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OUTDOOR THERMAL COMFORT REQUIREMENTS OF TAIWANESE AND HUNGARIANS IN THE WARM MONTHS

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1. INTRODUCTION

Hastened by the problems arising with the urbanization and climate change, as well as with the emerging importance of human well being recognized in urban planning and landscape design, there is an increasing need for information about the way how local people react to outdoor thermal conditions in different urban public spaces. Correspondingly, more and more outdoor thermal comfort projects are conducted to study the thermal conditions of squares, parks, promenades, and many semi-outdoor places as arcades or public transport stations (e.g. ***Nikolopoulou et al 2001, Spagnolo & de Dear 2003, Thorsson et al. 2004, Oliveira & Andrade 2007, Hwang & Lin 2007, Kántor et al. 2012a***). Besides the micro-meteorological measurements information is gathered about the reactions of people given to the thermal environment, including both their behavioral reactions and their subjective thermal assessments. The human monitoring means usually an adequately designed questionnaire survey and/or an unobtrusive observation series conducted according to well-structured schedule.

The increasing number of such outdoor thermal comfort studies around the world makes possible international comparisons (e.g. ***Nikolopoulou & Lykoudis 2006, Knez & Thorsson 2006, 2008, Kántor et al. 2012b***); i.e. to study the differences between the nations in the way they perceive the environmental conditions and reveal the factors behind them. The differences can be explained usually by the different climatic background conditions to which people became adopted both physiologically and psychologically, as well as their cultural characteristics in which their environmental attitudes and behavioral reactions are rooting.

Although such international comparisons discuss many ideas worth for consideration, there may be several shortcomings when comparing the thermal comfort-related reactions (e.g. the neutral temperatures, thermal sensation and preference characteristics) of different nations. For example, different research groups applied different indices which prohibit the direct comparison of their results. E.g. several studies used the (Outdoor) Standard Effective Temperature (e.g. ***Spagnolo & de Dear 2003, Hwang & Lin 2007, Lin et al. 2011, Yahia & Johansson 2013)***, while others the Physiologically Equivalent Temperature (***Knez & Thorsson 2006, Oliveira & Andrade 2007, Lin 2009, Mahmoud 2011, Kántor et al. 2012a, Makaremi et al. 2012, Krüger et al. 2013***) or the Universal Thermal Climate Index (***Lindner-Cendrowska 2013***). The international comparison of the ‘thermal neutrality’ in different nations for example would be reliable only based on the same index and based on the very same analysis method. The problem at this point is that different researchers derived the ‘neutral temperatures’ and/or ‘preferred temperatures’, as well as determined thermal sensation zones and rescaled the indices for their local conditions based on different analysis techniques (regression technique, probit models, using different subjective assessment categories to define ‘thermal suitability/‘acceptability’, etc.).

Other important issues which may influence greatly the comparability of the obtained results:

- the time schedule of the field surveys (time of the day and months of the year),
- the applied measurement methods (especially the measurement of the thermal radiation),

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- the types of the questionnaire scales (thermal sensation, thermal acceptability, overall thermal comfort, thermal preference) and their grading (e.g. 3, 5, 7, 8 or 9-degrees).

One of the earlier international comparisons can be regarded as the direct antecedent study of the present paper. Namely, the results originating from the first Hungarian outdoor thermal comfort campaign (***Kántor et al. 2012a***) were compared to the outcomes of a Taiwanese field survey series (***Lin 2009***) by plotting the mean thermal sensation votes (TSVs) of both nations against the Physiologically Equivalent Temperature (PET) (***Kántor et al. 2012b***). However, in spite of the very similar field surveys, the same index and analysis method in both countries, there were some important differences which weakened the reliability of that international comparison. These disturbing factors included the investigation time: the Hungarian database embraced only the early afternoon hours (12 am – 3 pm), while the Taiwanese all the afternoon; moreover, the Hungarian surveys were conducted only in the transient seasons. Secondly, there were dissimilarities in the grading of the applied thermal sensation scales (Hungarian: 9-degree, Taiwanese: 7-degree). Moreover, the two investigations obtained the mean radiant temperature (T_{mrt}), i.e. the most critical parameter of the thermal environment by different measurement techniques.

This study **aims** to overcome on the above mentioned shortcomings and make a **more reliable Hungarian–Taiwanese comparison** which is free from the disturbing effects originating from the different measurement design, by using a more carefully chosen Hungarian and Taiwanese database. On the other hand, this paper aims to **present some new ideas to study the thermal comfort-related assessments of people**, by distinguishing the thermal perception (sensation) and thermal preference patterns, as well as to assign thermal sensation and thermal comfort / discomfort zones of people.

2. METHODOLOGY

2.1 *Outdoor thermal comfort surveys*

The Hungarian–Taiwanese comparison presented in this paper is based on the data collected in the frame of two outdoor thermal comfort projects which main attributes are summarized in **Table 1**.

