A CONTRIBUTION TO THE THERMAL BIOCLIMATE OF HUNGARY – MAPPING OF THE PHYSIOLOGICALLY EQUIVALENT TEMPERATURE[58]

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Abstract: The thermal bioclimate is described here through the Physiologically Equivalent Temperature (PET). PET is a thermal index, which is based on the energy balance of the human body. It describes the effect of the thermal environment on humans. In this study, maps were created that show the geographical distribution of PET values in January and July for the area of Hungary. For the further analysis of the thermal bioclimate, data of the synoptical network for Szombathely station, recorded from 1996 to 2000 has been used. The produced maps and data can be used for various approaches in applied climatology i.e. tourism or detection of extreme biometeorological events and areas.

INTRODUCTION

For the bioclimatic evaluation of a specific location or area not only single meteorological parameter is required, but a complex evaluation of the effects of climate conditions and thermo-physiological values in order to describe the effects of the thermal environment on humans. Several models and indices were developed to calculate the extent of thermal stress during the last decades. The earlier bioclimatic indices (Discomfort Index, Windchill, thermohygrometric index-THI) consider only some meteorological parameters (***Thom, E. C.*** 1959, ***Steadman, R. G.*** 1971, ***Unger J.*** 1999, ***Matzarakis, A. et al.*** 2004). New models, based on human energy balance equation, produce so-called comfort indices – for example Predicted Mean Vote-PMV, Physiological Equivalent Temperature-PET, Outdoor Standard Effective Temperature-OUT_SET* – to evaluate the thermal stress on the body (***Fanger, P. O.*** 1972, ***Jendritzky, G. et al.*** 1990, ***Höppe, P. R.*** 1993, 1999, ***VDI*** 1998, ***Matzarakis, A. et al.*** 1999, ***Spagnolo, J. – de Dear, R.*** 2003). These indices can be applied in different time and spatial resolutions (***Jendritzky G. et al.*** 1990, ***Matzarakis, A. et al.*** 1999, ***Koch, E. et al.*** 2005). For example, describing a small area (e.g. surroundings of a building, part of a street), with fine resolution can be useful for architects and urban designers (***Matzarakis, A.*** 2001, ***Mayer, H. – Matzarakis, A.*** 1998). Micro-scale studies (e.g. bioclimatological description of a

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town) provide data for urban planning (***Unger J. et al.*** 2005). Examining even larger areas (eg. a whole region or country) has not only scientific value: the results of these studies can be the basis of planning regional recreation and tourism development (***Mayer, H. – Matzarakis, A.*** 1997, ***Matzarakis, A. et al.*** 1999, ***Matzarakis, A. et al.*** 2004).

The aim of this study is to present a bioclimatic analysis of Hungary by means of bioclimatical mapping with the aid of geo-statistical methods. The present study links geographical information (***Hastings, D. A. et al.*** 1999) with climatological data (***New, M. et al.*** 1999, 2000, 2002) in order to generate a spatial distribution of PET values of a region. The calculation of PET is performed with the aid of the RayMan Model, which calculates the thermal indices mentioned above (***Matzarakis, A. et al.*** 2000, 2006).

STUDY AREA AND METHODS

Study area

Although the original study was done for a larger area, this paper focuses on the description of bioclimatic properties in Hungary (the national border is marked with black line – *Figure 1*).

