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Benefits and opportunities of adopting GIS in thermal comfort studies in resting places: An urban park as an example

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ABSTRACT

The aim of the present paper is to recommend a methodology for the thermal comfort investigations of resting places (parks and squares) in urban environments. During three periods (three times 14 weekdays in transient seasons) 6775 visitors were mapped in half-hour intervals between 12 and 3 p.m. on a park in the inner city of Szeged (South-East Hungary). Besides marking the subjects' exact locations, some of their personal features were also noticed in table format. Physiologically equivalent temperature (°C) was calculated from the meteorological data measured by the site, to describe the thermal conditions of the measurement intervals. To reveal patterns of area usage according to thermal conditions, the observations data were digitized and processed within GIS application ArcView. The created area usage maps clearly illustrate the temporarily differences of attendance (on seasonally and daily basis too). These maps facilitate detection of preferred and ignored sub-areas in the function of thermal conditions (or any of the recorded subjective or measured objective parameters). The usefulness of these maps in practice, as well as the extension-possibilities of the presented methodology are also discussed.

1. Introduction

Because of the rapidly growing global population and the better working possibilities in cities more and more people live or work in them, which means increasing number of citizens, affected by the strains of urban environments: various kinds of air pollution, noise, odors, exhaustion due to the accelerated lifestyle, light pollution and last but not least thermal stress (Unger, 1999). Resting places such as parks and squares may mitigate the above-mentioned harmful effects by offering places for recreation and relaxation. As these "green islands" in urban environments have significant positive effect on life quality, the number of human comfort investigations related to them grows permanently (Nikolopoulou et al., 2001; Thorsson et al., 2004; Knez and Thorsson, 2006, 2008; Nikolopoulou and Lykoudis, 2006; Oliveira and Andrade, 2007; Thorsson et al., 2007; Mayer, 2008; Lin, 2009).

There are various aspects of human comfort concerning on visual, acoustic and thermal components of the surrounding environment. Broad range of these comfort conditions was examined in numerous open urban areas across Europe in the frame of the wide-scale project RUROS – Rediscovering the Urban Realm and Open Spaces (Nikolopoulou and Lykoudis, 2006). However, most of the projects and studies focus mainly on the thermal comfort conditions of the urban environments. Air temperature, air humidity, air velocity, and thermal radiation are critical parameters for human comfort as they affect the human energy balance through the thermal sensation. From these meteorological factors "state of the art" thermal comfort indices are calculated (e.g. PET – physiologically equivalent temperature, OUT_SET* – outdoor standard effective temperature) to evaluate the thermal conditions in a physiologically significant manner.

The usage of open public places in cities is more frequent if they offer thermophysiologically comfortable microclimate (Mayer, 2008). Nevertheless, several studies pointed out that the thermal comfort sensation of people in the open-air are influenced by many more factors beyond the meteorological parameters (Höppe, 2002; Nikolopoulou and Steemers, 2003; Thorsson et al., 2004; Knez and Thorsson, 2006, 2008). Nikolopoulou and Steemers (2003) emphasized the role of psychological adaptation, and evaluate the relative impact of the concerned parameters: naturalness, expectations and experiences, time of exposure, perceived control as well as environmental stimulation.

Swedish scientist organized a multi- and interdisciplinary research project "Urban Climate Spaces" – comprised scientists from the fields of climatology, psychology and architecture – to study the complex interactions between the place, climate and human behaviour (Thorsson, 2008). The design of a place (vegetation, artificial objects and surface cover) influences the micro-biometeorological environment, and defines the function of the area. The evolved comfort conditions, consequently the area usage depend on the emotional reactions triggered by the aesthet-

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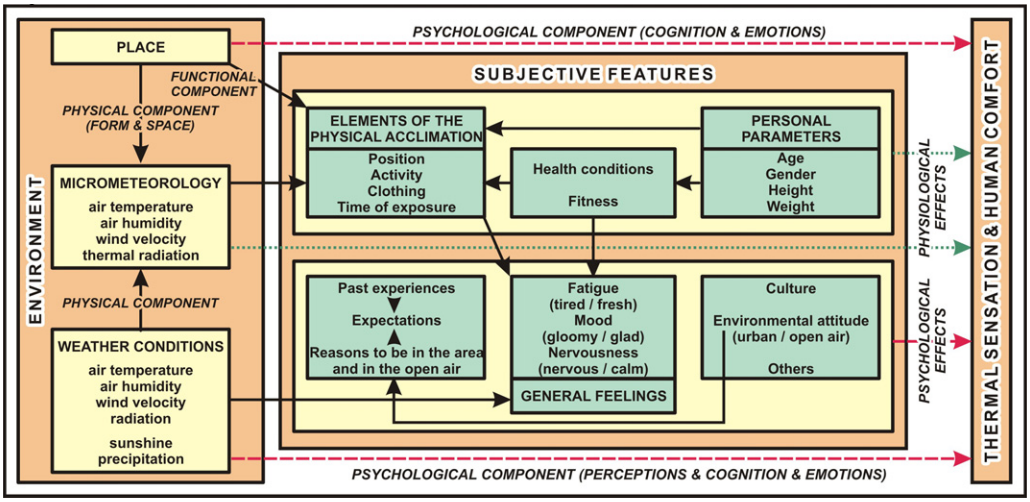

Fig. 1. Factors influencing the thermal comfort and their inter-relationships.

ical experiences offered by the place (Knez, 2005; Eliasson et al., 2007; Knez et al., 2009). Knez and Thorsson (2006, 2008) find significant influence of culture (Sweden vs. Japan) and environmental attitude (urban vs. open-air person) on people' thermal, emotional and perceptual assessments of a square and a park.

Based on the above-mentioned principles Fig. 1 illustrates that the comfort conditions evolved outdoors depend not only on the micrometeorological parameters acting in a physical–physiological way, but there are also numerous other factors working in a psychological manner too. If a study concentrates on whether an urban public space is appropriate for recreation, more specified and more detailed information is needed about the investigated area on the one hand and about the visitors staying on the site on the other hand. Measuring (or modeling) the thermal conditions evolved on the site with simultaneous human monitoring can provide these data. All of the human thermal comfort projects and studies have the ultimate objective to enlarge the knowledge concerning the area usage and thermal conditions of open urban spaces, as well as to prove suggestions which can adopt in practice for sustainable urban design.

Until the 2000s, there were no "state of the art" studies focusing on the thermal component of urban climate in Hungary. The first examination evaluated the microclimatic conditions in a physiologically significant manner (using the comfort index PET) had performed by Gulyás et al. (2006) in the inner city of Szeged (46°N, 20°E) – a medium-sized town in Hungary with a population of 170,000. Similarly, the first investigation which used also human monitoring (questionnaire-based data collection) by the objective measurements and comfort index calculations was also in this South-Hungarian city (Kántor et al., 2009a).

The aim of this study is to present the first stage of the proceeding long-term outdoor thermal comfort project in Szeged. On the one hand, the emphasis is on the human observations consisted of marking the visitors' exact locations on a map of the study area and recording some of their personal characteristics. On the other hand, data processing and illustration with geoinformatical software is accentuated. ArcView GIS 3.3 was used to create area usage maps from the collected data in the cases of various thermal conditions. These maps may be valuable tools in the course of discussion with urban planners. The field examinations were carried out in three study periods: spring 2008 and 2009, as well as in autumn 2009. The observation-based methodology is recommended for the thermal comfort investigations of small and medium-sized open public green areas (squares and parks) in urban environments in all cases when mobile biometeorological station is not available to measure the thermal parameters on the site.

