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HUMAN BIOCLIMATOLOGICAL EVALUATION WITH OBJECTIVE AND SUBJECTIVE APPROACHES ON THE THERMAL CONDITIONS OF A SQUARE IN THE CENTRE OF SZEGED

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Összefoglalás – A vizsgálat egy szegedi belvárosi tér humán bioklimatológiai értékelését tűzte ki célul. 2006 nyarának végén (augusztus 17, 22, szeptember 12) az Aradi vértanúk terén felállított mikrometeorológiai állomás segítségével mértük az emberek termikus komfortérzetét befolyásoló meteorológiai tényezőket, melyekből azután a RayMan modell segítségével termikus indexeket számítottunk. A kapott eredményeket összevetettük a mérésekkel egyidejűleg, kérdőívek felhasználásával nyert információkkal, melyek a területen tartózkodó emberek szubjektív véleményét tükrözik, hogy meghatározhassuk az emberek szabadtéri tartózkodását és termikus komfortérzetét leginkább befolyásoló tényezőket. Eredményeinket összevetettük a hasonló körülmények között végzett svéd és japán vizsgálatok eredményeivel.

Summary – The aim of the present study was the human bioclimatological assessment of a square in the centre of Szeged. We measured the meteorological factors influencing people's thermal comfort level on the Aradi square at the end of the summer of 2006 (17th, 22nd August, 12th September) with the help of a micro-meteorological station. Using these observational data we calculated the thermal indices with the RayMan model. We compared these (objective) results with the information derived from simultaneously filled questionnaires that reflected the subjective opinion of the people staying in the area, in order to determine the factors, which most likely influence the people's outdoor staying and sensation of thermal comfort. Our results were compared with results of Swedish and Japanese investigations with similar conditions.

Key words: urban square, thermal comfort, objective methods (meteorological measurements, modelling), subjective methods (social survey)

1. INTRODUCTION

Due to the increasing urbanization, people spend less and less time in the open air, and therefore the city parks and squares of appropriate qualities and quantities could play an important role in the recreation and outdoor activities of the city-dwellers. Up to now several comfort indices were created, which describe the thermal conditions of indoor or outdoor areas in the terms of human bioclimatology. Our long-term aim is to help the development of a universal thermal comfort index, which can be applied independently of the climatic zones (*Spagnolo and de Dear*, 2003), and of which the usage makes possible the evaluation of both indoor and outdoor areas. For this purpose, a thorough examination of the factors behind the – especially outdoor – thermal sensation is necessary; particularly the psychological reactions triggered by the area (*Nikolopoulou and Steemers,* 2003*, Nikolopoulou and Lykoudis,* 2006, *Thorsson et al*., 2004). Moreover, the examination of the different reactions of people living in different geographical regions/cultures for similar thermal conditions is also highly important (*Knez and Thorsson,* 2006).

The goal of the present study is the human bioclimatological evaluation of a square in the centre of Szeged using objective and subjective methods. We measured meteorological factors with a meteorological station and we calculated thermal indices (*PET* and *PMV*, see in *Section 2.2.1*) from these. Then we compared these (objective) results with simultaneously gathered information, derived from a social survey and reflecting the subjective opinion of the people staying in the area at the time. We did that in order to determine the factors that most likely influence people's attitude of staying outdoors and their sensation of thermal comfort.

2. MATERIAL AND METHODS

2.1. Study area

We took our examinations in Aradi square at the end of the summer of 2006 (17th, 22nd August, 12th of September) in Szeged. Based on large-scale climatic classification the region belongs to the Köppen *Cf* (warm-temperate with even distribution of precipitation) or the Trewatha *D.1* (continental climate with longer warm season) climate zone (*Unger and Sümeghy*, 2002).