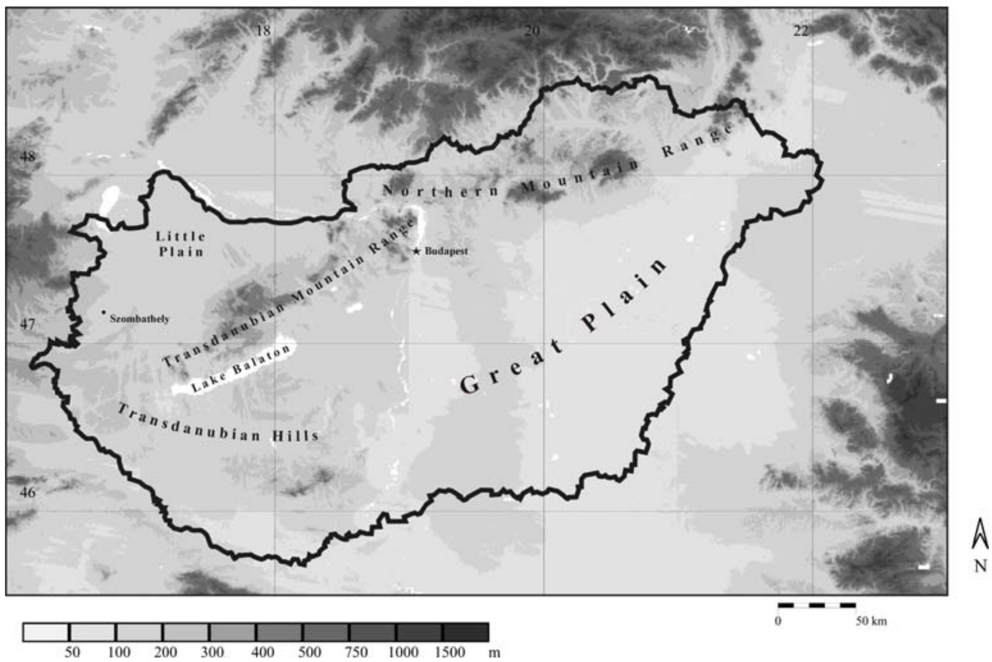

Figure 1 Geographical location and topography of Hungary
(the numbers are northern latitudes and eastern longitudes in degrees)

Hungary is situated in the Carpathian Basin almost in the centre of Europe between the latitudes 45º 48’ N and 48º 35’ N, longitude 16º 05' E and 22º 58' E with an areas of 93,030 km^2. As *Figure 1* shows, it has three basic relief types: the low-lying regions (under 200 m above sea level) of the Great Plain in the east, centre and south-east, and of the Little Plain in the north-west, which together cover for two-thirds of Hungary’s territory. There is the Northern Mountain Range (Északi-középhegység); and the mountainous (Transdanubian Mountain Range – Dunántúli-középhegység) and hilly regions of Transdanubia in the west and south-west (Transdanubian Hills – Dunántúli-dombság).

The main characteristics of Hungary’s climate and the frequent fluctuations in climatic factors are greatly due to the central position in Europe. Namely, Hungary is situated at the 'crossroads' of the East-European continental, the West-European oceanic and the subtropical Mediterranean climatic zones (***Pécsi, M. – Sárfalvi, B.*** 1964).

Using Köppen’s classification, Hungary fits in the climatic regions *Cf*, which is characterized by a temperate warm climate with a rather uniform annual distribution of precipitation. Its annual mean temperature is 10.4ºC (in Budapest/Lőrinc), the amount of precipitation is 516 mm. These values show little variance across the country due to the limited variation in topography (***WMO*** 1996).

Applied bioclimatic index

In this study one of the most widely used bioclimatic index, the PET is used, as it has a widely known unit (ºC) as an indicator of thermal stress and thermal comfort. This makes the results easily understandable and comprehensible for potential users. This is especially the case for planners, decision-makers, and even the public who might be not familiar with modern human-biometeorological terminology. PET evaluates the thermal conditions in a physiologically significant manner (***Höppe, P. R.*** 1999, ***Matzarakis, A. et al.*** 1999). It is defined as the air temperature at which the human energy budget for the assumed indoor conditions is balanced by the same skin temperature and sweat rate as under the actual complex outdoor conditions to be assessed. PET enables various users to compare the integral effects of complex thermal conditions outside with their own experience indoors (*Table 1*). In addition PET can be used all year and in different climates (e.g. ***Höppe, P. R.*** 1999, ***Mayer, H. – Matzarakis, A.*** 1997). Meteorological parameters influencing the human energy balance, such as air temperature, air humidity, wind speed and short- and longwave radiation, are also represented in the PET values. PET also considers the heat transfer resistance of clothing and the internal heat production.

Table 1 Physiologically Equivalent Temperature (PET) for different grades of thermal sensation and physiological stress on human beings (during standard conditions: heat transfer resistance of clothing: 0.9 clo internal heat production: 80 W) (***Matzarakis, A. – Mayer, H.*** 1996)

PET (°C)	Thermal sensation	Physiological stress level
	very cold	extreme cold stress
4	……………	………………
	cold	strong cold stress
8	……………	………………
	cool	moderate cold stress
13	……………	……………….
	slightly cool	slight cold stress
18	…………….	……………….
	comfortable	no thermal stress
23	…………….	………………..
	slightly warm	slight heat stress
29	…………….	………………..
	warm	moderate heat stress
35	…………….	………………..
	hot	strong heat stress
41	…………….	………………..
	very hot	extreme heat stress

RayMan model

One of the recently used radiation and bioclimate models, RayMan, is well-suited to calculate radiation fluxes (e.g. ***Mayer, H. – Höppe, P. R.*** 1987, ***Matzarakis, A.*** 2002), and thus, all our calculations for T_{mrt} and PET were performed using this model. The RayMan model, developed according to the Guideline 3787 of the German Engineering Society (***VDI*** 1998) calculates the radiation flux in easy and complex environments on the basis of various parameters, such as air temperature, air humidity, degree of cloud cover, time of day and year, albedo of the surrounding surfaces and their solid-angle proportions.