2. Steps of a thermal comfort study

To demonstrate the advantages of using a geoinformatical application in the course of thermal comfort examination the main steps of an outdoor study are presented. Beyond the general guidelines the study design applied in Szeged is described. From the software used during the various parts of the investigation the main emphasis is on the adaptation of ArcView GIS 3.3.

2.1. Preliminary arrangements

2.1.1. Study design selection

The first step of a human comfort study is to select the applied methods and the sampling area according to instrumentation and human resources. To estimate the thermal comfort conditions of a site in an objective way, human biometeorological comfort (stress) indices need to be calculated from meteorological parameters influencing the thermal sensation. These factors are directly measured on the site or simulated by numerical models. If there is no mobile micrometeorological station available to measure air temperature, air humidity, wind velocity as well as (solar and terrestrial) thermal radiation on the site at the adequate height of 1.1 m, data of the nearest automatic stationary station can be used.

A thorough thermal comfort examination should include a subjective approach besides the objective ones, as thermal comfort depends not only on the above-mentioned meteorological parameters, but also on different subjective features, too. There are two main types of methods to collect additional information about subjects included in a thermal comfort study: social surveys (questionnaires, structured interviews) and unobtrusive observations. By means of questionnaires more detailed information could be obtained about the visitors' thoughts, preferences and intentions, which make data processing much more complex. However, this kind of method can be both reactive and unrealistic (Thorsson et al., 2004), and it works well only with on-site microclimatic measurements. By unobtrusive observations data about many more people can be gained in a given time period, especially about the visitors' behavioral adaptation, and can be analyzed according to the current weather conditions, too.

2.1.2. Survey of the study area

Mapping the topography of the study area might be necessary depending on the applied investigation design. As buildings and trees are primary radiation-flux modifying obstacles, they have to be mapped. The surface cover types also need to be distinguished. In our study the exact coordinates (x, y, z) of artificial objects and

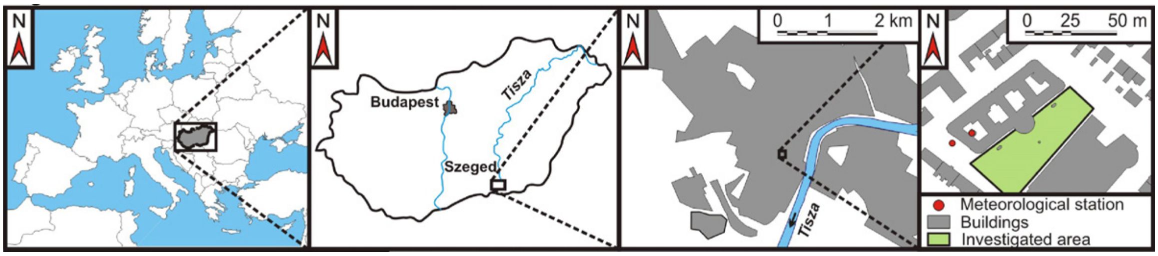

Fig. 2. Location of Hungary in Europe, Szeged in Hungary, and the study area in Szeged.

different surface covers were recorded by a SOKKIA geodesic station. The heights of trees and buildings were measured by a Vertex III ultrasonic altimeter. Besides, full and trunk heights, trunk circumference and the crown radius of the trees were also registered. This information will be useful in the future to set up the model of the area e.g. with the ENVI-met or RayMan software to calculate comfort indices from the measured meteorological parameters or to simulate the thermal conditions of the examined area (Bruse and Fleer, 1998; Bruse, 2003; Gulyás et al., 2006; Matzarakis et al., 2007).

Due to the lack of mobile meteorological station we selected a sampling area adjacent to the QLC 50 automatic meteorological station of the University of Szeged. This green area (ca. 5500 m^2) is located between the buildings of the University and the Information Centre (Fig. 2) and is regularly visited by a high number of students in the warmer periods of the academic year (spring and autumn), which makes it suitable for this kind of comfort studies using meteorological measurements and simultaneous human monitoring.

A paved pathway transects a large grassy sector, which is the main part of the study area. Some young (4–5 m tall) trees have been planted along the pavement, which offer only scanty shade. This site is surrounded by a morphological step, so its ground surface is about 1 m lower than the ambient areas. The northwestern side is shaded by a group of 20–30 m tall trees, so it has quite different microclimate. There are 10 benches offering places for relaxation, two can be found on the northeastern and southwestern end of the grassy area, and 8 along the pavement (Fig. 3). The area can be divided into different sub-areas (sectors) according to the area usage, the surface and shading conditions (see more details in Section 3.2).

The map for the subsequent human observations was made based on the survey of the study area. This was the first time during our investigation to take advantage of a geoinformatical application: the georeferenced map of the study area was created with the earlier mentioned ArcView GIS 3.3. The measured data can be visualized graphically in the View window of the software. Each surface cover type and the borders of the buildings are represented as polygons, while the locations of the trees are star-shaped point markers. The information appearing in the View window can be presented in table format too. These attribute tables contain not only the exact coordinates of the measured objects, but all of the surveyed data.

2.2. Field surveys

To perform a complex human thermal comfort study, objective measurements of thermal variables supported with information about the simultaneous use of the area (absolute attendance and data about the visitors) is required. As the aim was to study the recreational aspects of the area usage according to the thermal conditions, people only passing through the area were not included. It is important to accentuate that the employed methodology can adopt only in the cases of resting places, and cannot cope with transient place conditions.

The study was conducted in three periods: springs of 2008 and 2009 (from the second week of April to the middle of May) and autumn 2009 (between 8 September and 8 October) on every Tuesday, Wednesday and Thursday during the early afternoon (from 12 to 3 p.m.). The observations did not contain the winter period, because of the low-level open-air activity in this season in our climate. However, there was an examination period in summer 2008 which is not included in this study, as very low attendance was observed in July and August. It is attributable not only to the higher level of thermal stress, but to the absence of the main visitor group of the study area – the students of the university – too.

2.2.1. Observation of visitors

Human monitoring consisted of the unobtrusive observation of people lingering on the studied resting place. On the one hand the subjects were counted in every 10 min according to whether they stayed in the sun, penumbra or shade. Data about the 10-min number of visitors are referred to as momentary attendance.

On the other hand the presence was also measured cumulatively in half-hour intervals. The locations of the visitors staying at least 5 min in a given half-hour interval were marked with ID numbers on the map of the area (Fig. 3). Each half-hour between 12 and

Fig. 3. Detailed map of the study area for marking the visitors' locations.

Table 1
Instrumentation of the QLC 50 stationary station.

Parameter		Instrument	Measurement height (m a.g.l.)
Air temperature	Ta (°C)	HMP 35D, Vaisala	2
Relative humidity	RH (%)	HMP 35D, Vaisala	2
Wind speed	v (m s^{-1})	WAA 15A, Vaisala	26
Global radiation	G (W m^{-2})	CM 11, Kipp & Zonen	20
Data recording		MILOS 500, Vaisala	
Averaging period		10 min	

3 p.m. on each measurement day had its own map which includes the individuals' exact locations and a connected table contains the marked visitors' characteristics:

gender: male/female;
age group: (four categories by the looks) child/young/middle aged/old;
clothing: (in three categories) <0.45 clo/0.45–0.9 clo/>0.9 clo;
type of activity: active (e.g. playing, walking around in the area)/passive (e.g. standing, sitting, lying);
position: sun/penumbra/shade.

