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CHANGING THERMAL BIOCLIMATE IN SOME HUNGARIAN CITIES

Á NÉMETH

Climatology Division, Hungarian Meteorological Service, Kitaibel P. u. 1., 1024 Budapest, Hungary
E-mail: nemeth.a@met.hu

Summary: Today we can say that the climate change is a scientific fact. The majority of climate change research analyzes only the future conditions. However, we need to know that the future changes cannot be determined without knowledge of the past changes. In this paper the detected changes of thermal bioclimate are analyzed. For this analysis two different bioclimate indices were used. The first one is the Physiologically Equivalent Temperature, the well known bioclimate index, calculated by the RayMan model. The second one is a newly developed bioclimate index, the Universal Thermal Climate Index. Both indices have been calculated for Budapest, Debrecen, Szeged and Siófok, for 12 and 18 UTC. According to the results the annual means increased at both examined times of day. The seasonal means in spring and in summer increased unambiguously. In autumn and in winter the change is different. In winter the 1971-2000 averages are higher than the 1981-2010 averages. In autumn, the 1971-2000-s averages are generally lower than the previous 30-year average. But the last averages exceed all the 1971-2000 averages.

Key words: thermal bioclimate, climate change, Physiologically Equivalent Temperature, Universal Thermal Climate Index

1. INTRODUCTION

Thermal comfort is one of the determining factors of human health and quality of life. The heat balance of human body is very complicated; it depends on many external and internal factors. One of the most important external factors is the atmospheric environment. The characteristics of the physical condition of the atmosphere can be described by meteorological observations. What kind of role do these meteorological parameters play concerning human heat balance? However, it is important to know that certain facts should not be examined separately, but these facts affect our body in a complex way, co-operating with each other. For this reason these meteorological parameters determining the thermoregulation process of the human body are termed "thermal complex" in human bioclimatology. This thermal complex includes long-wave radiation, air temperature, wind speed and air humidity (Jendritzky 1993). The analysis of the thermal complex is possible with different bioclimate indices.

Human bioclimate has been present for a relatively long time in urban environment research in Hungary. A number of excellent studies were born in the field of urban bioclimate (Unger 1999, Gulyás et al. 2006). But the number of large-scale or regional human bioclimate research were rather small (Gulyás and Matzarakis 2007, 2009). Researches related to the changes of thermal bioclimate have started only in recent years, particularly the aspects of tourism climatology (Németh et al. 2007, Németh and Mika 2009).

We have more or less exact knowledge about the climate changes detected in our country. This knowledge provides correct background information for climate change research. We know the regional climate model results: in all seasons the air temperature is expected to increase in the Carpathian basin (Bartholy et al. 2008, Csima and Horányi 2008, Szépszó and Horányi 2008). With the thermal complex we can evaluate mainly how our life will be affected by these changes. For this it is necessary to recognize the changes of the thermal complex in the past.

The knowledge of thermal bioclimate and its changes is useful in the everyday life in many cases. Bioclimatological research provides essential information for the development of adaptation strategies especially in the urban environment where the human body is under stronger thermal stress which increases health risks. Modern urban planning and sustainable tourism development cannot be imagined without bioclimatological analysis. This study aims to demonstrate a changing thermal bioclimate in four cities in Hungary as an example. Although bioclimatological studies based on the adopted methodology are generally carried out at 12 UTC, but the thermal bioclimate conditions in the evening (18 UTC) are also examined in the interests of practical applications. The latter is important from the aspects of the environment, health or tourism.

2. MATERIAL AND METHODS

2.1. Study area

The cities (Fig. 1) selected for this research are Budapest-Pestszentlőrinc (47°25'N, 19°11'E, 139 m asl), Debrecen (47°29'N, 21°37'E, 105 m asl), Siófok (46°54'N, 18°2'E, 107 m asl) and Szeged (46°15'N, 20°5'E, 82 m asl). At the selection of the settlements, the following properties have been taken into account. All meteorological stations have exact long-time data series. The places of measurements have not been changed significantly in the last 50 years, so the data series are homogenous. This is particularly important for analyzing long data series. In addition, these towns are located in important touristic regions of Hungary.

