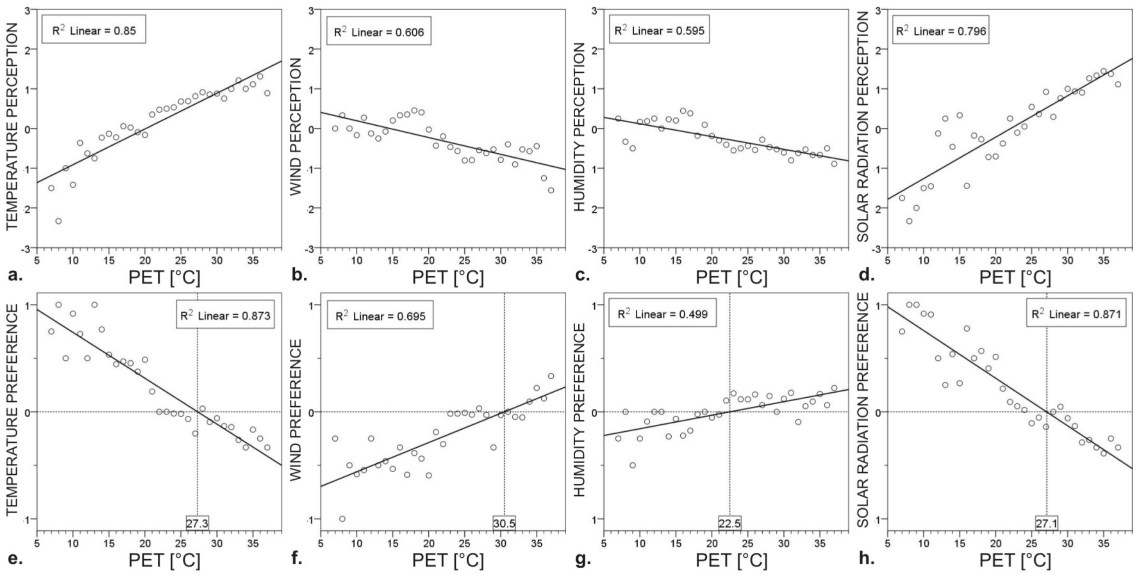

Fig. 6: Mean perception votes (a-d) and preference votes (e-h) vs. PET index (N=33)

4. Conclusions

This paper introduced a Hungarian thermal comfort study carried out in 29 weekdays in transient seasons (autumn and spring) in the centre of Szeged. Besides the on-site meteorological measurements 967 visitors were asked to assess the thermal conditions in terms of perceptions, preferences and thermal sensation.

Negative correlations was found between the perceptions and preferences in the cases of all meteorological variables, meaning that if a parameter was perceived weak, then it was usually desired to be stronger. Taking into account the large number of data the determination coefficients indicate relatively strong relationships, from which that refers on humidity is the weakest. Subjective thermal sensation relates stronger to the individuals' air temperature and solar radiation perceptions (positive correlation), than to their perceptions about wind velocity and air humidity (negative correlation).

Examination of subjective perceptions against the objective parameters of thermal environment (Ta, v, RH, Tmrt) set light on Hungarians pronounced sensitivity against the variations of air movement (v) and radiant environment (Tmrt). According to their perception and preference votes people react less to the changes of humidity (RH).

Conducting the same examination with PET instead of the basic parameters, we obtained stronger correlations with the perceptions and preferences of all the individual parameters, except for the perceptions of wind velocity and solar radiation. A "set-point value" has been arisen around PET=27°C, where Hungarians' preference votes change their signs, i.e. above this value they wished for lower air temperature and less solar radiation. They desired, however stronger air movement only in situations warmer than PET=30.5°C.

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