The cloud cover was also observed according to three categories: clear/partly cloudy/overcast. Determination of the subjects' position was not possible in cases of overcast and longer cloudy conditions.

The human monitoring was carried out by 2 (or 3) observers helping each other: one of them marked the visitors on the map and the other recorded their characteristics in the table. To get reliable picture on the area usage as well as to make exact recordings about the visitors, the observers changed their locations permanently and did not sit on the benches. The ID counters started from 1 in every half-hour interval so the absolute cumulative attendance could be easily derived at the end of the given interval. Altogether, during the three observation periods (three times 14 days, 252 half-hour intervals) 6775 marked visitors and their connected subjective information were produced.

2.2.2. Meteorological measurements

To describe the thermal conditions, 10-min averages of air temperature (Ta, °C), relative air humidity (RH, %), wind velocity (v, m s^{-1}) and global radiation (G, W m^{-2}) were obtained from the QLC 50 station by the site (Table 1). Temperature and humidity were measured at a height of 2 m in a Stevenson screen (at street level near the building), while the wind and radiation data on the top of the university building, where there are no sky obstructions: at 26 m and 20 m above ground level, respectively. Sensors are marked as red points in Fig. 2.

2.3. Data processing and analysis

2.3.1. Index calculation

Physiologically equivalent temperature PET (°C) was selected as an objective measure of thermal comfort conditions (Mayer and Höppe, 1987). PET is based on the Munich Energy-balance Model for Individuals (MEMI), which models the thermal conditions of the human body in a physiologically relevant manner. The index is defined as the air temperature at which, in a typical indoor setting (as reference environment) the heat budget of the human body is balanced with the same core and skin temperature as under the actual, complex outdoor conditions to be assessed. The following assumptions are made concerning on the reference indoor environment and the subject:

- there is no solar radiation, so the mean radiant temperature equals to air temperature;
- the air is calm, wind velocity is set to 0.1 m s^{-1};
- water vapour pressure is set to 12 hPa;
- work metabolism is 80 W corresponds of light activity, which is added to basic metabolism;
- heat transfer resistance of clothing is 0.9 clo (Höppe, 1999).

Fig. 4 shows the ranges of PET correspond to various levels of thermal strain as well as thermal sensation. PET values around 20 °C indicate neutral, comfortable thermal conditions, while higher values than 23 °C mean increasing probability of discomfort and physiological stress due to warm, lower values than 18 °C due to cold conditions. The presented ranges are only valid for the mentioned values of work metabolism and thermal insulation of clothing, additionally they are effective in Central European climate (Matzarakis et al., 1999).

Previous to index calculation, wind speed data were reduced to the reference height of 1.1 m according to Matzarakis et al. (2009):

$$v_{1.1} = v_h \cdot \left(\frac{1.1}{h}\right)^{\alpha}, \quad \alpha = 0.12 \cdot z_0 + 0.18,$$

where v_h is the wind speed (m s^{-1}) at the height h (m), α is an empirical exponent, depending on the surface roughness and z_0 is the roughness length. In our case h = 26 m and z_0 = 0.42, as the sample area is in the densely built-up inner city. This type of reduction is supported by other thermal comfort studies conducted in urban environment (Spagnolo and de Dear, 2003a,b; Swensson et al., 2003; Nikolopoulou and Lykoudis, 2007).

The thermal comfort index calculation took place with the help of the radiation and bioclimate model RayMan developed according to the Guideline 3787 of the German Engineering Society (Gulyás et al., 2006; Matzarakis et al., 2007, 2010). Input meteorological variables were the recorded air temperature, humidity, and radiation, as well as the reduced wind velocity. The calculated PET values referred to a person (default: 1.75 m, 75 kg, 35 years old standing male) who stays in the sun.

We decided to use the measured global radiation data (without reduction by RayMan according to the ambient obstacles: buildings and trees) because of the nature of the study. By this way, the produced index values are more representative of the thermal con-

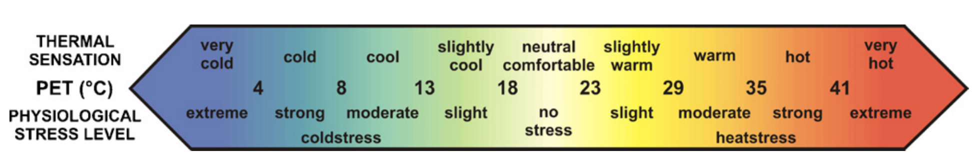

Fig. 4. PET ranges for various thermal sensation and stress levels (according to Matzarakis et al., 1999).

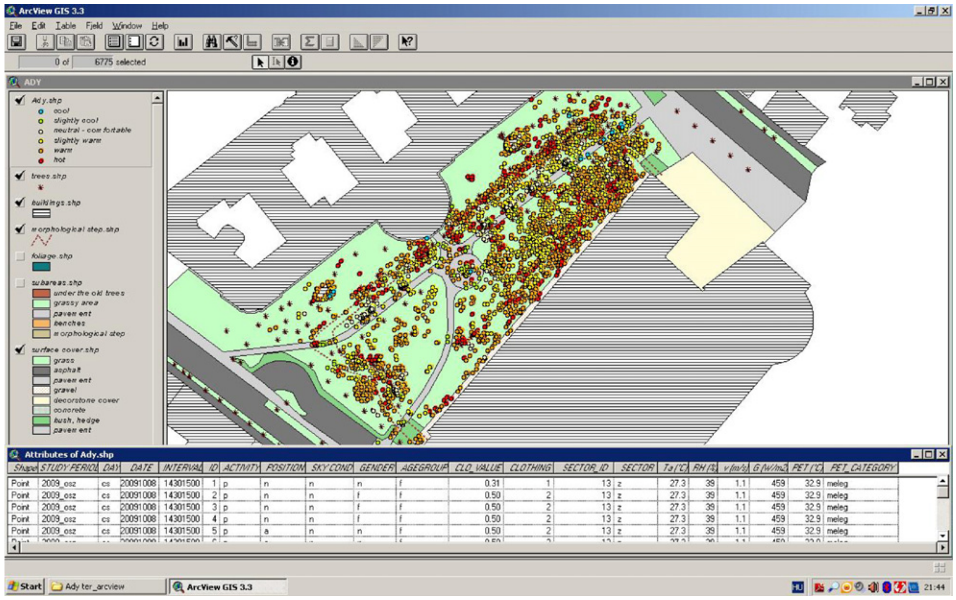

Fig. 5. Interface of the ArcView GIS program: markers of visitors in the View window are colored according to PET categories, and the connected attribute table contains all of the recorded information.

ditions of measurement intervals, and are independent for various microclimatic features on the different parts of the area. Comparing the observation data with these indices we are able to study the weather-related area usage and behavioral adaptation of visitors.

