UNIVERSITY OF SZEGED
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Summary of PhD thesis

# Human Bioclimatic Assessments at Different Scales

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# 1. Introduction and research objectives

Human bioclimatology examines the effects of climatic circumstances on the human body. This thesis focuses on those components of these impacts which affect the thermal balance of the body, and thus influence the thermal sensation of a person. Thermal comfort (i.e. comfortable thermal sensation and the smallest amount of climatic stress) is one of the primary conditions of people's proper quality of life. It has an impact on every ordinary or leisure activity inside or outside the city. This is the reason why there has been a worldwide increase of interest and case studies in this field (in the last few years).

The rapid increase of global population in the past few decades resulted in the increase of urban population and the growth of densely populated urban areas. The intensification of urban climate phenomena, like urban heat-island, in the ever expanding cities can lead to higher bioclimatic stress and health problems for the residents in summer. It is especially true nowadays when this process is amplified by the global climatic change. One of the possible consequences is that the climatic stress on the human body also changes. It increases (e.g. in summer during heat waves) and decreases (in winter and/or during periods lacking in light). The consequences of this phenomenon must be known in order to develop strategies to reduce the negative effects. It is possible to prepare for these changes only if we know the phenomenon and its consequences, and that is also how we can work out efficient strategies to reduce the negative effects. It is necessary, for example, to optimize the urban thermal comfort circumstances, preferably in a way which does not impose unnecessary burden on the environment (e.g. the excessive and occasionally unnecessary use of air-conditioning, etc.). The climatic conditions of Hungary (a basin with strong continentality) and the predicted effects of the global climatic change in the Carpathian-basin further increase the need for such studies. It can be particularly important in a city like Szeged, where the sunshine duration and the average temperature are higher than the Hungarian average. It is very important to know how these natural conditions affect the comfort feeling of the inhabitants of Szeged.

Accordingly, the following aims were set at the beginning of my research:

- To present a short description of the history, theoretical background, and most up-to-date results of the international human bioclimatology research in Hungarian language;
- To describe a method suitable for quantifying the thermal comfort of the human body and showing its application in different spatial and temporal dimensions in Hungary;
- To quantify the thermal comfort situation of different micro-environments in Szeged;
- To examine the most crucial differences between the urban and rural areas on the example of Szeged;
- To characterize the connection between the extent of physiological climatic load and meteorological parameters in mesoscale;
- To present data for city designers in order to optimize urban human comfort;
- To create and analyze the human bioclimatic map of Hungary in macroscale.

## 2. Methods, data collection, and processing

Due to the huge differences in the spatial and temporal scale of the examined processes, there were different methods applied on different areas.

The 200x200m sample area of the **micro**scale investigations is situated in the city center of Szeged. This area is densely built-up; the narrow street canyons are mainly bordered with 2-3-storey buildings. Two methods were used for microscale studies. In the first case, human bioclimatic indices (PET – Physiologically Equivalent Temperature and PMV – Predicted Mean Vote) were calculated based on the data provided by the fixed meteorological station (e.g. temperature, relative humidity, global radiation, 10-minute averages of the wind speed), which is located in the centre of the research area. Calculations were performed using the RayMan (ver 2.0) radiation and bioclimatic model. The parameters of surface geometry were changed with the help of the model, and the effects of such morphological changes on the human bioclimatic conditions were examined. In the second case, the calculated indices were based on meteorological data collected from six designated locations in the same sample area. The results were used to present the bioclimatic variability occurring in a small area.

A larger examined area and longer examination time period were chosen for a **meso**scale study of the example of Szeged. According to the widely used practice in urban climate studies, the characteristics of two distinct locations were compared from bioclimatic aspects. The modifying effect of the city can be studied at the location situated in the built-up city center, while the effect of the city is negligible at a location on an arable land with an open horizon. Hourly average values of each meteorological parameter (collected between 01.03.2003 – 30.11.2003) were used to calculate PET values. Based on these datasets the difference in physiological stress on urban and rural residents was described. PET categories were created according to the physiological stress levels. Descriptive statistical analyses (e.g. absolute and relative frequency), correlation and linear regression analysis were used to show the link between the meteorological parameters and the extent of bioclimatic load. The analysis was also performed based on seasons and parts of the day to describe the development of physiological stress during a certain period of time.

The main aim of the **macro**scale examination was to create the bioclimatic map of Hungary by combining bioclimatic and geographical data. The spatial distribution of the PET index was calculated for each month. Due to the lack of a detailed measured meteorological dataset, the CRU (Climatic Research Unit) database (University of East Anglia, Norwich, UK) was used. The data collected between 1961-1990 (temperature, wind speed, relative humidity, monthly sunshine duration) were the basis for the performed calculations. The spatial resolution of the calculated PET values was enhanced to 1 km using multiple linear regression (independent parameters: geographical latitude, altitude and altitude above sea level). For this, data from the so-called GLOBE digital model were used.