Table 1 main information about the outdoor thermal comfort projects in Hungary and Taiwan

	Hungary	Taiwan
Climate	warm-temperate	hot-humid
City	Szeged	Taichung, Yunlin, Chiayi
Study areas	6 outdoor places	5 outdoor places
Time	10 am – 6 pm	8 am – 6 pm
Year	2011 – 2012	2005 – 2006
Months	~~March – Oct~~ June – Aug	~~Jan – Dec~~ Mar – Nov

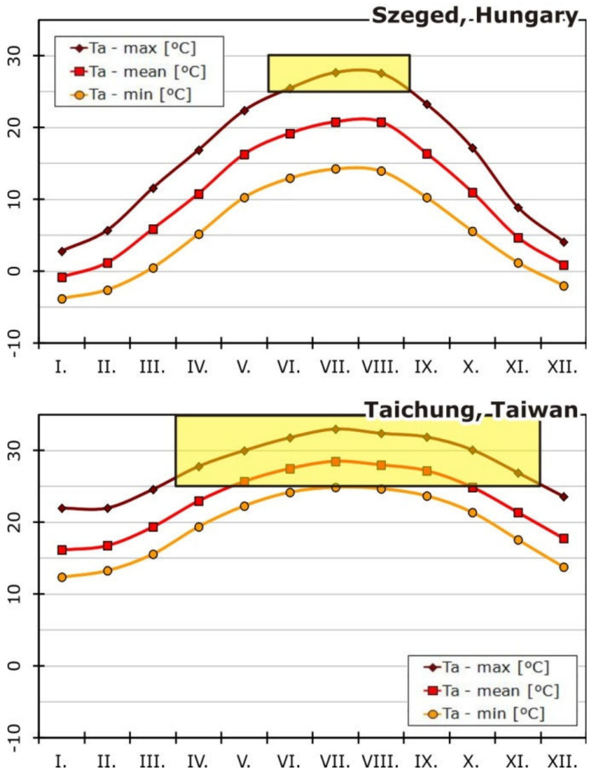

Figure 1 annual temperature distribution in Szeged and Taichung based on 1981–2010 data (Hungarian Meteorological Service; Central Weather Bureau). Yellow rectangles mark the months selected for the analysis presented in this paper based on the criteria: T_a max > 25°C.

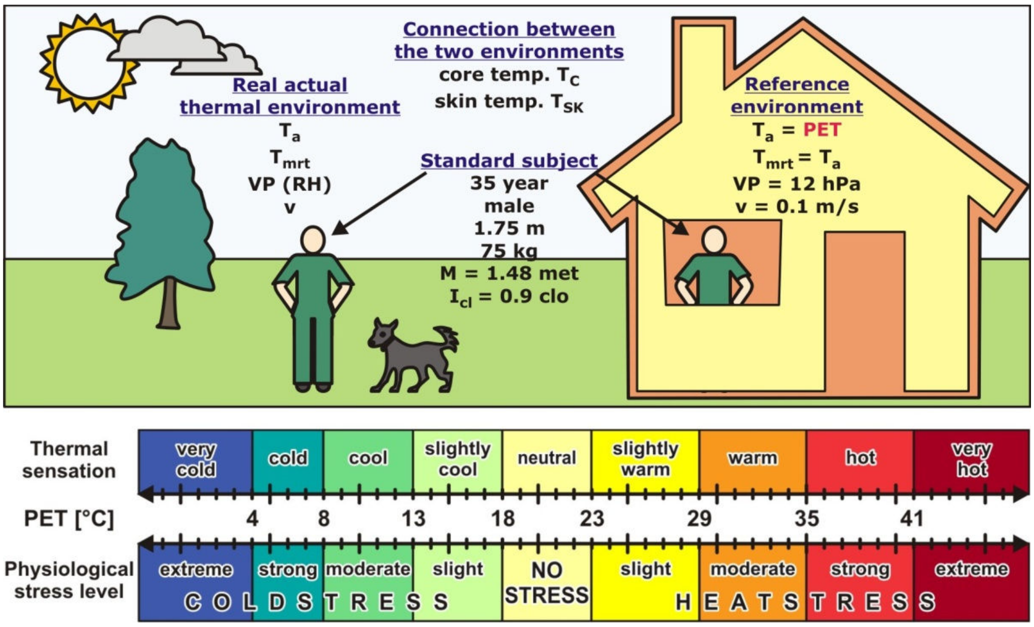

Figure 2 explanatory figure for the PET index (above) and its original thresholds (below) reflecting the thermal sensation classes and the physiological stress levels reaching the human body (constructed according to *Mayer & Höppe 1987, Höppe 1999, and Matzarakis et al. 1999*)

Both field survey campaigns were conducted in different urban environments and consisted of parallel micrometeorological measurements and questionnaire surveys with the users of the outdoor public places. The Taiwanese field surveys were conducted mainly during the year of 2005 in three Central Taiwan cities (***Hwang & Lin 2007***), while the Hungarian data were collected in the frame of the second great outdoor thermal comfort measurement campaign in Szeged, South Hungary (***Kántor & Kovács 2014***). While the Taiwanese measurements covered all months of the year, the two-year long Hungarian surveys focused only those seasons which are suitable for outdoor urban recreational activities in Hungary, namely spring, summer and autumn. Only those months were selected for the present analyzes which can be regarded as summer months; i.e. when the average value of daily maximum temperatures (T_a max) exceeds 25°C (**Table 1, Fig. 1**). These months include June, July and August in **Hungary** (**summer**), while they cover 9 months in **Taiwan** from March to November (**hot season**).

As an objective measure of the thermal environment, the **Physiologically Equivalent Temperature PET** [°C] was chosen. PET summarizes the combined thermo-physiological effect of the air temperature (T_a [°C]), air humidity (described with vapor pressure VP [hPa] or relative humidity RH [%]), wind velocity (v [m/s]), and the thermal radiation (expressed as the mean radiant temperature T_{mrt} [°C]) on the human body (***Mayer & Höppe 1987, Höppe 1999***).