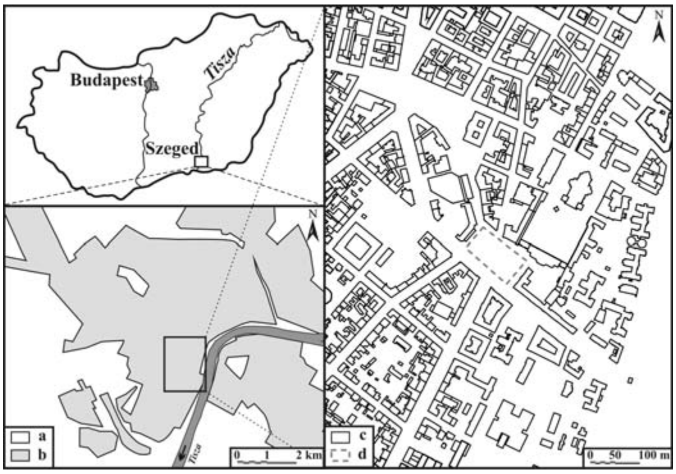

Fig. 1 Location of Szeged in Hungary, as well as the location of the study area in Szeged: (a) open area, (b) built-up area, (c) buildings, (d) border of the investigated square

The area of the Aradi square (*Figs. 1 and 10*) is about 7300 m^2, and it is divided by tram rails from south to north. Its west side is covered by pavements and grass courts, while the east side is dominated by asphalt cover. There are plenty of deciduous and some coniferous trees on both sides of the square, which offer shadow for people in the warm period.

2.2. Methods

We applied objective and subjective methods in order to get an appropriate picture of the thermal conditions of the area. The objective approach is based on thermal indices calculated from measured meteorological parameters with the help of one of the comfort-models (RayMan). The basis of the subjective method was the investigation of the people's opinion visiting the area in the form of questionnaires. The two approaches have been applied simultaneously in order to compare the obtained results with each other.

2.2.1. Objective method

The two human bioclimatological indices we used are the *PMV* (Predicted Mean Vote) and the *PET* (Physiological Equivalent Temperature). *PMV* predicts the mean assessment of the thermal environment for a large sample of human beings by values according to the seven-point (from -3 to +3) ASHRAE comfort scale (*Table 1*) (*Mayer and Höppe*, 1987). In real (extreme) weather situations *PMV* can be higher than +3 or lower than -3.

Table 1 Comparison of *PMV* (Predicted Mean Vote) and *PET* (Physiological Equivalent Temperature) ranges for different human sensations and thermal stress level by human beings. (Internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo) (*Matzarakis et al.,* 1999)

PET (°C)	PMV	Human sensation	Thermal stress level
		very cold	extreme cold stress
4			
	-3	cold	strong cold stress
8			
	-2	cool	moderate cold stress
13			
	-1	slightly cool	slight cold stress
18			
	0	comfortable	no thermal stress
23			
	1	slightly warm	slight heat stress
29			
	2	warm	moderate heat stress
35			
	3	hot	strong heat stress
41			
		very hot	extreme heat stress

PET is based on the Munich Energy Balance Model for Individuals (MEMI), and is defined as the air temperature at which the energy balance for assumed indoor conditions is balanced with the same mean skin temperature and sweat rate as calculated for the actual outdoor conditions (*Mayer and Höppe* 1987). A *PET* value of around 20°C is characterised as comfortable, higher values indicate increasing probability of heat stress, and lower values indicate increasing probability of cold stress (*Table 1*).

The meteorological data have been obtained by a HWI type mobile meteorological station with Vaisala and Kipp&Zonen sensors, which was placed in a point of the area (*Fig. 3*), where it was exposed to direct radiation during the whole day. *Table 2* contains the characteristics of the sensors for air temperature (T_a), relative humidity (*RH*), wind velocity (v) and global radiation (*G*). The ten-minute averages of the parameters were recorded by a data logger, in the first two occasions from 8.00 a.m. to 7.00 p.m., and in the 12th of September from 8.00 a.m. to 6.00 p.m.

Using the measured parameters we calculated comfort indices *PMV* and *PET* with the help of the RayMan model, developed according to guideline 3787 of the German Engineering Society (*VDI* 1998), which calculates the radiation fluxes within urban structures based on parameters including air temperature, air humidity, degree of cloud cover, air transparency, time of day and year, albedo of the surrounding surfaces, and their solid angle proportions (*VDI* 1994). *Fig. 2* shows the picture of the investigated area, generated with RayMan.