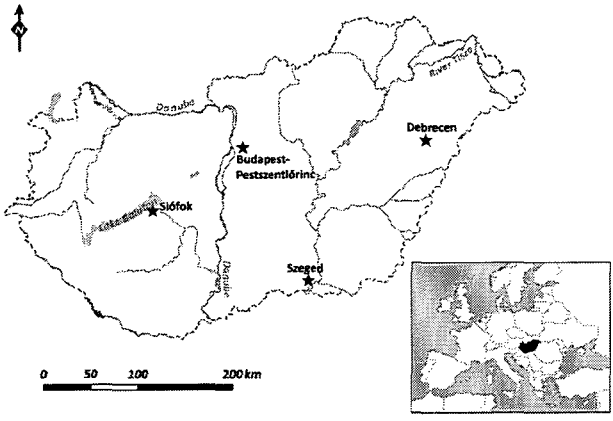

Fig. 1 Geographical location of the selected cities

2.2. Methods

The change of thermal bioclimate practically means the change of thermal sensation or comfort climate. We can analyze it by way of bioclimate indices. In human

bioclimatology more and more indices are available, from simple ones, which use only meteorological input parameters, to more complex indices which take into account the human energy balance. In this paper two complex bioclimate indices were applied.

The Physiologically Equivalent Temperature (PET) is one of the most common bioclimate indices. It is derived from the Munich Energy-balance Model for Individuals (MEMI) (Höppe 1984, 1999). The MEMI models the thermal conditions of the human body physiologically. Besides meteorological parameters (air temperature, relative humidity, wind speed and cloudiness) some physiological and geographical inputs are required for calculating PET. For the calculation the RayMan software was used (Matzarakis et al. 1999 2007). The calculation was carried out for a 35 years old, 175 cm tall man with a weight of 75 kg who is sitting and wears normal clothing (0.9 clo).

The PET values were defined according to different thermal perceptions for temperate climate (Matzarakis and Mayer 1996). Because of this the original PET scale (Table 1) can not be used worldwide, so for example for (sub)tropical climate another PET scale is usually applied (Lin and Matzarakis 2008).

Contrarily, the most recent bioclimate index is the Universal Thermal Climate Index (UTCI) which is developed by COST Action 730 (Jendritzky et al. 2009). After model comparisons it became a consensus to base UTCI on Fiala's multi-node model (Fiala et al. 2001). This model simulates the heat transfer inside the body and at its surface taking into account the anatomical, thermal and physiological properties of the human body. The UTCI is the air temperature which, under reference conditions, would produce the same thermal strain as in the actual thermal environment (Blazejzcyk et al. 2010).

Table 1 Ranges of the Physiologically Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI) for different levels of physiological stress and thermal sensation (Matzarakis and Mayer 1996, Blazejczyk et al. 2010)

PET (°C)	UTCI (°C)	Grade of physiological stress	Thermal sensation
above +41	above +46	extreme heat stress	very hot
-----	+38 to +46	very strong heat stress	strongly hot
+35 to +41	+32 to +38	strong heat stress	hot
+29 to +35	+26 to +32	moderate heat stress	warm
+23 to +29	-----	slight heat stress	slightly warm
+18 to +23	+9 to +26	no thermal stress	comfortable
+13 to +18	0 to +9	slight cold stress	slightly cool
+8 to +13	-13 to 0	moderate cold stress	cool
+4 to +8	-27 to -13	strong cold stress	cold
-----	-40 to -27	very strong cold stress	strongly cold
below +4	below -40	extreme cold stress	very cold

Both meteorological and non-meteorological (metabolic rate and thermal resistance of clothing) reference conditions were defined (Jendritzky et al. 2009, Blazejczyk et al. 2010):

- a wind speed of 0.5 m/s at 10 m height (approximately 0.3 m/s in 1.1 m),
- a mean radiant temperature equal to air temperature and,
- vapour pressure that represents a relative humidity of 50%; at high air temperatures (>29°C) the reference humidity was taken constant at 20 hPa.

– a representative activity to be that of a person walking with a speed of 4 km/h (1.1 m/s). This provides a metabolic rate of 2.3 MET (135 Wm^{-2}).

For calculating the UTCI the air temperature, mean radiant temperature, water vapour pressure and wind speed are required (Jendriztky et al 2010). A pre-alfa version of the software was used for calculation. This software can be downloaded from the COST Action 730's website (www.utci.org/cost.php).

The PET and UTCI values were calculated for 12 and 18 UTC, for the period 1961-2010 and for the mentioned four meteorological stations. Then these values were averaged for climatological standard periods: 1961-1990, 1971-2000 and 1981-2010.