The main advantage of RayMan is that it facilitates the reliable determination of the microclimatological modifications of different urban environments, since the model considers the radiation modification effects of the complex surface structure (buildings, trees) very precisely. Beside the meteorological parameters, the model requires input data on surface morphological conditions of the study area and on personal parameters.

Data

The used climate data for this analysis was provided by the data collation program at the Climatic Research Unit (***New, M. et al.*** 1999, 2000, 2002). The required data for the thermal bioclimate analysis -these are air temperature, relative humidity, sunshine and wind speed- are available at monthly resolution for the climate period 1961 to 1990 at ten minute resolution for the specific area. The calculated PET grid values have been used as dependent variable. They have been recalculated into a higher spatial resolution (1 km) through the use of geo-statistical methods (independent variables were latitude, longitude and elevation). For this purpose the digital elevation data of the GLOBE data set (***Hastings, D. A. et al.*** 1999) was used.

An additional analysis has been performed for the selected station (i.e. Szombathely) for the period 1996 to 2000 for 12 UTC in order to describe the thermal bioclimate conditions more analytically on daily basis.

RESULTS

Spatial distribution of PET in Hungary

From the produced monthly and seasonal maps, only one for the winter period (January), and one for the summer period (July) are presented here. The statistical relationship is very high ($r > 0.9$) for all months and seasons.

The spatial distribution of the average PET in January for the period of 1961-1990 is shown in *Figure 2.* The orographical situation of Hungary is not diverse: most of the country lies on plains below 200 m latitude, thus the bioclimatic conditions are relatively homogeneous. The whole country is categorised as being subject to extreme cold stress levels. The regional differences are not more than 5ºC. The lowest PET values (-9ºC) can be observed in the areas with higher latitude, especially in the Northern Mountain Range. Due to the effect of the oceanic climatic zone, the winter is milder in Transdanubia. This is the main reason why the PET values are not so low (-7, -8ºC) in the Transdanubian Mountain Range than in the Northern Mountain Range.

The southern situated Transdanubian Hills have the highest monthly average PET values in the country, partially due to the mediterranean influence. Towards the eastern borders of the country, the PET values are decreasing due to the increasingly continental (and Carpathian) climate. The cold stress increases towards the north and north-eastern borders of the country.

Figure 3 shows the spatial distribution of the average PET values for July during the examined time frame. The ΔPET is higher in this month than in January (11ºC) and covers three stress levels (*Table 1*). In July, however, the bioclimatic situation in the plains are more homogeneous than in January. There is a maximum PET value of 24ºC in the whole Great Plain. The only exceptional area is the north-eastern region near the Ukrainian border, where the close proximity of the Carpathian Mountains and the higher air humidity caused by the quite numerous streams and rivers reduce the heat stress. The areas free of heat stress are the terrains above 200-400 m above sea level, where the thermal sensation is "comfortable" (*Table 1*). The PET values are further decreasing in the mountains to the "slightly cool" thermal sensation (15-16ºC).