Table 2 Measured meteorological parameters, instruments and accuracy

Parameter	Instrument	Accuracy
T_a (°C)	Vaisala	± 5 %
RH (%)	Vaisala	± 5 %
v (ms^{-1})	Vaisala	± 5 %
G (Wm^{-2})	Kipp&Zonen	± 1-3 %

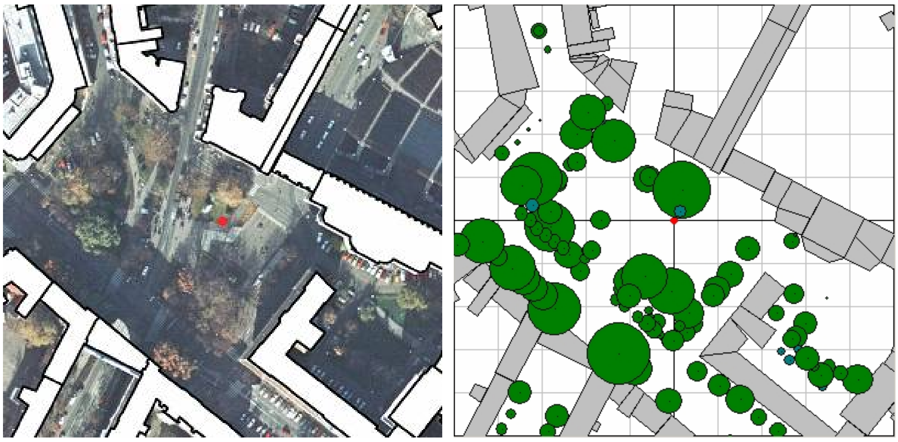

Fig. 2 Aerial view of the Aradi square (the buildings are stressed) (left), and the simplified picture of the square generated by RayMan (right). The place of the measuring station is marked by red.

Especially during sunny weather, the mean radiant temperature (T_{mrt}) is the most important input parameter for the energy balance – thus also for RayMan – therefore the recent comfort-indices include it. T_{mrt} is defined as the uniform temperature of a surrounding surface giving off blackbody radiation (emission coefficient = 1) which results in the same energy gain of a human body as the prevailing radiation fluxes (*Höppe*, 1992). T_{mrt} may be an input parameter for RayMan as well as an output provided the above mentioned parameters are known.

2.2.2. Subjective method

In order to find the psychological factors behind the attendance of the outdoor areas and the thermal comfort sensation which emerges there, we made a social survey with structured interviews simultaneously with the meteorological measurements. Altogether 844 questionnaires were filled by the answers of the randomly selected people during the 3 days mentioned above. Each interview took about 2-3 minutes, and the questioner recorded the time of the beginning of the interview. According to an earlier arrangement – with a few minor modifications – we used the questions already used by *Knez and Thorsson* (2006) in their investigation in Sweden and Japan.

At the beginning of the interview we recorded the subject's position (whether he/she is on the sun or in shadow; sitting / standing / walking), and his/her clothes as well. The data on clothes were converted into the clo-unit typical of summer clothes (*Spagnolo and de Dear*, 2003). Demographic variables, such as age, sex and whether the subject works or lives near the square were recorded, too.

First the following simple questions were asked from the interviewed persons:

- "*How often do you come here?*" (daily; plenty times a week; few times a week; few times a month; rarely; it is the first time)
- "*What is your main reason for being here?*" We were curious whether the area was only on the subject's way going home / school / etc., or he/she purposely came to the place in order to walk / be in the open-air / meet somebody / etc., or both of them.
- "*How long have you been in the open air, and in this area?*" The time was measured in minutes.

Then they were asked to answer the following questions by responding to scales ranging from 1 to 5:

- "*What do you think about today's weather?*" (a) cold/warm; (b) calm/windy; (c) dry/humid and (d) bad/good for outdoor activity.
- "*What do you think about the momentary conditions of the square?*" (a) cold/warm; (b) calm/windy; and (c) dry/humid; (d) unpleasant/pleasant
- "*How do you feel yourself in the square at the moment?*" (a) tired/fresh; (b) gloomy/glad; (c) nervous/calm.

Participants also estimated their thermal comfort by responding to a 9-point scale ranging from very cold (-4) to very hot (+4), with a score of 0 rating as comfortable (*Knez and Thorsson*, 2006). This vote is referred to as *ASV (Actual Sensation Vote)* and it is a subjectively perceived value reflected one's thermal sensation-level.

We asked the participants about what they thought the actual temperature was This is the *estimated temperature* (T_{est}). The estimation was helped by 9 temperature grades.

The questionnaire also measured the participants' *urban vs open-air person attitude* on a 5-point scale ranging from 1 (mostly urban person) to 5 (mostly open-air person) related to the question: "How much of an urban person (find pleasure in street life, shops, the amusements of the city) and open-air person (find pleasure in the sea, the woods, nature) are you?".