3. RESULTS AND DISCUSSION

3.1. Variation of annual averages

According to the 50-year average of the annual mean PET at 12 UTC, the thermal bioclimate of the examined cities is "slightly cool" (PET_{YEARLY} = 13.2 - 14.2°C) with "slightly warm" summer (PET_S = 27.2 - 28.9°C) and "very cold" winter (PET_W = -2.5 - (-1.8)°C). On the basis of UTCI at 12 UTC, the thermal bioclimates of selected cities are "comfortable" ($UTCI_{YEARLY}$ = 12.9 - (13.9)°C) with "warm" summer ($UTCI_S$ = 26.7 - 28.3°C) and "cool" winter ($UTCI_W$ = -3.5 - (-1.9)°C).

The 30-year average of the annual means of PET and UTCI, calculated for 12 UTC, increased on a slightly different scale (Fig. 2). The averages grew significantly in Szeged and Budapest, but the change in Siófok is negligible. The average PET in Budapest was the lowest in the period 1961-1990. However, in the last 30 years the average PET of Budapest was the second highest. According to the results the UTCI changes more than the PET. The many-year average of UTCI increased from 13°C to about 15°C during the investigated period in Budapest. Meanwhile, the UTCI average in Siófok increased with only 0.5°C over this period, and reached just over 13°C.

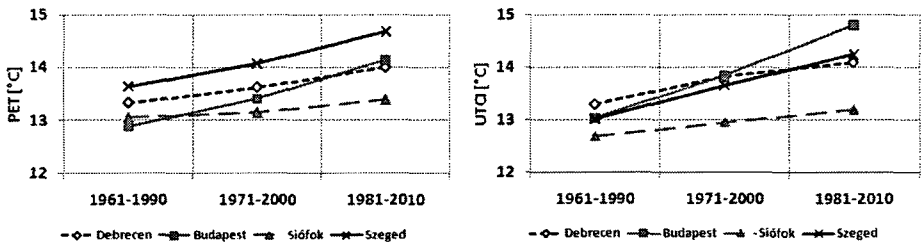

Fig. 2 Variation of 30-year averages of annual means of Physiologically Equivalent Temperature (left) and Universal Thermal Climate Index (right) at 12 UTC

If we analyze the bioclimate indices at 18 UTC, the difference between the two indices is clear (Fig. 3). The PET indices of the different stations are changing almost to the same extent. Interestingly, the highest average of PET occurs in Siófok. Then the sequence of Budapest, Szeged and Debrecen follows. The UTCI curves run somewhat different. The

UTCI changes in Siófok and Debrecen are not equable in the examined periods, in the third 30-year period the growth is lower.

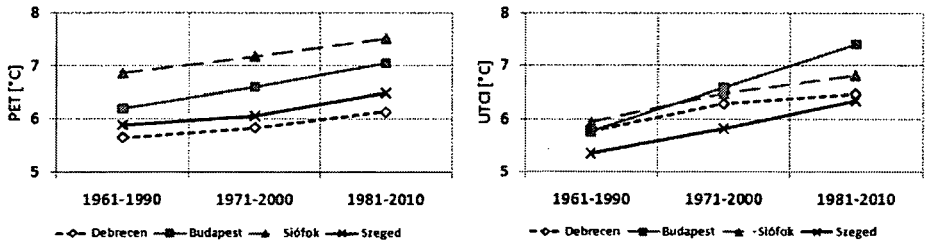

Fig. 3 Variation of 30-year averages of annual means of Physiologically Equivalent Temperature (left) and Universal Thermal Climate Index (right) at 18 UTC

3.2. Variation of seasonal averages

Analyzing the seasonal means of PET at 12 UTC (Fig. 4) in spring and summer a clear increase occurs. The change of PET average in summer is significant between the periods of 1961-1990 and 1981-2010, it is about 2°C in all stations. In autumn the situation is different. The autumn averages are lower in period 1971-2000 than the previous period, but after this the average increases. In winter the PET averages changed in the opposite direction than in autumn. The average of PET for period 1971-2000 is higher than the previous period however the averages of 1981-2010 lag behind from this. Only Budapest does not fit to in this trend because the seasonal averages of PET in winter increase permanently.