The PET index can be interpreted as the air temperature (T_a) of a typical indoor environment (with T_{mrt}=T_a, VP=12 hPa, v=0.1 m/s) in which the human body experience the same level of thermal stress (and as a consequence has the same physiological reactions which result in the same body core temperature and skin temperature) as in the real outdoor environment which can be described with various T_a, T_{mrt}, VP and v values (**Fig. 2**). The PET thresholds presented on the **Fig. 2** refer to a typical Central-European subject; specifically a 35 year old, 1.75 m height, 75 kg male (with a basic metabolic rate of 80 W) who performs light activity (which contributes with additional 80 W to his metabolic rate and therefore his overall metabolism is M = 1.48 met) and who wears a typical suit (with a thermal insulation of I_{cl} = 0.9 clo).

Table 2 summarizes the instrumentation of the **micro-meteorological stations** applied during the Hungarian and Taiwanese field surveys to measure all of the parameters necessary to calculate the PET index.

Table 2 instruments measuring the parameters of the thermal environment and the accuracy of the sensors

	Hungary	Taiwan
T_a [°C] air temperature (& T_w – wet-bulb temp. in Taiwan)	Thermocap, WXT 520, Vaisala (±0.3°C at 20°C) (±0.25°C at 0°C)	Pt100 1/3 DIN with forced ventilation, LSI-Lastem (±0.1°C at 0°C)
RH [%] relative humidity	Humicap, WXT 520, Vaisala (±3% at 0–90%) (±5% at 90–100%)	from wet and dry bulb temperatures LSI-Lastem (±2% at 15–45°C)
v [m/s] wind velocity	ultrasonic anemometer, WXT 520, Vaisala (±3% or ±0.3m/s; the greater)	cup & vane anemometer, LSI-Lastem (1.5% at 0–3 m/s) (1% above 3 m/s)
T_g [°C] globe temperature	–	standard black globe with a Pt100 DIN-IEC 751 sensor (±0.15°C at 0°C)
K_i & L_i [W/m²] short- and long-wave radiation flux densities	Rotatable CNR-1 & CNR-2 net radiometers, Kipp & Zonen	–

The greatest difference between the Hungarian and the Taiwanese projects was in terms of the **radiation measurements and the calculation of the T_{mrt}** (mean radiant temperature), which is the most critical parameter of thermal environment; especially in outdoor environments during sunny conditions. The **Hungarian** group applied the **six-directional method** introduced by *Höppe* (*1992*) and measured the short- and long-wave radiation flux densities (K_i and L_i respectively) from 6 perpendicular directions (two vertical and 4 horizontal directions) with rotatable net radiometers consisting of 2 pyranometers and 2 pyrgeometers facing in the opposite directions. The T_{mrt} was calculated according to the equation (*Höppe 1992, VDI-3787 1998*)

$$T_{mrt} = \sqrt[4]{\frac{\sum_{i=1}^{6} W_i \cdot (a_k \cdot K_i + a_l \cdot L_i)}{a_l \cdot \sigma}} - 273.15$$

where a_k and a_l are the radiation absorption coefficients of the clothed human body in the short- and long wave domain (with 0.7 and 0.97 values, respectively), σ is the Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}$ W/m^2K^4) and W_i is the direction-dependent weighting factor (for a standing reference subjects W_i is 0.06 for the vertical and 0.22 for the horizontal directions, while for a spherical reference shape 0.167 value belongs to all directions).

The **Taiwanese** research group applied the **globe thermometer technique**; measured parallel the globe temperature (T_g), air temperature (T_a) and wind velocity (v) and calculated the T_{mrt} from these parameters according to the equation (*ISO-7726 1998*)

$$T_{mrt} = \sqrt[4]{(T_g + 273.15)^4 + 2.498 \cdot 10^8 \cdot v^{0.6} \cdot (T_g - T_a)} - 273.15$$

The T_g was measured with standard black globe thermometer which has the problem of absorbing too much radiation in the short-wave domain, and therefore the calculated T_{mrt} overestimates the real T_{mrt} in sunny situations.

To overcome the problem of the different radiation measurement techniques (six-directional and black globe), the **Taiwanese T_{mrt} values were recalculated and corrected** in every case when the strong direct solar radiation would result in an overestimation. The applied correction functions (different equations for sunny and cloudy situations) were derived by using a parallel radiation measurement series from the years of 2010–2011 conducted in Taiwan which included six-directional and black globe recordings. The 1-min averages of K_i and L_i as well as T_g, T_a and v values were collected in the daylight hours of 12 days (*Kántor et al. 2014*).

Table 3 lists those **characteristics of the questionnaire surveys** which are important for the present international comparison. To fit the age distribution of the Taiwanese survey, **only the 14–50 years old subjects were selected** for the Hungarian database. Moreover, to exclude the disturbing effects in thermal perception and preferences, this study **analyses only the healthy subjects**. Both nations' questionnaires asked people to assign their general health conditions according to the categories 'poorer than usual' / 'as usual' / 'better than usual'. Using this information only those became the subjects of this study whose self-reported health status was not poorer than usual. After applying these filters together with the measurement-season selection criteria (Hungarian summer and Taiwanese hot season), both nations' database included ca. 550–560 questionnaires (Table 3).