With the help of the questionnaires we can clearly get a lot of information, which cannot be achieved by the "traditional" estimation using indices that are relevant only in thermo-physiological terms.

3. RESULTS AND DISCUSSION

The results are discussed in the next steps:

- Presentation of the daily variation of the measured parameters and the indices.
- Analysis of the data from the structured interviews.
- Comparison of the calculated (objective) data and the people's subjective opinions.
- Comparison of the information obtained from the questionnaires belonging to the comfortable *PET*-range with the earlier published (*Knez and Thorsson*, 2006) Swedish and Japanese results gained in similar circumstances.

3.1. Evaluation of the objective measurements

Fig. 3 shows the daily variation of different indices on the first day. According to it, the running of the *PET* can be compared rather with the T_{mrt}, than with the T_a. The variation of the *PMV* was almost the same as that of the *PET* (not shown). This indicates one of the most important characteristics of RayMan: the significant role of the radiation conditions during the calculation of the indices; namely the people's thermal comfort sensation is mainly determined by the amount of radiation they are exposed in a given place.

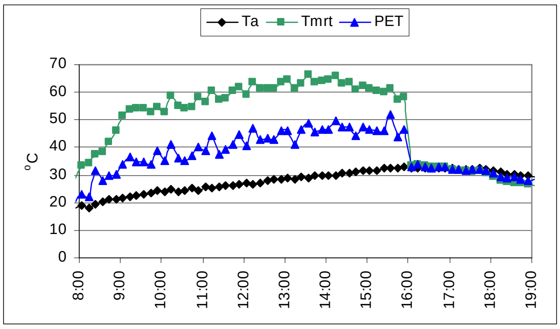

Fig. 3 Daily variation of T_a, T_{mrt} and *PET* on the Aradi square in Szeged (17th August 2006)

3.2. Evaluation of the subjective measurements

During the three days the majority of the interviewed persons were young, preferred to stay in the shade, and attended the square daily (sometimes more than one occasion). Most of the people found the weather warm, dry and calm (and so they thought about the momentary weather conditions, too), and a remarkable majority found it appropriate for open-air activities (*Fig. 4*).

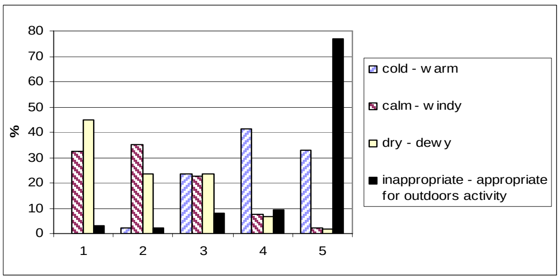

Fig. 4 Frequency of the answers for the current days in 5-degree scales

In order to know if there is any difference between the answers of the people with "urban vs. open-air attitude", how this characteristic effects the answers, and which answers are affected the most, the originally 5-degree scale was simplified to a 3-degree (so 1 and 2 were the "urban", 3 was the "neutral", 4 and 5 were the "open-air" category) one. This operation was performed for other opinions with 5-degree scales too. Apart from the question for tiredness and the *ASV* relating to the comfort sensation we found no connection with the "urban vs. open-air" attitude. The people with "open-air" attitude are usually more tired than the ones with "urban" attitude (*Fig. 5*) and the "neutral" ones find most likely comfortable the actual conditions of the square (*Fig. 6*).

The explanation for the more tired mood of the "open-air" people is that although they would have more gladly spent their times in nature, somehow they had to stay in the town, of which the crowdedness and noise-level influence affects that kind of people more negatively. However, they found the place as much comfortable as the people with "urban" attitude (*Fig. 6*), which is more likely due to the fact that the design of the square is very reminiscent of a park (which counterbalances the inconvenience of the urban environment to a certain extent).