2.3.2. Data digitization and data coupling within ArcView

The tables of the collected personal characteristics were digitized in Microsoft Excel. Then the half-hour averages of the measured and calculated objective parameters (Ta, RH, v, G, PET) characterizing the thermal conditions of the observation intervals were attached to these subjective data according to the time of the measurement. The investigation maps were digitized within ArcView GIS. As a result, cumulative attendances of every half-hour were represented on layers, on which people's locations were signed with circle-shaped point markers. The attribute tables of this half-hour layers were expanded according to the subjects' ID numbers with the subjective and objective parameters which were summarized earlier in Microsoft Excel. Finally, all data of the half-hour layers (coordinates of visitors and all of the attached attributes) were joined together resulting in a layer with 6775 marked visitors and their whole datasets (Fig. 5).

2.3.3. Preparing data for statistical analysis with ArcView

Due to this integrated data processing within ArcView it is possible to select anyone from the visitors of the area. It is easy to query the selected subjects' personal data (gender, age, clothing, position, activity) and location, the time period (day, half-hour) when they stayed in the area, and the thermal characteristics of the given time period (Ta, RH, v, G, PET). The software makes it possible to select, aggregate or divide visitors into different groups according to any (combinations) of the above-mentioned information of the attribute table, in other words, prepare data for the subsequent statistical analysis. This can be done also based on the registered visitors' location: the markers in the View window can be selected one by one or grouped. Descriptive and inferential statistics were carried out within Microsoft Excel and SPSS 11.0 software.

2.3.4. Representation of results

Besides the above-mentioned benefits of ArcView, this program is very useful to visualize the results. The commonly used forms representing the results of statistical analyses (diagrams, tabulations, statistical measures describing the significance and the strength of the relationships) become very informative together with area usage maps, which may facilitate the discussion with designers. Human comfort investigations in urban environments emphasize the analysis of the area usage in a spatio-temporal manner. To study these patterns, sectors (sub-areas) can be created according to various categories, for example exposure, shading, surface cover, function, etc.

The markers representing the visitors might be colored by any objective (time, thermal variables) or subjective (personal data) characteristics of the attribute table. So, it is easy to get information on the area usage: in what circumstances (in what time, by what thermal conditions) what kind of visitors (according to given personal parameters) took a seat in the given sub-areas (for example on the top of the morphological step). Determination of which sectors were preferred at different micro-biometeorological conditions might be a very important result.

3. Selected results

3.1. Visitors of the area and the thermal characteristics of the measurement periods

The subjects' distribution according to gender showed that there were roughly twice as many females (65.3%) as males (34.7%), and only few of the visitors were rated active (1.6%). The large majority (94%) belonged to the 'young' age category in their twenties. These people were probably students and came to the area to hang out between their lectures (the area locates between two educational buildings and all of the study periods fall within the academic year).

Thermal conditions of the three study periods are compared based on the distribution of the average PET categories referred to the half-hour observation intervals (Fig. 6). Each period contained 14 measurement days with 6 intervals meaning 84 PET data per study period. Cold thermal conditions occurred only one time in spring of 2008, and only this season contained both of the cool and hot PET ranges in remarkably proportion. Hot conditions are missed in spring of 2009, while the following autumn period did not contain PET categories cooler than neutral. The thermal differences between the three measurement campaign are statistically significant ($\alpha = 0.00$), and moderately weak according to values of the

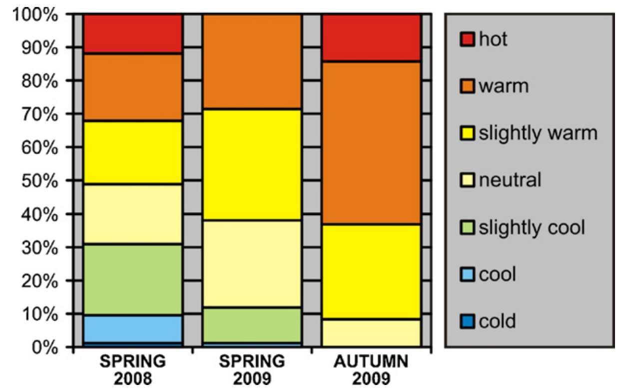

Fig. 6. Thermal characteristics of the three study periods based on the PET categories.

Cramer's V = 0.357 and Contingency coefficient C = 0.450 (n = 252). C and V are statistical measures applicable describing the relationship between nominal by nominal or nominal by ordinal (like in our case) measures.

3.2. Attendance according to the thermal conditions

First, the momentary attendance is discussed in accordance with the thermal conditions taking the detailed dataset from the 10-min human and environmental monitoring. As few observations are missed, this means n = 737 data pairs: number of visitors plotted as a function of the momentary Ta or PET (Fig. 7). While in the cases of lower air temperature and PET values the momentary attendance is near to zero, it shows greater numbers and a remarkable scatter by warmer conditions. Fitting a secondary function on these two datasets, the relationship seems somewhat stronger in the case of PET (R^2 = 0.36) than with Ta (R^2 = 0.32). According to the fitted curves the maximum number of visitors may be expected by very hot conditions, which can be explained partly with the behavioural adaptation, and partly with psychological factors influencing the thermal comfort sensation as well as the outdoor staying of visitors.

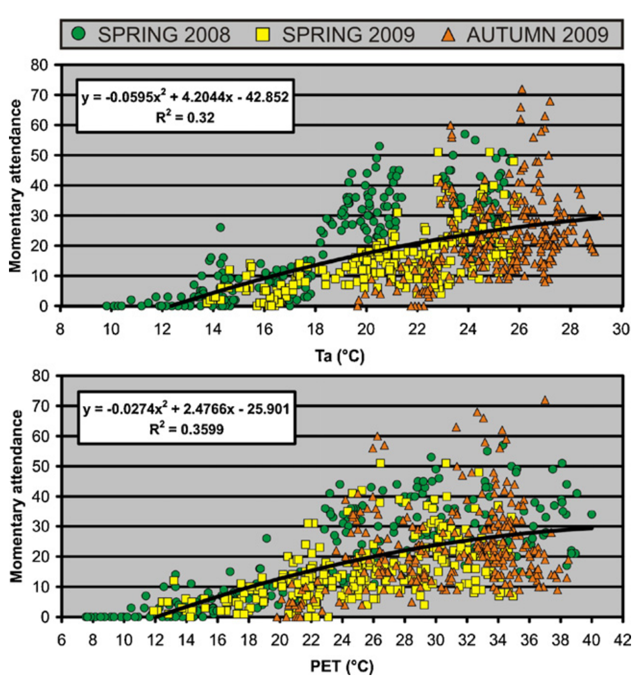

Fig. 7. Momentary attendance as a function of the air temperature (Ta) as well as PET values.

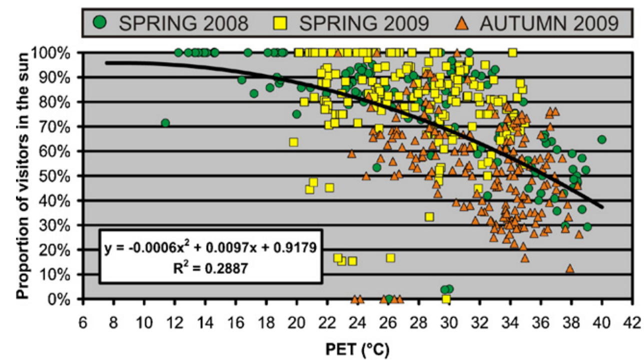

Fig. 8. Proportion of visitors in the sun according to the PET values.