For data processing, statistical analyses and graphic visualization Microsoft Excel, SPSS 11.0, Corel Draw X3 and Surfer 8.0 software were used.

# 3. Summary and discussion of results

## *3.1. Thermal comfort properties of urban micro environments*

**3.1.1.** Complex surface geometry results in mosaic-like microclimatic parameters. Thus it is expected, that even the microscale human bioclimatic characteristics show a great variability. This diversity is not primarily linked to the thermal but rather to the radiation conditions. There is 30-40 % difference in the PET values depending on whether the direct radiation reaches the body, while the temperature, humidity and wind speed values are constant. This difference can even cause a difference of two categories in the human physiological stress. Human bioclimatic variability is higher than could be expected from the microclimatic conditions. The extremes are even higher if we compare the results of the research carried out in Szeged with the results of international research, which is probably due to the higher global radiation values. It presents itself as strong heat stress during periods of high temperature and radiation in summer (Gulyás et al., 2003, 2004).

**3.1.2.** The moderation of the physiological load on humans can be most effectively achieved by modifying the radiation situation. While there are rather limited possibilities for altering the buildings, changing the tree vegetation seems easier. Despite the fact that the trees occupy small areas in the densely built-up city centers (small parks, trees alongside roads), they have a strong effect on the human comfort. Our studies show that trees can reduce the physiological load by 5-10 % (daily average and during daytime, respectively) even with the same building arrangement. In such a small scale, this is correlated not with the total amount of vegetation-covered area but the shading effect of individual trees (Unger et al., 2005; Gulyás et al., 2006).

### *3.2. Thermal comfort, modified by the city on a mesoscale study*

**3.2.1.** The maximum of the PET value was slightly higher (0.4 °C) but the minimum was considerably higher (6.4 °C) in the urban area, than in the surrounding rural area between March and November, 2003 (Matzarakis and Gulyás, 2006). The frequency distribution of the hourly averages of the PET values shows that the number of both hot and cold extreme values is higher in the rural than in the urban areas. This phenomenon is owing to the undisturbed direct radiation (sky view factor ≈ 100%). While the difference in the length of the *hot* and *very hot* period is about 1% (compared to the full length of the studied term), this difference is 8% between the *cold* and *very cold* categories. Thus we can conclude that the human bioclimatic modifying effect of the city is more pronounced in the physiologically more demanding cold periods, and a slight reduction in the length of the hot stress periods can also be observed. The length of the comfort heat sensation period was twice as much in the urban area compared to the rural area during the complete examined time period. The modification effect of the city is slight in spring and autumn, but it significantly increases the length of comfort period in summer. It can be concluded from the analysis of the frequency distribution of PET values that the city has a moderating and compensating effect on the human comfort conditions (Gulyás et al., 2009).

**3.2.2.** Analyzing the extent and distribution of physiological load in relation to the surrounding area, an evident negative shift can be detected in the city during the day and a positive shift during the night compared to the rural areas. It may not necessarily be caused by the small temperature difference during daytime, but the urban heat island can be responsible for it during the night. The difference of daily averages can be 10-12 °C (PET), which may mean a 2-3 physiological load category difference. The daily course of ΔPET values shows the widest intervals in summer, and the smallest in autumn.

### *3.3. Characterization of the connection between meteorological parameters and the extent of physiological load*

**3.3.1**. A strong positive linear correlation can be observed between air temperature, radiation and the PET value in both areas. In the case of relative humidity and PET the correlation is also linear, but negative with a higher variation than in the former cases. Interestingly, there was no significant relation between wind speed and PET. This is in contradiction with previously published results, but those observations were made with higher (2-5 $ms^{-1}$) wind speed at lower $T_{mrt}$. In our case, the measuring point was located at the edge of a street canyon. Very low wind speed was calculated with the applied wind speed reduction to 1.1 m height (particularly in the town centre), which is the human bioclimatic standard. This remarkably low wind speed was observed in every season and was probably the reason for the unexpected results (Gulyás et al., 2009).

**3.3.2.** Linear regression analyses show that the strongest correlation between air temperature and physiological load can be measured (independently of seasons) at night. The temperature affects human comfort less dominantly during the day, this correlation, however, depends on the season and the examined area. The extent of this decrease is the highest in summer and in an urban environment (Gulyás et al., 2009).

**3.3.3.** The $T_{mrt}$ (which describes the radiation situation) and the PET index have a strong correlation every season of the year and every time of the day. The determination coefficient decreases below 0.9 only in spring and autumn at night. This phenomenon is in fact the mesoscale manifestation of the phenomenon that also exists in microscale, indicating the crucial role of radiation in forming the thermal comfort (Gulyás et al., 2009).