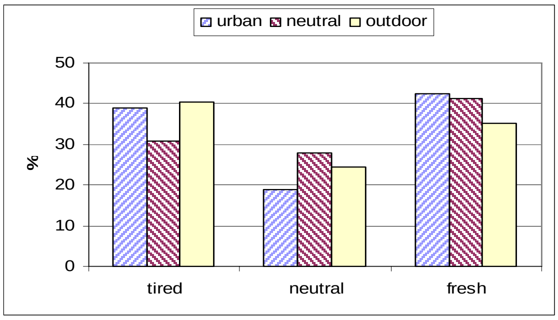

Fig. 5 Frequency of the actual tiredness of the interviewed persons according to the "urban−open-air" attitude

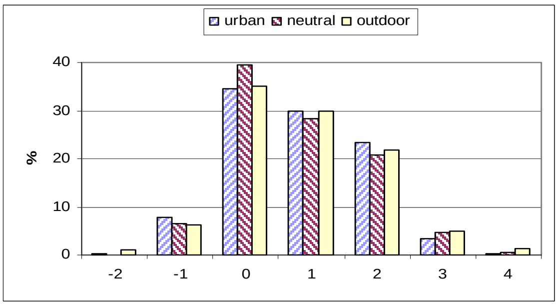

Fig. 6 Frequency of the *ASV*-values relating the people's actual comfort sensation according to the "urban-open-air" attitude

3.3. Comparison of the two different approaches

Comparing the *ASV* relating to the human thermal sensation with the *PMV* calculated with the model, we realized that the vote number reflecting the people's subjective opinion in comparison with the *PMV* occurs more likely in the 'comfortable' domain and those that border, and rarely occurs in the categories indicating extreme stress-level (*Fig. 7*).

The explanation of the phenomenon is the following: people prepare themselves for much more extreme conditions during their staying in the open-air, which leads to the widening of 'comfortable' and its neighbouring domains. However, the applied indices relate to the indoor reference-conditions, and they were developed in connection with the comfort zones typical of indoor areas. These zones are much narrower, because of the thermal conditions expected in buildings are artificially maintained near the comfortable level. With this it can be also explained that some of the calculated *PMV* values exceed the limits of the expanded (from -4 to +4) scales (*Fig. 7*). So in the light of the results it is inappropriate to apply the indoor comfort zone without modifying its limits in outdoor examinations.

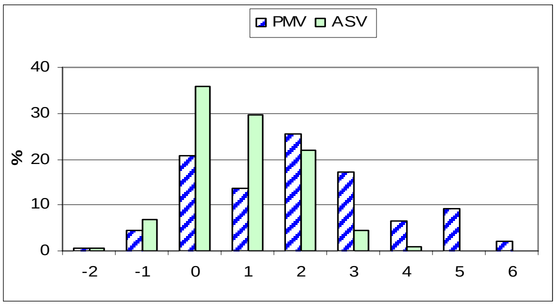

Fig. 7 Frequency of the calculated *PMV* and the interviewed *ASV* values

If one spent more time in the area of examination, the difference was substantially smaller between the *ASV* given by the person and the actual *PMV* (*Fig. 8*). According to this the RayMan model and similar models can give a real outcome in the case of long-term exposure, thus they are appropriate only in a limited way for the evaluation of the sensation of people with a short-time exposure.

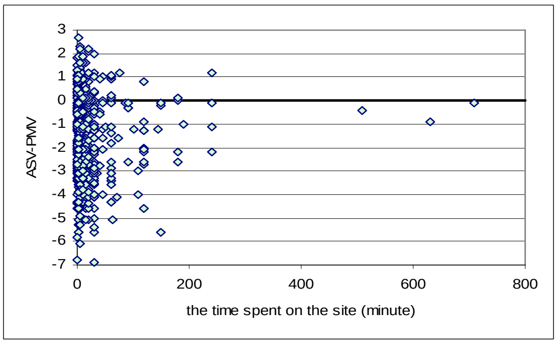

Fig. 8 Differences between the *ASV* values of the interviewed people and the *PMV* values in the time of the interview, as a function of the time spent in the area

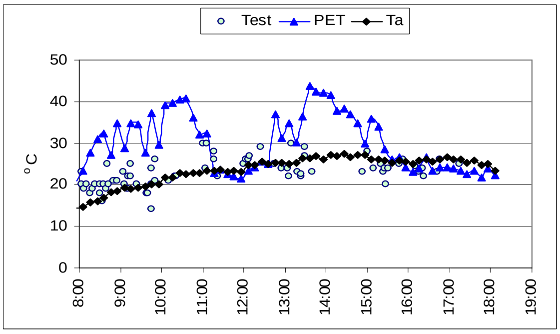

Fig. 9 Diurnal course of T_a, *PET* and T_{est} (indicating the values estimated by the people staying in sun) on 12th September