Fig. 8 illustrates one of the fundamental behavioural changes, namely altering the exposure to the sun (position) with increasing thermal load. However, there are many cases when despite hot conditions (PET > 35 °C) relatively large proportion of subject lingered in the sun (more than 50%). This can be attributed to the psychological effect of longing for outdoor staying and sunshine in the transitional periods, especially after the cold winter season. Visitors in springtime endured higher levels of thermal stress than in autumn: in spring of 2009 more visitors were observed on the site by PET values above 36 °C, as well as greater proportion of them exposed themselves to the sun compared to the next study period (Figs. 7 and 8).

Considering the data of the cumulative attendance, there are a lot of opportunities to show the presence in temporal and/or spatial manner. Aggregating the data of the six half-hour periods according to the measurement days within ArcView serves summarized datasets of the given days. Spatial illustration of these daily cumulative attendances results area usage maps (of any single days) on which preferred places are easy to detect. In addition, thermal conditions of the given day can be presented on the map: by coloring the markers showing the subjects' locations according to the predominant PET ranges of that given day.

For example, on 6 May 2009, which is described with slightly cool and neutral thermal characteristics, there were only few people in the area, and they preferred sitting on the benches (Fig. 9). On the other hand, 29 April and 14 May 2008 had warmer PET categories and the examined area had higher attendance. On these days the individuals also preferred sitting or lying on the grass beside the benches. By the hot thermal conditions on 14 May there were also a couple of people sitting on the northwestern side, on the top of the morphological step. The highest numbers of visitors were found on days with such warm and hot thermal conditions in spite of the physiologically harmful circumstances. It can be explained by the mechanisms of physical and psychological adaptation – partly mentioned in the results about the momentary attendances.

Recordings on the visitors' subjective features made it possible to analyze their behavioural adaptation (may be conscious or not) to changing thermal conditions. Fig. 10 contains diagrams illustrating the relative attendance of selected groups of visitors as a function of the prevailing PET categories. Fig. 10A clearly shows the increasing proportion of subjects wearing lighter clothing (decreased thermal insulation values) with higher PET values. Kendall's tau-b (τ_b) = −0.314 and Spearman's rho (ρ) = −0.345 express statistically significant (α = 0.00), negative relationship between these two ordinal variables, based on all of the observed data (n = 6775).

Besides, this way of physical adaptation, visitors can decrease the heat strain by changing their exposure to the sun as well as the level of their activity. In warmer situations people tend

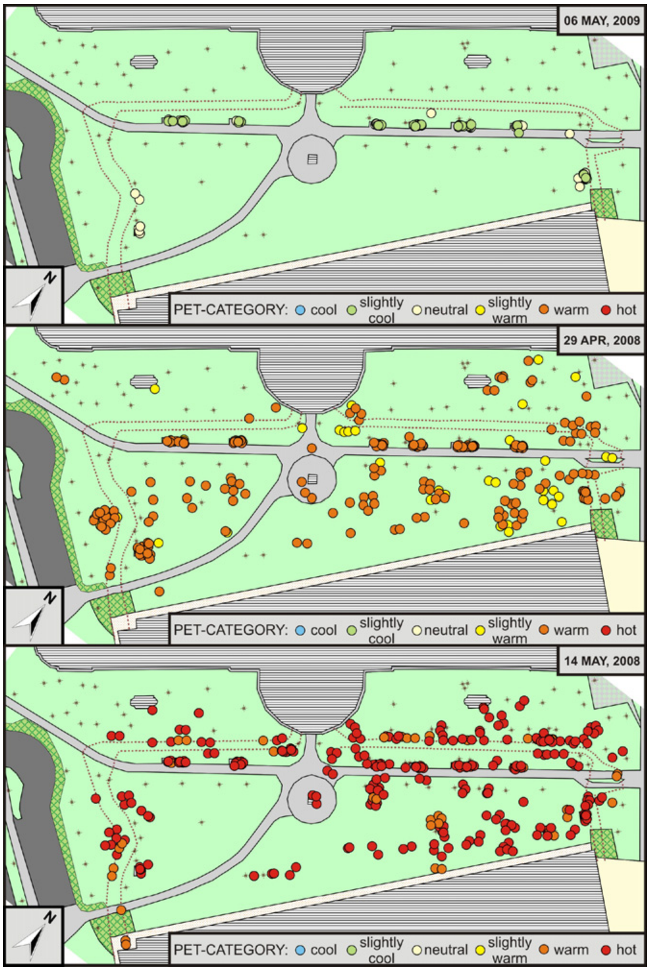

Fig. 9. Visitors distribution on the study area on three selected days which have considerably different thermal conditions.

to move into areas in the shade and penumbra (Fig. 10B), however the relationship ($\alpha = 0.00$) between visitors position and PET categories as ordinal measures is somewhat weaker: $\tau_b = -0.215$ and $\rho = -0.239$ ($n = 5761$). The generally dominant passive forms of activity (principally sitting and lying) become even more frequent by higher PET categories, while the walking subjects completely disappear (Fig. 10C). The relationship is significant ($\alpha = 0.00$), but very weak ($V = 0.142$ and $C = 0.1422$, $n = 6775$) due to the low proportion of active subjects, as well as due to some playing young people mapped on the large grassy area by hot circumstances. Fig. 10D shows an interesting tendency: the proportion of male subjects slightly decreased with the warmer conditions ($V = 0.063$ and $C = 0.063$, $\alpha = 0.00$, $n = 6775$). The assumption, that it can be explained with the preference of females for sunbathe (exposure themselves to the sun by warm–hot conditions) proven to be false. No significant differences were found in positional distribution of male and female subjects ($\alpha = 0.058$). The distortion of the above-mentioned tendencies in the case of the lowest PET category is due to the fact that the absolute attendance was significantly lower by these situations (Fig. 10).

There are two important facts related to the present study worth to be mentioned. Besides the favorable design facilitates the adaptation by offering various microclimatic conditions; the accessibility of the study area also affects positively the number of people using it. On the other hand, the investigations were conducted in transient periods, when situations with extreme stressful thermal conditions (PET > 41 °C) did not occur for a relatively long time.