**3.3.4.** The correlation between relative humidity and PET is less strong than in the case of the above mentioned two parameters. The value of the determination coefficient is smaller at night than during the day, independently of the season. This indicates that the effect of humidity on the human comfort is smaller during the night than during daytime. This is more pronounced in autumn. According to the determination coefficients the impact of the RH on human comfort is higher in the rural area than in the city. The strongest correlation can be observed in the rural areas, during daytime in autumn (Gulyás et al., 2009).

### *3.4. Macroscale bioclimatic characterization of Hungary*

**3.4.1.** The thesis presents a possible way of data interpretation for linking geographical and bioclimatic data. This method was used to produce the first bioclimatic map of Hungary, based on the distribution of PET monthly average values with 1 km resolution. Generally speaking, the PET value increases with the decrease of altitude above sea level and in the N-S direction. This direction changes in winter to NE-SW. Thus the Northern Mountain Range and NE part of the Great Plains offer the highest cold stress in winter, these areas have the lowest PET values from spring to autumn. The difference between the highest and the lowest PET values is between 5-11 °C, depending on the month. The difference is smallest in winter and highest in late spring and summer (Gulyás and Matzarakis, 2007).

**3.4.2.** A homogeneous distribution of human comfort categories can be observed in winter. The area of the whole country belongs to the *extreme cold* category, which can be explained by the low complexity of the relief. However, this research and conclusion indicated the necessity of refining the cold comfort categories, to fit them better to climatic situations similar to those in Central Europe (Gulyás and Matzarakis, 2009).

**3.4.3.** Differences between the extreme values observed in the country area can be detected when the radiation is higher (from spring till autumn). This shows the dominant role of radiation in shaping the human comfort situation (as similarly shown in the smaller scale studies). A difference of two categories can be observed during summer months along the N-S gradient described in point 3.4.1. (Gulyás and Matzarakis, 2009).

**3.4.4.** PET values are decreasing with the increasing altitude, in good agreement with the decreasing temperature. However, this relation is not the same in the case of different mountains. For example when comparing the Mecsek Mountains to the Visegrád Mountains, which are almost at the same altitude, it is clearly visible, that the Mecsek does not differ from its surroundings in a bioclimatic aspect, unlike its counterpart. The differentiation depending on the height is more significant in the Visegrád Mountains. The "merging" of the Mecsek into the surrounding area is the most pronounced in winter. A possible explanation for this phenomenon is the bioclimatic equalizing impact of the Mediterranean climate in the SW part of the country. In the north, the increasing continental climatic effect stresses the importance of elevation above sea level in the formation of bioclimatic conditions. This effect can be the reason for the N-S, NE-SW PET changing direction described earlier (Gulyás and Matzarakis, 2009).

# List of publications directly used in the dissertation (9)

(* signifies journals with an impact factor)


1. ***Gulyás, Á**., Unger, J., Balázs, B. and Matzarakis, A.,* 2003: Analysis of the bioclimatic conditions within different surface structures in a medium-sized city (Szeged, Hungary) *Acta Climatologica et Chorologica Univ. Szegediensis 36-37,* 37-45.
2. ***Gulyás Á.**, Unger J. és Matzarakis, A.* 2004: A városi környezet mikroklimatikus jellemzőinek bioklimatológiai szempontú elemzése Szeged példáján. *2. Magyar Földrajzi Konferencia, Szeged CD-ROM ISBN 963-482-687-3*
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7. ***Gulyás, Á**. and Matzarakis, A.,* 2007: Selected examples of bioclimatic analysis applying the physiologically equivalent temperature in Hungary *Acta Climatologica et Chorologica Univ. Szegediensis 40-41,* 37-46.
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### *Other publications related to the subject (10)*


1. *Lakatos, L.,* ***Gulyás, Á.,*** 2003: Connection between phenological phases and urban heat island in Debrecen and Szeged, Hungary. *Acta Climatologica et Chorologica Univ. Szegediensis 36-37,* 79-83.
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6. *Kántor, N., **Gulyás, Á.** és Unger, J.,* 2008: Városi humán komfort objektív és szubjektív megközelítésben. *MMT Agro- és Biometeorológiai Szakosztályának előadó ülése, OMSZ Székház, Budapest, 2008. június 12.* (előadás)
7. *Kántor, N., **Gulyás, Á.**, Égerházi, L. and Unger, J.,* 2008: Objective and subjective aspects of an urban square's human comfort – case study in Szeged (Hungary). *5th Japanese-German Meeting on Urban Climatology, Albert-Ludwigs-University of Freiburg, Germany, 6-8 October 2008* (poszter)
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