Fig. 9 shows the diurnal variation of the measured T_a, the calculated *PET* and the subjective T_{est} parameter during the third day. The figure contains only the T_{est} values estimated by the people sitting or standing in the sun, because these people's positions were the most comparable with the position of the meteorological station. The variation of T_{est} is more similar to the measured air temperature, than to the calculated *PET* values. It can be explained by the people's long- and short-term experiences (see *Thorsson et al.*, 2004; *Nikolopoulou and Steemers*, 2003). During one day with weather conditions not unusual at the season people can estimate the temperature appropriate for the season more precisely, especially when the thermal conditions were the same in the preceding days. Since the investigated days occurred in a time period, of which the days were very similar regarding the weather conditions, people did not encounter with suddenly changed air temperature or sun radiation values, so they could estimate more precisely the temperature typical of those days.

3.4. International comparison

Now we compare our data within the comfortable *PET*-range (only 63 questionnaires from the 844!) with the recently published Swedish and Japanese data obtained at similar conditions (*Knez and Thorsson*, 2006). The two squares of the already published studies are typical for the medium sized Swedish and Japanese cities (*Fig. 10*). *Table 3* contains some data related to the study areas and the examinations made there.

Fig. 10 Photos of the Hungarian, Swedish and Japanese squares: Aradi square (Szeged), Gustav Adolfs torg (Göteborg), Matsudo Station Square (Matsudo)

According to *Fig. 11* the square in Szeged is visited most frequently, and in case of the question on the reason for being there most answers were the same ("The area was only in the way").

Comparing the answers on 5-degree scales, the Japanese participants found the similar thermal conditions (comfortable according to the *PET*) much warmer than the others (*Table 4*). It can be explained by the differences between the cultures (see *Knez and Thorsson*, 2006), but it is more likely, that the explanation lies in the design of the areas.

In the Hungarian square the vegetation is more abundant that makes the area more evocative and aesthetical. Moreover, the trees provide shade on a significant part of the area (see *Fig. 10*), which makes the thermal conditions of the square more comfortable during the warm and hot (summer) periods. The area – due to its design – increases the chance of the physical and psychical adaptation (*Thorsson et al.*, 2004) by offering different microclimatological conditions that permit staying there for a long time. In contrast, the Swedish and Japanese squares have a great extent of paved surface, and there is negligible or no vegetation. Without shading the amount of solar radiation people are exposed to increases and it produces a more unpleasant sensation during the warm periods. The Japanese square has the least vegetation and the largest ratio of pavement with large albedo, which explains the above mentioned inconveniences and the greatest difference from 0 (or the comfortable condition) at *ASV*.

Table 3 Information related to the Hungarian, Swedish and Japanese study areas and examinations

Geography	Country	Hungary	Sweden	Japan
	City	Szeged (46°15'N, 20°16'E)	Göteborg (57°42'N, 11°58'E)	Matsudo (35°78'N, 139°90'E)
	Population	160,000	500,000	500,000
Climate	General	warm-temperate	martime	temperate
	Summer	warm, dry	cool	warm, humid
	Winter	mild, dry	mild, humid	mild, dry
	Mean annual temp.	11°C	7.6°C	15.6°C
Study area	Name	Aradi square	Gustav Adolfs torg	Matsudo Station Sq.
	Size	7300 m^2	6000 m^2	2000 m^2
	Surface cover	grass, concrete	different cobblestones	light coloured clinkers
	Vegetation	grass, deciduous and coniferous trees	a few deciduous trees	none
Examination	Time of the study	Aug., Sept. 2006	April 2004	March 2004
	Time of the day	from morning to evening (8.00-19.00)	at noon (11.00-15.00)	at noon (11.00-15.00)
	Number of persons questioned (at comfort PET level)	63	43	63

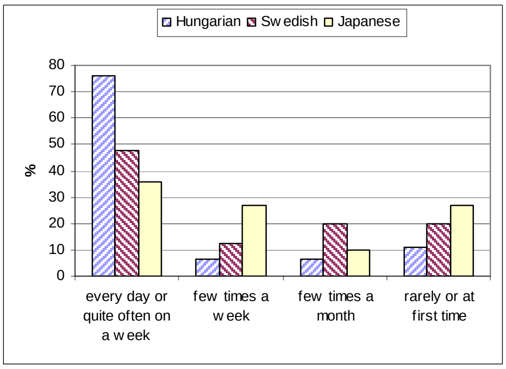

Fig. 11 Frequency of the interviewed persons in the Hungarian, Swedish and Japanese squares regarding how frequently they visit the area