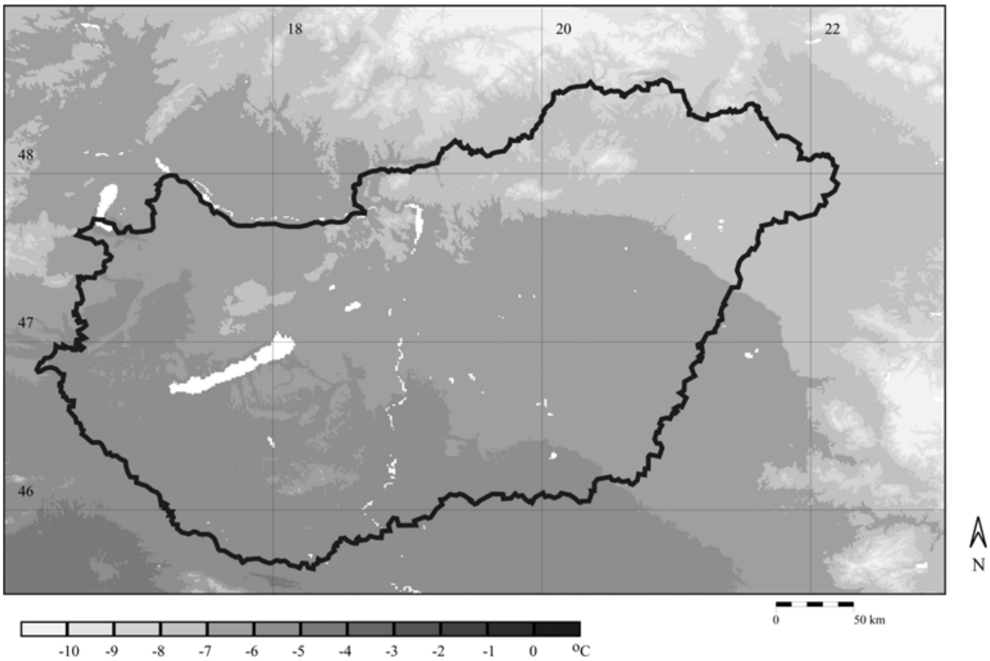

Figure 2 Geographical distribution of PET for January

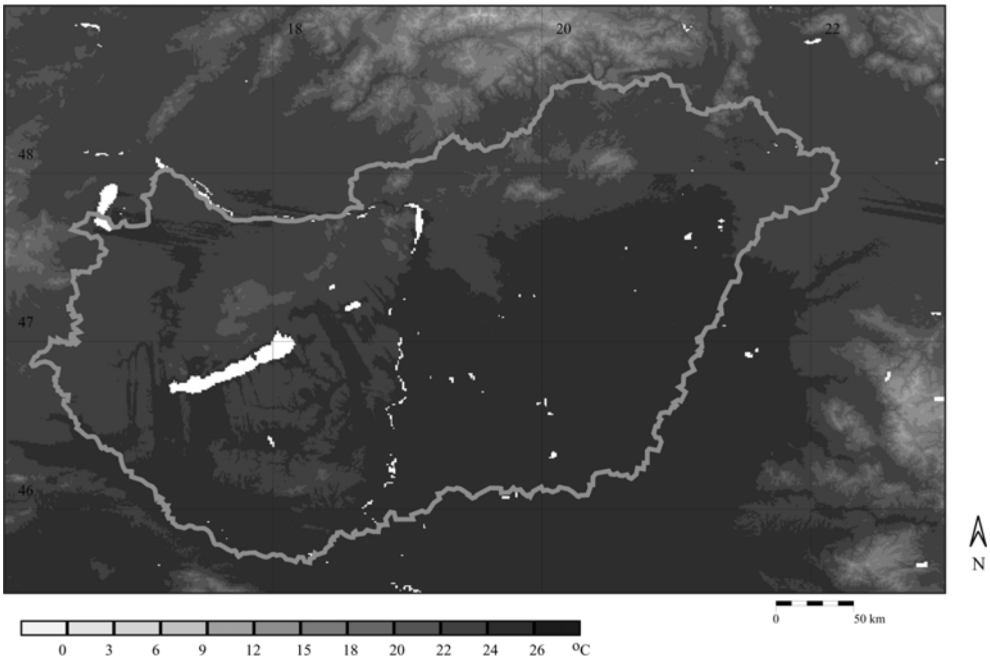

Figure 3 Geographical distribution of PET for July

It should be noted that the coastline of Lake Balaton, one of Hungary's most popular tourist destination, shows the lowest cold stress level in January. The situation is different in summer, when the heat stress is high around the lake, especially on the northern coast which is surrounded by mountains. This situation, which is caused by the southern exposure and the reflexion from the water surface, creates ideal circumstances for water-based recreational activities.

Selected station

An additional analysis that has been performed with the PET index, based on daily meteorological values of a certain location, provides an opportunity for a more detailed analysis of the bioclimatic situation of the selected area. The chosen meteorological station (Szombathely) is situated close to the western border of the country in proximity to the Alps. Its climate is characterised by the oceanic effect throughout the year.

The bioclimatic diagram (*Figure 4*) gives information on the percentages of different bioclimatic classes of PET, plotted in decas (10 days intervals) during the whole year, based on the data measured data for 12 UTC in the period of 1996-2000.