During the field surveys the main emphasis was on the evaluation of the thermal environment. Interviewees were asked to mark their **Thermal Sensation Vote** (**TSV**) on the standard ASHRAE thermal sensation scale in Taiwan, ranging from cold to hot. In Hungary, however, 9 main TSV categories was adopted to fit the variable outdoor thermal conditions as well as to correspond to the 9 thermal sensation classes of the PET index (Fig. 2). However, to make the international comparison as reliable as possible, in this study the categories of the Hungarian database are reduced and the extreme votes of –4 / +4 are turned into –3 / +3.

Table 3 main information about the selected questionnaires used in this study

	Hungary	Taiwan
Personal factors	age, gender, health conditions, etc.	
Criteria	14 – 50 year old subjects only healthy subjects	
Studied subjects	553	558
TSV	~~very cold (-4) – very hot (+4)~~ cold / cool / sl. cool / neutral / sl. warm / warm / hot	cold (-3) – hot (+3)
TPV	-1 / 0 / +1 want cooler / no change / want warmer	
SPV	-1 / 0 / +1 want less sun/ no change / want more sun	
WPV	-1 / 0 / +1 want slighter wind / no change / want stronger wind	

The other important elements of the questionnaires were about the **preferences** of the people. Subjects were asked to choose one from three options which express whether they want any changes in terms of some thermal parameters to feel (more) comfortable. For example, a **Thermal Preference Vote** (**TPV**) of 'want cooler' means that regardless of the current thermal sensation (e.g. neutral TSV) the subject would prefer a decrease in the temperature. Or the contrary, it is possible to wish for 'no changes' in temperature (TPV=0) in spite of the fact that the subject's TSV is warm. Taiwanese and Hungarian researchers applied the same 3-3 options also to measure the sunshine-, and wind-related preferences (Table 3), called as **Sun Preference Vote** (**SPV**) and **Wind Preference Vote** (**WPV**).

2.2 *Analyzes*

This paper investigates the national differences between Hungarians and Taiwanese subjects in terms of their thermal assessments in the warm months as a function of the PET index (as objective measure of the thermal environment).

In the case of the **thermal sensation**, mean values are calculated from the TSVs according to each 1°C-wide interval of the PET index, and then curves are fit to the 'mean TSV vs. PET' dot series. Contrary to the method applied by earlier studies, second degree functions are fit as they result in better determination coefficients (R^2 values). Using these functions the ***neutral temperature*** of Hungarians and Taiwanese can be defined as that PET value where the mean thermal sensation is neutral, i.e. mean TSV=0. Moreover national thermal sensation zones can be derived by substituting 0.5, 1.5, 2.5, etc. values as mean TSV into the mean TSV vs. PET function. E.g. the ***neutral zone*** is that PET range where the mean TSV is between –0.5 and 0.5. At this point it is worth noting that the original 9-degree TSV scale of the Hungarian project is more suitable to rescale the thermal sensation class boundaries of the PET index, as the 7-degree scale applied in this paper does not allow to allocate 'very hot' and 'very cold' thermal sensation zones.

To analyze the **thermal preference** patterns a different method is used, as in this case there were only three categories to chose (TPV: –1, 0, +1). Therefore instead of the mean values and regression analysis, it seems more suitable to analyze the probability of the different votes as a function of the PET index. First of all the percentage of the different TPVs are calculated in each 1°C-wide PET bin. Then probit models are fit to illustrate the changing probabilities of the 'want warmer' and 'want cooler' preference votes as the PET index increases. In this study the preferred temperature is ascertained differently than in the earlier studies (e.g. ***Hwang & Lin 2007, Lin et al. 2011***) where it was allocated at those temperature where the 'want cooler' and 'want warmer' probability lines crossed each other. Here the ***preferred temperature*** is assigned at that PET value where the probability of the 'want no change' thermal preference vote is maximal. (The probability of the 0 TPVs are calculated by subtracting the sum of –1 and +1 probabilities from 100%).

The ascertained preferred PET and its vicinity cane be regarded also as ***comfortable thermal conditions*** based on the definition: thermal comfort is the condition of mind that expresses satisfaction with the thermal environment, i.e. when the subjects wish for neither cooler nor warmer conditions. Using the 'want no change' probability line we can derive thresholds of this domain by identifying that PET range where at least half of the subjects is satisfied; i.e. where the probability of 'want no change' vote exceeds 50%. Based on the same idea, ***heat / cold discomfort*** can be started at those PET values above which / below which at least half of the subjects prefer cooler / prefer warmer conditions.

Besides the thermal preference votes, it is worth studying also the **sun and wind preferences** with the same technique and allocate ***other heat-related discomfort thresholds*** at PET values above which the probability of 'want less sunshine' and 'want stronger wind' votes exceeds 50%. This is based on the idea that the exposition to direct solar radiation causes extra heat load which contributes to the heat-related discomfort at higher PET values. Additionally, the cooling effect of the air movement is desirable at warmer conditions, except the cases of very high environmental temperatures when the convective heat transfer directs to the human body and not from the body, as well as the cases of very strong air movement when the degree of physical discomfort (e.g. dust blowing) may overcome to the wished cooling effect.

3. RESULTS

3.1 *Thermal conditions during the interviews*

Table 4 summarizes the micro-biometeorological background conditions of the interviews in Hungary and Taiwan. The T_a values were quite similar during the measurements (the mean difference is less than 2°C), but the Taiwanese subjects were exposed to much stronger radiation environment (compare the mean and median T_{mrt} values). The wind was only slightly stronger in Taiwan, but there were great differences in the VP and RH values revealing that the daytime humidity is much higher in Taiwan than that in Hungary (**Table 4**).