We can draw a parallel between the interviewed people's mood (gloomy-glad) and the answers of how pleasant they felt the actual conditions of the area (*Table 4*). The Japanese participators seemed to be less happy, and they felt themselves the least pleasantly in their environment. In contrast, for both of the questions the Hungarian achieved the greatest average values. According to this one can suppose some relationship between people's comfort and their judgement on the studied urban area. A person in a less good mood will likely find her actual place more unpleasant and the actual thermal conditions as well. The phenomenon works vice versa: the mood can be influenced easily by the aesthetical experience of their surroundings and the surroundings that give appropriate (comfortable) thermal sensation are predominantly the consequence of the design of the area.

Table 4 Average values of the answers of people visiting the Hungarian, Swedish or Japanese areas on 5-degree and 9-degree scales, which relate to the evaluation of the areas and the people's actual sensation

	Hungarian	**Swedish**	**Japanese**
Cold-Warm [1 – 5]	3.35	3.40	4.15
Unpleasant-Pleasant [1 – 5]	4.65	4.20	3.50
Nervous-Calm [1 – 5]	3.95	4.25	3.75
Gloomy-Glad [1 – 5]	3.85	3.78	3.25
ASV [(-4) − (+4)]	0.3	0.2	0.8

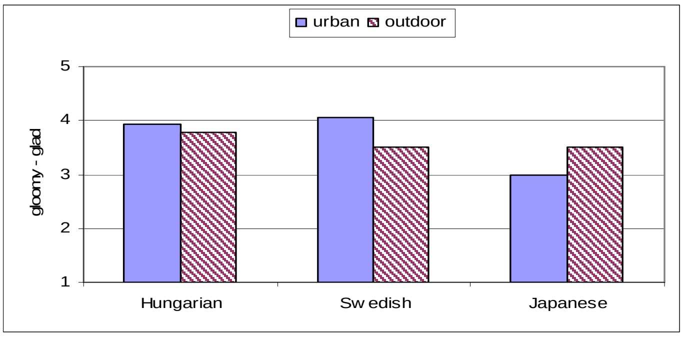

Fig. 12 Average values of the answers for the question "How do you feel yourself at the moment?" on a 5-degree scale by the interviewed persons' nationality and "urban−open-air" attitude

Fig. 12 also relates to the socio-cultural differences. While the difference in the answers of the Hungarian participants were not so large between the people with "urban" and "open-air" attitudes, in the cases of the other two nations the differences were more remarkable. Moreover, in contrast to the Swedish and Hungarian results, the Japanese people with "urban" attitude were in the worse mood.

4. CONCLUSIONS

Our examinations showed some differences between the values based on subjective estimation (*ASV*, T_{est}) and on the common human bioclimatological indices (*PMV, PET*). On one hand, the phenomenon can be explained with the fact that the models similar to RayMan are unable to examine the short-term (temporary) exposition; on the other hand, it is explicable with the application of indoor methods for outdoor comfort examination – without the modification of the comfort-zone limits. The similarity between the people's answers and the air temperature emphasizes the short- and long-term experiences with the thermal environment.

The study intends to draw attention to the importance of the vegetation. First, the trees can modify the radiation conditions to a great extent, and they can provide great alleviation with their shades during particularly during the hot periods. Besides, the green areas within a certain city structure can influence the mood and way of sensation of the people staying in the area to a great extent by their location, size and condition, and so incidentally influence the thermal estimation of the area. Based on the results some connection can be established between the judgement of the areas (comfortable-uncomfortable) and the mood and thermal sensation of people.

The difference between the answers of people of different cultures (Hungarian, Swedish and Japanese) and "urban–open-air" attitudes draws the attention for the further necessity for investigation of socio-cultural factors. This direction could have particular importance in the adjustment of comfort and discomfort indices developed in the future, based on uniform principles, since people with different cultures and accustomed to different climate can react in different ways to the same thermal conditions.

There is a need for similar examinations in a great quantity and in areas in diverse climate-zones as well, in order to develop a universally applicable comfort-model and index, which can be modified according to the area of use (or rather the people and culture typical to the area).

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