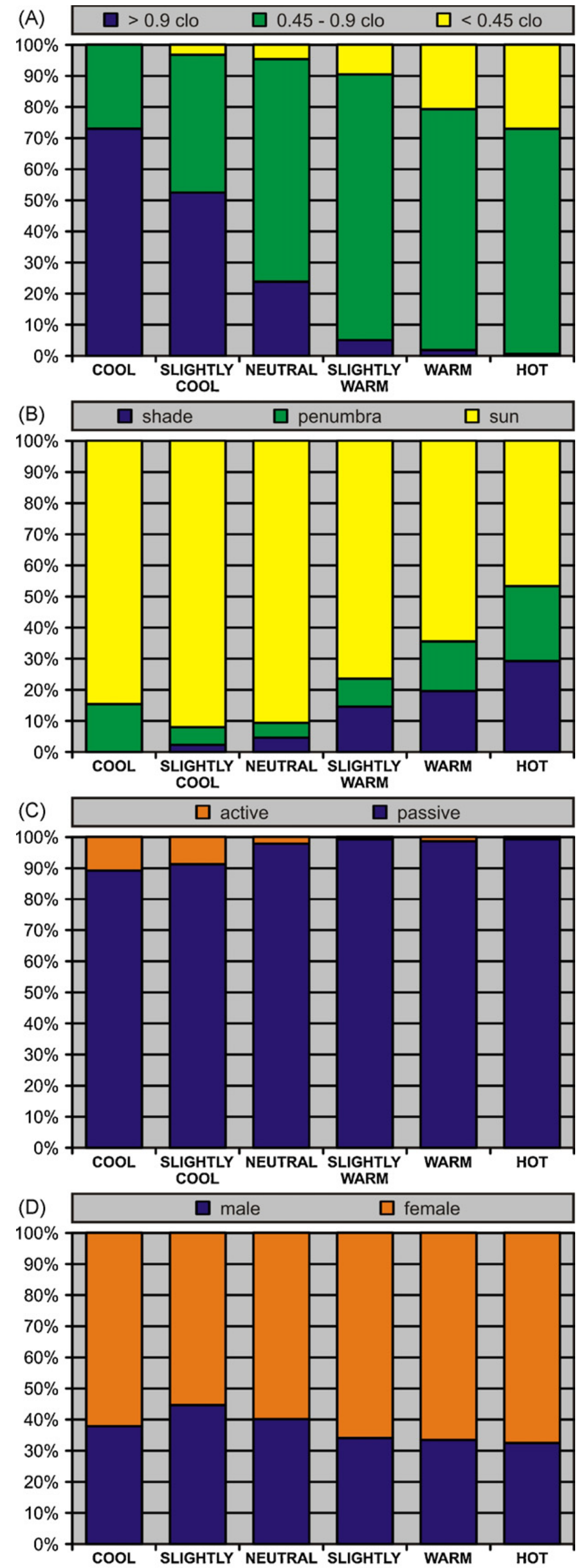

Fig. 10. Relative attendance as a function of the PET values in the cases of various groups determined according to the visitors' clothing (A), position (B), activity (C) and gender (D) during the whole study period.

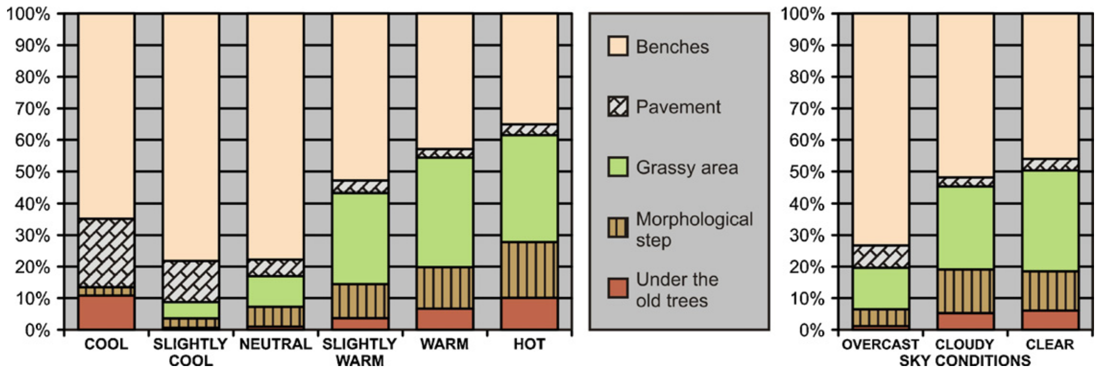

Fig. 11. Percentage distribution of the visitors in the selected sub-areas according to the momentary PET categories and sky conditions during the whole study period.

3.3. Spatial usage of the area

In order to study the spatial patterns of the area usage five sub-areas (sectors) were defined. Three "natural" sectors are: the large grassy area stretches on the southeastern side which contains also the northeastern and southwestern sides of the morphological step – exposed greatly to the sun; the northwestern side shaded by the old, tall trees; and that part of the morphological step, which is shaded by these old trees. The pavement and the 10 benches were also separated and become discrete sectors as they have quite different characters and functions ("artificial" sectors).

All sectors had the highest number of visitors (absolute attendance) at clear sky and warm thermal conditions, but the relative attendance of the selected sub-areas showed remarkable tendencies according to the amount of sunshine and thermal comfort categories (Fig. 11). The relative usage of the benches was predominant at overcast-cloudy sky and cooler thermal circumstances. With the increasing amount of global radiation (clear sky) and at higher PET ranges even greater portion of visitors stayed in the grassy sector. In parallel, the relative attendance of the morphological step and the shady sector under the old trees become also higher. This can be attributed to the fact that the seating capacity of the benches is obviously limited, so in the cases of warmer conditions (which can be characterized by higher attendance) more and more subjects had to take seats on the other sectors. On the other hand, greater PET values associated with sunny conditions and many people came into the area to sunbathe. Furthermore the nature and extent of the grassy sector permitted to take place even in greater groups.

These results can be illustrated also on a map (created within ArcView) which shows the area usage according to the thermal conditions (Fig. 12). Physical adaptation of people in the case of warm–hot circumstances is indicated by the numerous subjects on the shady–penumbra sectors of morphological step and under the old trees. The differences between the attendances of the selected sectors according PET categories were found significant ($\alpha = 0.00$), with moderately weak relationship between the predominant thermal conditions and the area usage of different sectors: $V = 0.212$ and $C = 0.391$ ($n = 6775$).

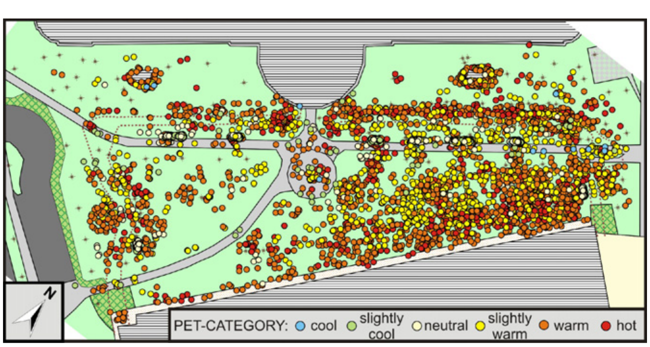

Fig. 12. Spatial usage of the area according to the thermal conditions during the whole investigation period.

The markers showing the visitors' locations can be colored also according to any of the recorded subjective characteristics within the ArcView program. The resulted area usage maps – similar to Fig. 12 – help to illustrate the differences between the area usages of the various groups of people according to clothing, activity, age, gender or position, for example.

The relationship between the visitors' clothing and the attendance of the mentioned sectors is significant, but not strong ($\alpha = 0.00$, $V = 0.139$, $C = 0.193$, $n = 6775$). People in warmer clothes (>0.9 clo) sat mainly on the benches or stand by them on the pavement, while the grassy sector, the morphological step and the area under the old trees were used almost never by these subjects. This is because in the cases of cooler conditions (when people wore heavier raiment) the ground surface was too cold to take seat on it. Besides, lower air temperature often occurred together with overcast sky conditions when the total attendance was significantly lower.

The area usage shows some differences in the cases of passive and active subjects, due to the more active subjects preferred the pavement and the sub-area under the old trees for walking around during cell phoning or walking the dog, as well as the large grassy area for playing. These results are supported by the moderately weak V and C values ($\alpha = 0.00$, $V = 0.280$, $C = 0.269$, $n = 6775$). Nearly all of the old and middle aged subjects sat on the benches or stayed on the pavement and near by, while they used very rarely the natural sectors ($\alpha = 0.00$, $V = 0.114$, $C = 0.194$, $n = 6775$). There was only inconspicuous difference in the spatial usage of the study area according to the gender of the visitors: ($\alpha = 0.00$, $V = 0.060$, $C = 0.060$, $n = 6775$).