Table 4 range (minimum – maximum), mean, and median values of the measured and calculated objective parameters

	Hungary (N=553)	Taiwan (N=558)
PET [°C] range	17.6 – 53.9	17.9 – 49.8
mean; median	32.3; 32.2	41.4; 42.9
Ta [°C] range	19.9 – 38.1	17.7 – 36.9
mean; median	29.8; 30.4	31.6; 32.3
Tmrt [°C] range	20.8 – 70.8	23.6 – 66.1
mean; median	37.8; 35.0	54.8; 58.2
v [m/s] range	0.1 – 2.9	0.3 – 3.2
mean; median	0.97; 0.90	1.21; 1.00
VP [hPa] range	7.7 – 20.3	12.5 – 34.6
mean; median	14.4; 14.6	27.9; 28.5
RH [%] range	16.7 – 62.7	45.0 – 85.0
mean; median	35.5; 33.4	59.3; 60.0

Although the Hungarian PET range is wider and the maximal PET value is higher, the mean and median values obviously reveal that the heat stress was much stronger in Taiwan (**Table 4**). As there were only two extreme high PET values in Hungary they will be excluded from the subsequent 'thermal assessment patterns vs. PET-bins' analysis and only the common 18–50°C domain will be investigated.

3.2 *Distribution of the different thermal assessment votes*

Fig. 3 shows the frequency distribution of all assessment votes. The investigated database covers the warm months, correspondingly there are almost no ‘cool’ (–2) **TSVs** and the occurrence of ‘slightly cool’ (–1) votes is still very low. Interesting national difference is however that although the greater levels of heat stress (generally higher PET values) in Taiwan, Taiwanese subjects opted most frequently the ‘slightly warm’ (+1) votes followed closely by the ‘neutral’ (0) TSVs. In Hungary however the ‘warm’ (+2) and ‘hot’ (+3) votes dominated.

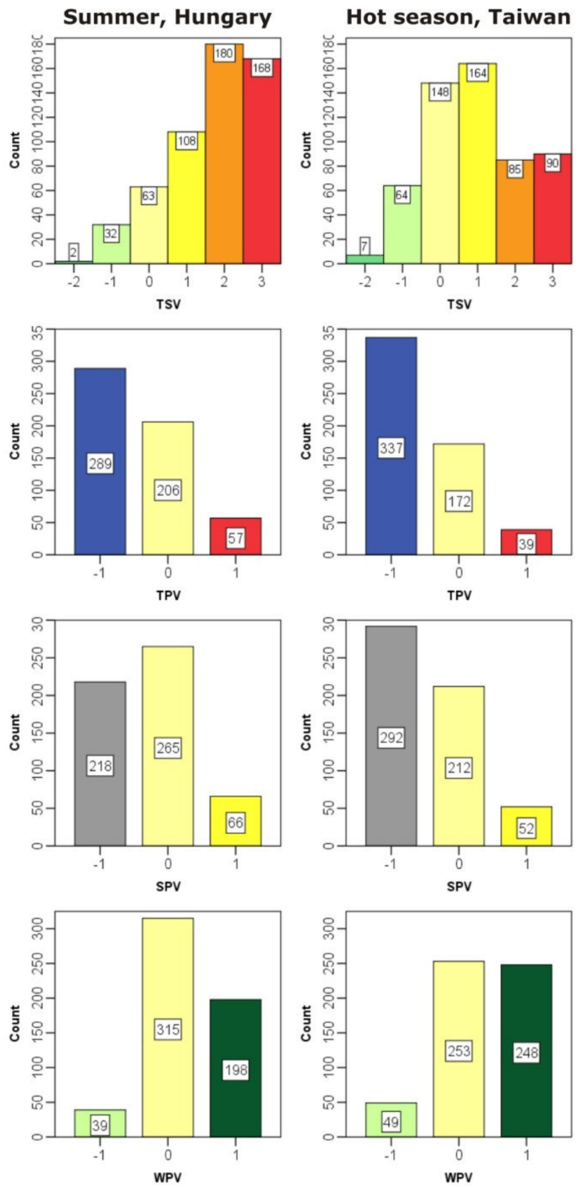

Figure 3 Number of cases when subjects voted for the different categories of thermal sensation (TSV), thermal preference (TPV), sun preference (SPV) and wind preference (WPV)

The order of **TPV** frequencies is the same in both nations: most of the subjects ‘wanted cooler’ (–1) and only few of them ‘preferred warmer’ (+1) conditions (Fig. 3). In Taiwan however the prevalence of ‘wanted cooler’ votes is more obvious. The distributions of sun and wind preference votes are totally different in Hungary and Taiwan.

In the case of Taiwan we can see similar tendencies of **SPVs** than in that of TPVs with the highest occurrence of ‘want less sunshine’ (–1). In Hungary however the ‘want no change’ SPVs dominated. In the case of wind preferences too, the occurrence of 0 **WPVs** is considerably higher in Hungary, while in Taiwan it equals to the ‘wish for stronger wind’ (+1) WPVs.

3.3 *Subjective thermal sensation vs. the objective thermal conditions*

According to the procedure described in *Section 2.2*, mean TSV values were calculated in each PET degree and plotted against them (Fig. 4). The derived ***neutral temperature*** is considerably higher in **Taiwan** (**26°C**) than in **Hungary** (**19.5°C**) indicating that Taiwanese people are better adapted to the hot environmental conditions.