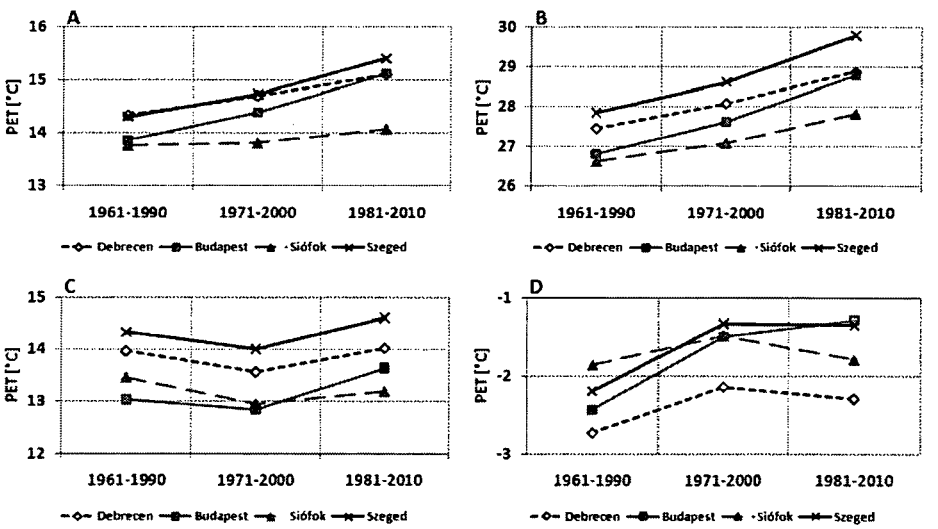

Fig. 4 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Physiologically Equivalent Temperature at 12 UTC

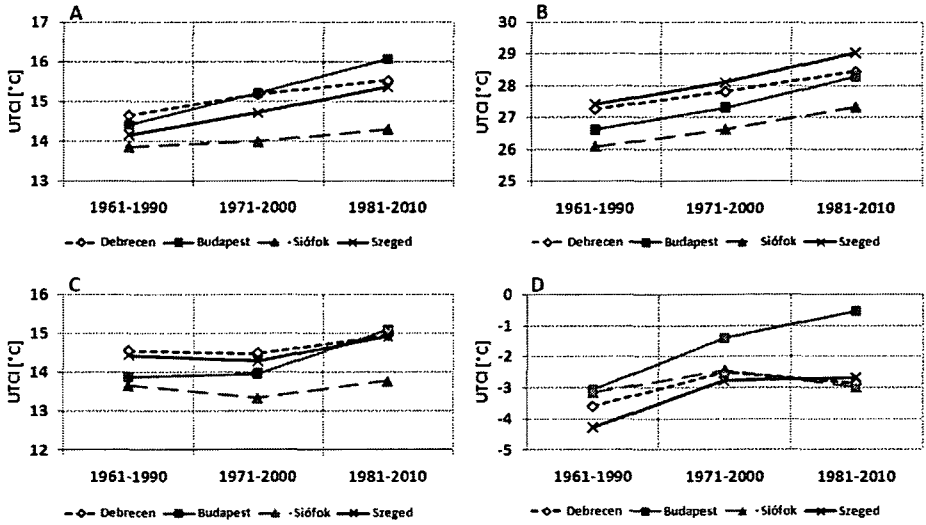

Fig. 5 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Universal Thermal Climate Index at 12 UTC

The variations of the UTCI averages at 12 UTC (Fig. 5) are similar to PET but the extent of change in this case is smaller. In autumn it can be observed that the differences between the averages of 1971-2000 and 1961-1990 are rather small (< 0.4°C). The averages of 1981-2010 exceed the past periods' averages in all station. The change is significant in Budapest especially; here the average of the last 30 years exceeds the averages of the previous periods with more than 1°C. In winter, it is notable that the values in Budapest behave differently from the other stations.

The thermal bioclimate is only slightly different from this in the evening hours. The averages of PET in spring at 18 UTC increased in all stations (Fig. 6). It is noticeable that the averages in Szeged and Debrecen move together in every period and these values are lower with about 1°C than the averages in Siófok and Budapest. In summer, the situation is the same as in the case of the values at 12 UTC, the seasonal averages are changed to the same extent in the examined stations. As we have already observed, in autumn the average initially decreases, and in the third 30-year period at each station an increase of PET occurs. Changes in the winter period are a reverse of this tendency.