The spatial area usage according to the visitors' position was expected to provide the highest C and V values, because the sub-areas have different vegetation and exposure to the sun. It is proven by $V = 0.415$ and $C = 0.506$ ($\alpha = 0.00$). The sample size is a little bit lower in this case ($n = 5761$), as some measuring periods had overcast conditions and the visitors' positions could not be determined.

Fig. 13 shows remarkably differences between the spring and autumn study periods according to their area usage by higher PET values (PET > 29 °C) regarding the visitors' position. From the 1330 visitors who were observed in the area by warm and hot thermal conditions in spring 2008, 864 (65%) stayed on the sun. This proportion was 76% in spring 2009 (587 people exposed to the sun from the 768). Contrarily, it is only 43.4% in autumn 2009, when the greater part of visitors chose a position in penumbra or shade.

These differences can be explained with the thermal experiences in the former season. Due to the demand for shiny and warm

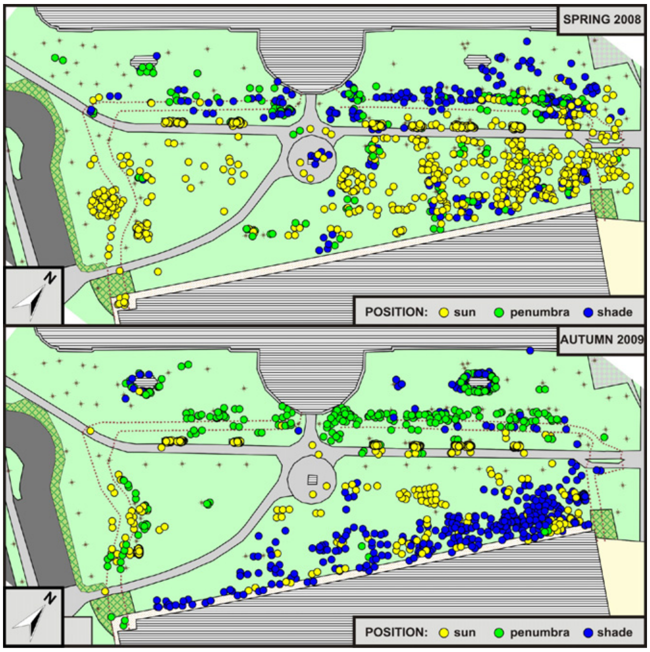

Fig. 13. Differences in the visitors' area usage as well as position by warm–hot thermal conditions according to the observation periods.

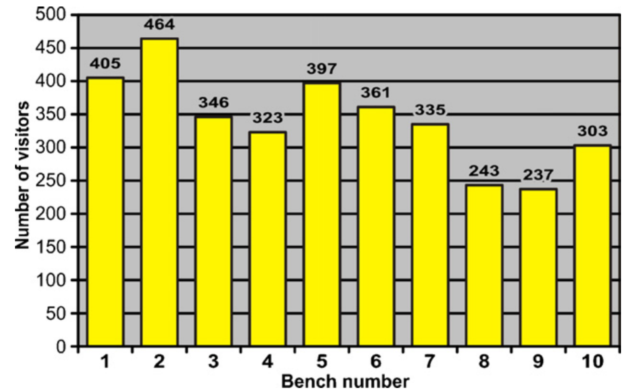

Fig. 14. Differences in the usage of the benches on the area during the whole study period.

conditions in winter, the people in spring tend to expose themselves to thermophysiologically stressful conditions on the sun in a greater extent, than in autumn, after the long warm season. This tendency exists also for shorter time periods too: the presence and the proportion of visitors in the sun rise suddenly in warmer, sunnier days following a longer time period with purer weather conditions, which did not permit the outdoor staying.

The two maps in Fig. 13 also show the altered shading conditions resulted the different seasons. The northeastern side of the area was shaded by the high trees to a different extent during the measuring periods depending on the elevation of the sun and the status of the foliage (vegetation period). These old trees offered mainly penumbra in autumn, and pronounced shadow in springtime. The main source of shade in the large grassy area is the building of the Information Center on the southeastern side.

In the next paragraphs, explanations follows for some of the characteristics which are detectable on the above presented maps and concerning the most preferred parts of the study area. Due to primary functions, benches are the most preferred sitting places on the area, almost regardless to thermal conditions. Besides standing visitors who were conversing to the subjects located on the benches, sitting visitors were found also on the stairways parts of the pathways. There are two concrete flowerbeds beneath the old trees which are also frequently used by sitting visitors, as the top of the morphological step griddles around the large grassy area.

As long as the higher usage level of benches in cases of shiny, hot–warm thermal conditions is due to the visitors' frequently changeover, the high presence on the grassy sector can be explained by its extension and nature which allowed people to gather in greater groups. Generally the people stayed there much longer than in the other sectors if the ground temperature was acceptable.

The presented maps unequivocally show that people congregate the northeastern (right) side of the area (Figs. 9, 12 and 13). This interesting pattern is attributed to the fact that this side of the area stretches closer to the busier street. The main entrance of the university and the Information Centre is also on this side, that is why the visitors came across from this way. This "from the right to the left tendency" is clearly noticeable in the cases of all sectors. Very low attendance was observed on the left part of the grassy sector between the two arms of the pathway and the morphological steps, probably due to the negative, enclosed feeling generated by this area composition, which would evolve in people staying there.

The above-mentioned direction dependent tendency is shown in Fig. 14 in the cases of the benches. Number of visitors sitting on the 1st bench (on the northeastern side) is appreciably greater, comparing to the other one (10) located on the opposite side of the grassy area. By converging to the southwestern side along the pavement, the usage of benches (2–9) decreases also continuously. In the cases of double benches 3–4 as well as 8–9 the attendance is lower, but the tendency is the same. This can be attributed to the mainly unconscious behavioural characteristic that people tend to take a place as far as it is possible to the other, foreign visitors. Because the double benches do not allow too extent personal sphere, the demand for privacy surmounts the effect of distances, and visitors choose rather a single bench even if it locates "far", on the other side of the area.

4. Discussion

4.1. Discussion of the results

The present study investigated the attendance of an urban resting place in the central area of Szeged under various thermal conditions by means of human and environmental observations. The changes of the personal characteristics and reactions with the warming thermal environment (expressed by the PET ranges) clearly exemplify the mechanisms of the physical (behavioral) adaptation aimed to extend the time of staying outdoors (Fig. 10). Namely, the amount of clothing decreased (average clo values reduced), visitors moved into the shaded sub-areas, similarly to findings of Thorsson et al. (2004) as well as the generally dominant passive forms of the activity became even more frequent with warmer situations. Nevertheless, a fair number of visitors stayed in the sun even during warm–hot thermal periods with strong direct radiation. Some reasons for this tolerance against the more stressful thermal conditions are connected to the psychological aspects of thermal comfort, discussed by Nikolopoulou and Steemers (2003) and Knez et al. (2009) in detail in their works.