Using the .5 mean TSV values the projected thresholds for the nationally updated PET–thermal sensation scales show totally different pictures (Fig. 4). The determined thermal sensation classes for the warm months of Taiwan covered the ‘slightly cool’ to ‘warm’ domains, while they included categories from ‘neutral’ to ‘hot’ in Hungary. The ***neutral zone*** locates not only at higher PET values but it is significantly wider in **Taiwan** (**21–33°C; 12°C wide**) than in **Hungary** (**17–22.5°C; 5.5°C wide**) meaning that Taiwanese people react less intensively to the changes of the thermal environment around the neutrally perceived conditions. However, their sensitivity seems to increase at higher PET values (greater slope of the fit curve; shorter ‘warm’ domain) while in Hungary we can see the opposite case (flattened curve at higher PET values; considerably wider ‘warm’ domain).

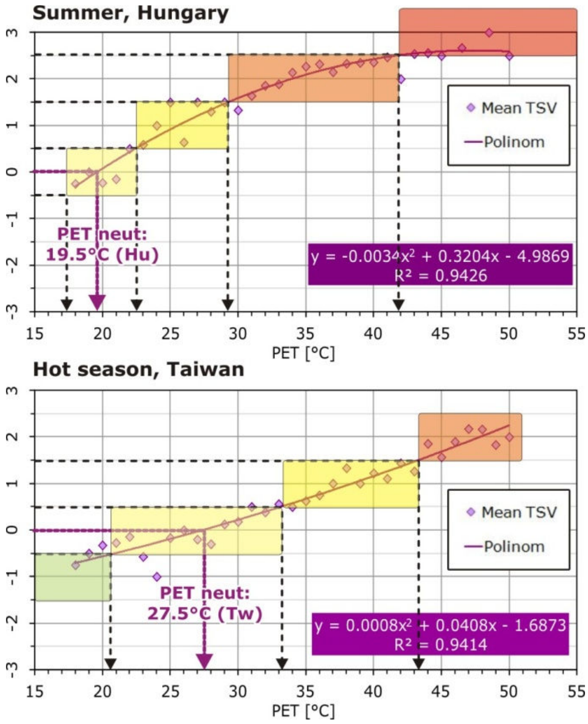

Figure 4 Mean TSV vs. PET functions as well as the derived ***neutral temperatures*** and ***thermal sensation ranges*** for Hungarians and Taiwanese

3.4 *Thermal preference vs. the objective thermal conditions*

Fig. 5 summarizes the analysis results based on the thermal preference votes. In line with the ideas described in *Section 2.2*, the preferred temperature was allocated at that PET value where the probability of the 'want no change' (0) TPVs is maximal. In Taiwan this maximal probability is 66%, while in Hungary it hardly reached the 50%. Surprisingly, the ***preferred temperature*** of **Hungarians** (**26°C**) was a little bit higher than the **Taiwanese** value (**23.5°C**).

According to Figs. 4–5, Hungarians perceive neutral at lower PET values (19.5°C), yet they wish for warmer conditions (26°C), while in Taiwan the neutral and comfortable conditions are closer to each other (27.5°C and 23.5°C) and the people prefer a bit cooler conditions.

Fig. 5 allows comparing the tolerance of Taiwanese and Hungarians against the changes of the thermal environment. Using the 50% as dividing line, the ***preferred / comfortable zone*** is defined here as those thermal conditions where at least half of the subjects are satisfied with the thermal environment and 'want no changes'. This zone is much wider in **Taiwan** (ca. **15–32°C; 17°C wide**) than in **Hungary** (**24.5–27.5°C; 3°C wide**) indicating that Hungarians express dissatisfaction much easier. This can be rooted in the different cultural background.

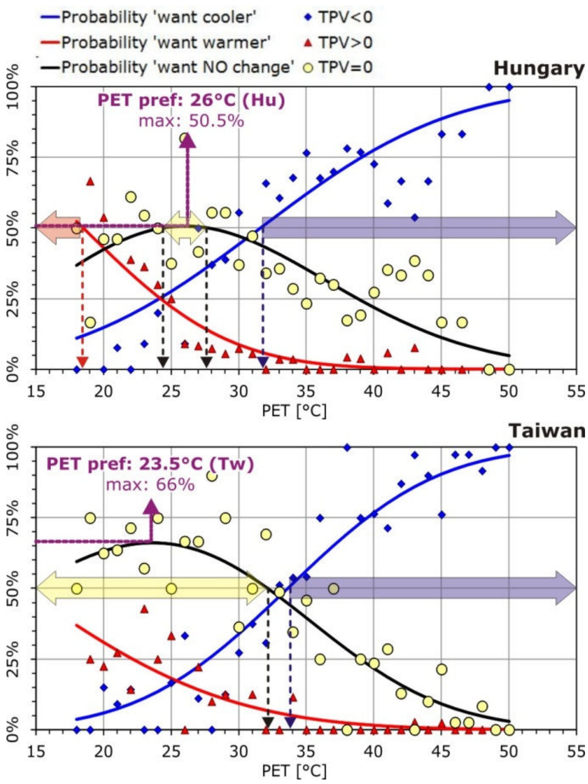

Figure 5 Probabilities of the different TPVs (–1: want cooler, 0: want no change and +1: want warmer) according to the PET as well as the derived ***preferred temperatures*** and ***thermal comfort/discomfort ranges*** for Hungarians and Taiwanese

The probability of the 'want cooler' TPVs exceeded the 50% above **33.5°C** in **Taiwan**. The corresponding ***heat discomfort threshold*** in **Hungary** was found at 2°C lower PET value (**31.5°C**). In the case of **Hungary** it was possible to assign also the ***cold discomfort threshold*** (**18.5°C**) based on the 50% probabilities of the 'want warmer' votes.