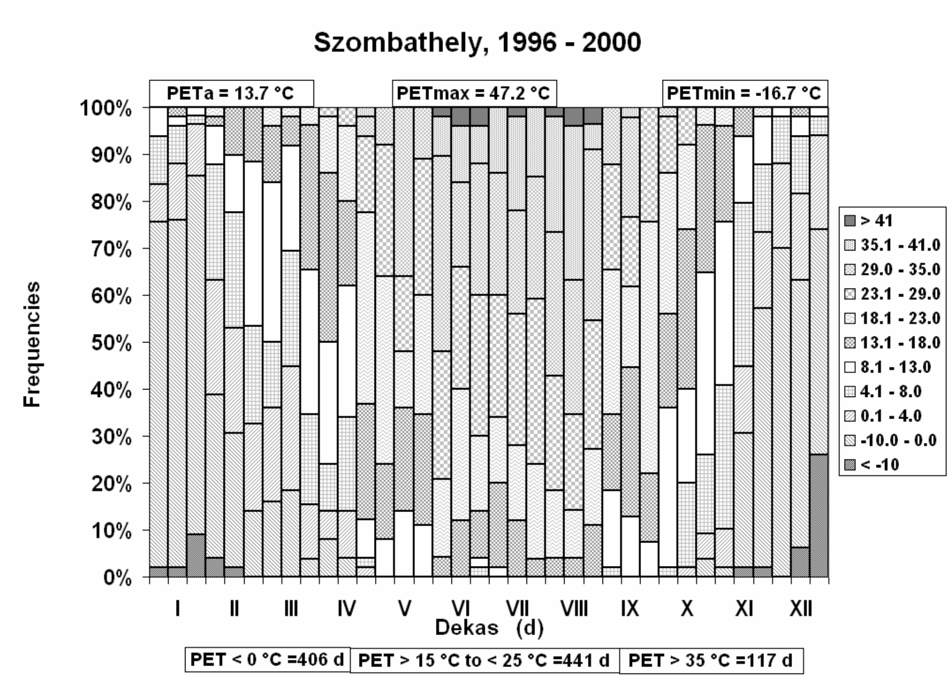

Figure 4 Bioclimate diagram for Szombathely for 1996 to 2000 for 12 UTC

The diagram also shows the following values:

- the mean PET value in the examined time period (PETa)
- the maximum PET value in the examined time period (PETmax)

- the minimum PET value in the examined time period (PETmin)
- the amount of days for the examined period with PET < 0ºC, PET between 15ºC and 25ºC and PET > 35ºC.

The climate data obtained for Hungary show that January has the lowest average mean temperature (***WMO*** 1996). However, the lowest PET values (most extreme cold stress) were calculated with the highest probability in Szombathely in December and January. It is also important to note that the first days with moderate heat stress occured in spring; heat stress becomes even more intense in May. The possible reason for this phenomenon is the increasing continental effect that occurs in the Carpathian Basin, resulting in shortened transitional seasons (spring and autumn). This effect cannot be masked by the western location of the examined meteorological station. The frequency of the days with strong and extreme heat stress (PET > 35ºC) is constantly increasing during the summer months and reaches the highest values in the first decas of August. The amount of days with PET > 35ºC for the examined period is 117. These days occur from the end of April and often continues until the end of September. The bioclimatic data clearly shows the presence of several days with comfortable thermal sensation in early autumn ("Indian Summer"). The second and third decas of September show higher numbers of days with slight and moderate heat stress.

CONCLUSIONS

Spatial data are required in order to describe and analyse the bioclimate of regions or areas. The methods exist, and the thermal indices based on the energy balance of humans present an appropriate method.

Bioclimate maps can be produced by existing gridded data and geo-statistical methods for meso scale and micro scale resolution for a region. When applying a time resolution of several months, it is impossible to discover the whole range of thermal bioclimate conditions, especially in extreme events. Extreme conditions can be analysed through the use of data from synoptical or climatological networks.

Because of the used ten days intervals, which are more detailed than monthly resolutions and also more relevant not only for recreation and tourism, the presented bioclimate diagram constitutes a highly effective method.

For the bioclimate of Hungary the produced maps presents a first approach in the field of high resolution maps, which can be helpful for diverse issues like human health and tourism. Additionally, periods of extreme cold and heat waves can now be detected.

The climate becomes more continental towards north, north-east throughout the country. This is represented in the bioclimatic properties of the examined area: the thermal stress tends towards the extremities also in summer and winter.

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