Because the visitors in outdoor (resting) places are aware of that they cannot influence the atmospheric (climatic) conditions, wider ranges of thermal environment are tolerated in the open-air than indoors, where – in general – climatic changes are regulated and do not occur naturally (Nikolopoulou and Steemers, 2003). Additionally, forms of perceived control over the sources of discomfort have a great importance on the subjective feeling of thermal comfort, consequently on the patterns of the area usage. People become more tolerant to the thermal environment and stay longer despite even the physiologically stressful conditions if they expose themselves voluntarily to these thermal conditions and can leave when they wish, as well as if they have the choice to select from various microclimatic opportunities within the place. The former aspect of perceived control concerns the time of exposure, the latter, spatially aspect relates to the physical form and the function of the area (Nikolopoulou and Steemers, 2003; Knez et al., 2009).

The selected resting place is an excellent example of how an aesthetical urban park with appropriate design can enhance the citizens' time staying in outdoor environment. Besides accessibility, the success of this place is due to the fact that it enables both physical and psychological adaptation by offering more sectors with different surface covers and shading conditions. People have the chance to choose that 'sub-area' which meets their demands and which offers them the most favorable micro-bioclimatic conditions for their activity. In the cases of strong solar radiation visitors can move, for example, to the shaded morphological step, when they wish.

According to Nikolopoulou and co-authors, environmental stimulation may be the main reason for outdoor staying and the variable conditions in time as well as in spatial manner preferred to static environments (Nikolopoulou and Steemers, 2003; Nikolopoulou and Lykoudis, 2006). People came to the area to enjoy the stimulating effects of sunshine, to become refreshed and fill up both physically and psychically.

The dissimilar patterns of area usage (positional distribution of visitors) in the cases of spring and autumn (Fig. 13) caused by different needs for sunshine and warm conditions emphasize the role of thermal experiences and expectations. According to the "logical physiological explanation", higher proportion of visitors had to be exposed to the sun in autumn than in springtime, because of the greater extent of acclimatization to hot conditions after the hot summer period. Contrarily, we have found opposite trend: people tended to avoid the direct exposure to sun in autumn, and the minor proportion of them are in shaded sectors in springs of 2008 and 2009. These findings can be attributed to the psychological effects of the expected and desired thermal conditions which are different in each season.

The spatio-temporal patterns of area usage detectable in Figs. 9, 12 and 13 resulted by the behavioural and psychological responses to the different meteorological conditions, as well as to the emotions generated by the design of the area.

4.2. Significance of the investigation design and adoption of GIS software

As thermal sensation of people is not only based on thermophysiological reactions triggered by the actual thermal environment, but also on numerous subjective psychological and behavioural features, recent human comfort studies conducted in urban environments apply human monitoring (unobtrusive observations, structured interviews) by the thermal comfort index-based assessment. Social survey with questionnaires is the best way to enlarge the knowledge about the complicated relationships between the thermal environment and the evolved subjective human reactions, by asking the people to report their thermal sensation, preference for better conditions, satisfaction with the actual thermal comfort conditions, perceptions, emotions, attitude, etc. (Spagnolo and de Dear, 2003a,b; Stathopoulos et al., 2004; Thorsson et al., 2004; Nikolopoulou and Lykoudis, 2006, 2007; Knez and Thorsson, 2006, 2008; Oliveira and Andrade, 2007; Knez et al., 2009; Lin, 2009). However, the authors opine that the effectiveness of unobtrusive observations may not underrate. This kind of human monitoring can provide also valuable and useful information, particularly if it is followed by geoinformatical data processing – as it is discussed below.

The present study consisted of a preliminary survey of the sample area, meteorological measurements of the thermal comfort variables near the site (environmental monitoring) and simultaneous observations of the visitors who came to the area (human monitoring). This investigation design is very useful for the thermal comfort examination of small-sized urban parks and squares since in relatively short time a lot of information can be obtained by using tables of personal characteristics in each half-hour. By recording the visitors' exact spatial locations besides their personal characteristics, and processing these data within a GIS application, we had wide-ranging possibilities for data analysis and representation of the results.

The adopted GIS software (ArcView) facilitates to mark and select visitors for further descriptive and inferential statistical treatment not only based on the individuals' characteristics, but on their locations, too. The area usage can be showed on the whole or can be separated and presented according to any of the objective or subjective parameters. Consequently, the spatio-temporal presence of certain groups, additionally the attendance of particular sub-areas in accordance with the meteorological conditions became easy to analyze.

Figs. 9, 12 and 13 clearly illustrate the benefits of maps constructed with geoinformatical software in terms of the interpretation of statistical results. These area usage maps are more expressive than the pure statistical measures (commonly used by theoretical sciences) without graphical illustrations, which are especially important in the course of discussion with urban planners, civic designers aiming to construct more comfortable urban areas. Further advantage of these maps, that they clearly show the preferred and ignored parts of the area at various or at the same atmospheric conditions.

The presented methodology has a lot of inherent opportunities, and it is worth to be extended both in a temporal and spatial manner. In order to increase the knowledge on the usage of urban public spaces as a function of the thermal environment, other urban squares and parks will be mapped and analyzed by similar way. Besides studies based on observations, questionnaire-surveys can also be processed in ArcView, providing that interviewees' location is mapped on the sample area. If a study consists of on-site meteorological measurements, this mapping procedure can be done even in the case of mobile micrometeorological station. The attribute table connected to the layer of subjects may contain all of the recorded subjective parameters of the questioned individuals and their answers to the asked questions, as well as the thermal conditions and time of the interview.

Based on the georeferenced data processing in GIS software as well as the global informational network, it is possible to establish a common, international database, supposing that researchers feel inclined to sharing their datasets. Such a common database – summarize the results of scientist dealing with applied urban climatology, thermal comfort, environmental psychology in different geographical regions with different architectural and cultural background – may definitely facilitate the international comparisons in this field.

5. Conclusions

This paper described the methodology and some findings obtained from an outdoor thermal comfort study carried out in a park in the densely built-up city center of Szeged. The study design proved to be appropriate to record relatively lots of subjective information about the visitors in half-hour observation intervals. 6775 visitors were observed (mapped and characterized with some subjective parameters) during the three periods of the study. From the observation data – digitized and processed within ArcView GIS – area usage maps were created.

The presented results have thrown some light on the possible behavioral reactions of people to adapt to the overall thermal conditions, by changing their clothing, position and activity.

On certain days the absolute attendance (number of visitors) was found surprisingly high in spite of the thermally stressful conditions. This is explained by the mechanism of psychological adaptation besides the above-mentioned spontaneous reactions of physical adaptation.

Findings of statistical analyses concern to the differences in area usage according to thermal conditions (or any measured or observed parameter) became very expressive thanks to the area usage maps created within ArcView. These maps clearly illustrated the daily and seasonal differences of attendance. Interesting directional-dependent tendency was found in the spatial distribution of visitors, who tended to congregate the northeastern side of the area.

These maps may be valuable tools in the course of discoursing with urban planners about design strategies, which aim to construct urban microenvironments (parks, squares, etc.) which enhance the social outdoor activity in cities through the benefit of the appropriate thermal comfort conditions. The importance of the topic is obvious, as the efficiency, well-being and health of citizens are positively (or negatively) influenced by the thermal comfort conditions, so by developing and maintaining comfortable conditions urban life quality will be enhanced (Mayer, 2008).

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