3.5 *Sun and wind preferences vs. the objective thermal conditions*

According to the expectations, the ‘wish for less sunshine’ (–1 SPVs) and ‘stronger wind’ (+1 WPVs) became dominant with higher PET values (Figs. 6–7). The national difference between the ***sunshine-related heat discomfort*** thresholds is only 1°C, meaning **36.5°C** in **Taiwan** and **35.5°C** in **Hungary** (Fig. 6).

The ***wind-related heat discomfort*** thresholds are more close to each other: it can be found at **39°C** in **Taiwan** and **38.5°C** in **Hungary** (Fig. 7). However, the probability lines of the wind preference votes are clearly different in Taiwan and Hungary; therefore it is worth discussing also the subjects’ wind preferences according to the wind speed as well.

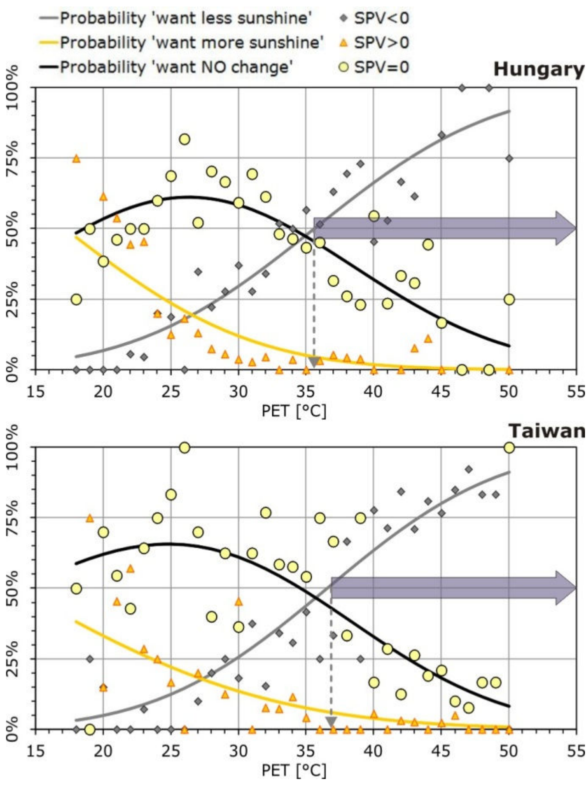

Figure 6 Probabilities of different Sun Preference Votes (–1: want less sunshine, 0: want no change and +1: want more sunshine) according to the PET as well as the derived ***want less sunshine thresholds*** for Hungarians and Taiwanese

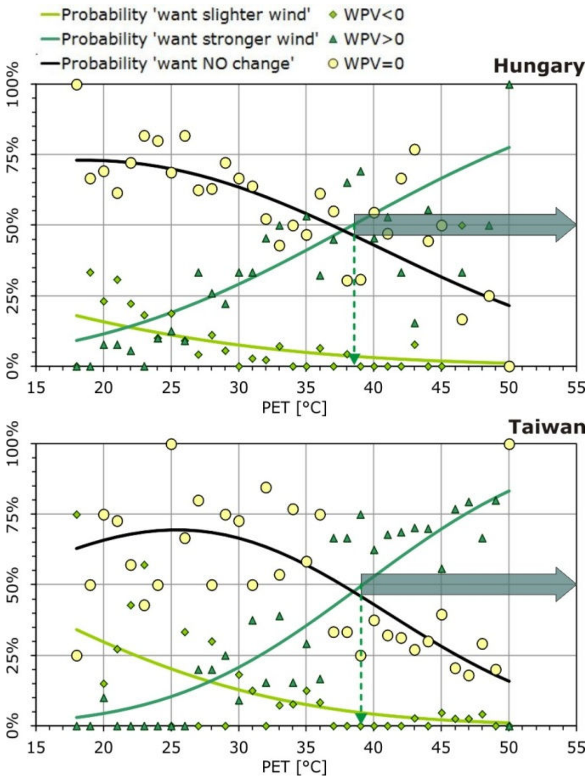

Figure 7 Probabilities of different Wind Preference Votes (–1: want slighter wind, 0: want no change and +1: want stronger wind) according to the PET as well as the derived ***want stronger wind thresholds*** for Hungarians and Taiwanese

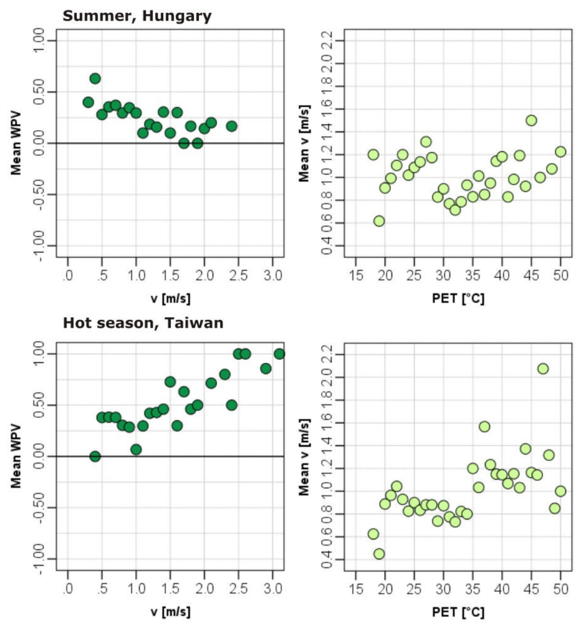

Figure 8 Mean WPVs in each 0.1 m/s-wide v bin, as well as the mean v vales in each 1°C-wide PET bin

The WPVs were averaged according to every 0.1 m/s-wide v interval, and then plotted against them (Fig. 8). Mean wind preference votes were always positive (mean WPV>0), indicating that most of the people wanted stronger air movement. This is the consequence of the data were gathered in the warm seasons with higher PET values (Table 4), therefore the people generally wished more intensive air movement to cooling their bodies.

However, the expected tendency is that with the increase of wind velocity the mean wind preference votes will become lower, namely the subjects wish for slighter air movement to avoid the physical discomfort. Fig. 8 confirms this tendency only in the case of the Hungarian subjects, and just the opposite trend can be seen for Taiwan. The unexpected tendency can be explained with the coincidence of stronger air movement and higher PET values in Taiwan, and the subjective preferences of Taiwanese, i.e. their desire for cooler conditions overcame the wish to lower the physical discomfort because of the stronger wind (Fig. 8).

4. SUMMARY

Fig. 9 summarizes the main findings of this study:

- The ***heat-related discomfort thresholds*** (the PET values above which at least half of the subjects want cooler conditions (–1 TPV), less sunshine (–1 SPV) and stronger wind (+1 WPV)) are closer to each other in Taiwan and start at a bit higher PET values than the corresponding thresholds in Hungary.
- Both of the ***comfortable domain*** (where at least 50% of subjects want no changes in temperature), and the ***neutral range*** (where the mean TSV is between –0.5 and 0.5) are much wider in Taiwan than the corresponding PET zones in Hungary. Accordingly, Taiwanese people are more tolerant against the changes of the thermal environment when the conditions are not too extreme.
- The ***neutral temperature*** (the PET value at which the mean TSV=0) is 8°C higher in Taiwan than in Hungary, proving that Taiwanese people are better adapted (physiologically and mentally) to the hot (and humid) climatic conditions.
- The ***preferred temperature*** (the PET at which the probability of 'want no change' TPVs is maximal) is 2.5°C lower in Taiwan than in Hungary, and it is below the Taiwanese neutral temperature. This indicates that although Taiwanese people got accustomed to the heat, they prefer somewhat cooler conditions, while Hungarians assess as comfortable clearly warmer thermal conditions than that they perceive neutral.

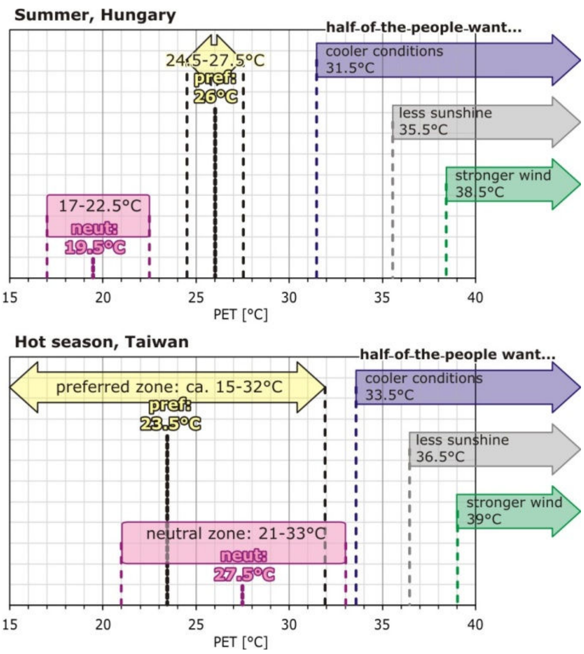

Figure 9 Characteristics of the thermal conditions related assessment patterns of Hungarians and Taiwanese in the warm months

Finally, Fig. 10 proves that thermal neutrality does not equal thermal preference:

- The ***preferred thermal sensation*** (the TSV where the mean TPV=0) in the warm months is **neutral** (-0.15) in **Taiwan** and **slightly warm** (0.8) in **Hungary**.

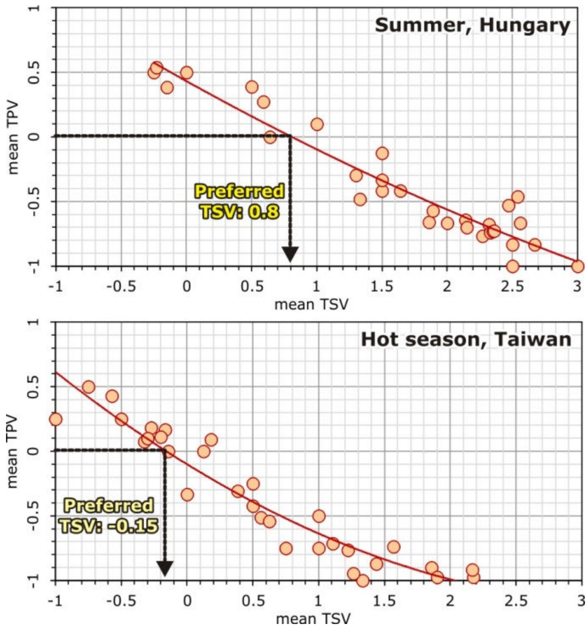

Figure 10 Preferred thermal sensation of Hungarians and Taiwanese in the warm months: that mean thermal sensation vote where the mean thermal preference vote equals 0

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