According to the average UTCI (Fig. 7) in spring Budapest shows a higher increase than the other three stations. The 1981-2010 average in Budapest was about one degree higher than the average of the other stations. In summer, the UTCI values in each of the four examined cities were almost equal. The differences between the individual stations do not reach a half degree. In autumn, usually the 1971-2000's averages are lower than in the previous 30 years, except in Budapest. Then, large and small increases occur in the averages. Meanwhile, in Budapest the average of many years' UTCI increased at an accelerating rate. The winter averages of UTCI for 1971-2000 increased compared to the 1961-1990's averages, and then a slight decrease occurs.

Budapest is the exception in this case too, because in winter the average UTCI has not decreased in the last 30-year period.

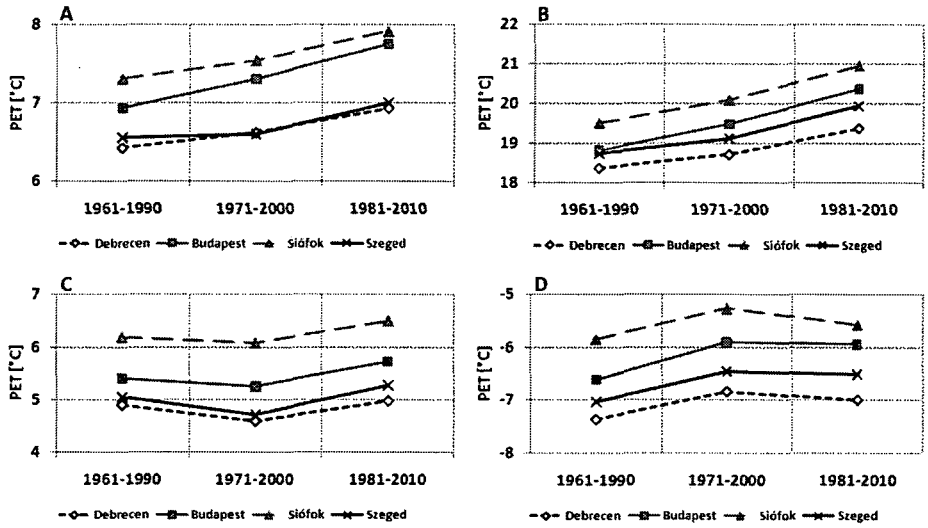

Fig. 6 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Physiologically Equivalent Temperature at 18 UTC

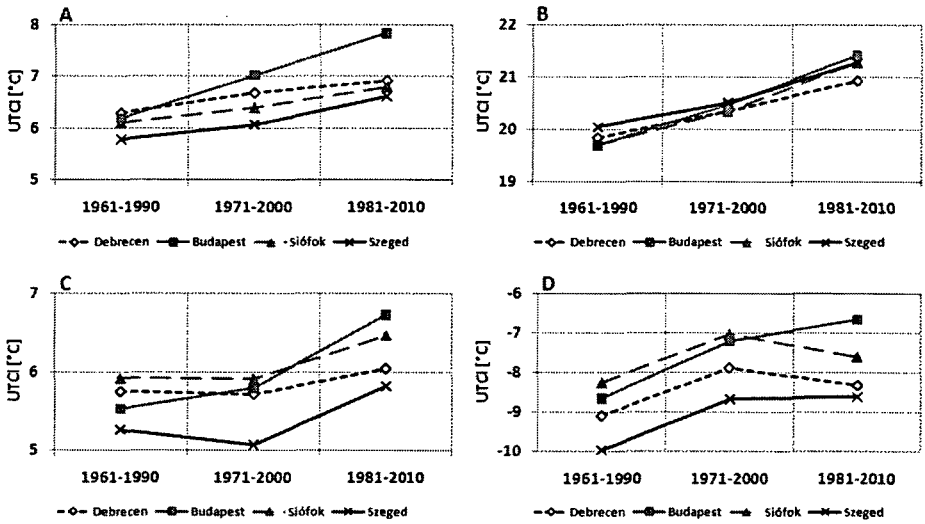

Fig. 7 Variation of 30-year averages of spring (A), summer (B), autumn (C) and winter (D) means of Universal Thermal Climate Index at 18 UTC

4. CONCLUSIONS

Based on the results the following conclusions can be drawn.

- The annual means of PET and UTCI increased in the last three 30-year periods at 12 and 18 UTC, too.
- The spring and summer average of PET and UTCI increased at both times, and the direction of changes was the same as in the case of the annual means. The extent of increase is significant in summer.
- In autumn the thermal bioclimate changed in a different way. The 1971-2000 averages are lower than the 1961-1990 averages. But in the last 30-year period the autumn averages increased significantly, especially in Budapest.
- In winter the bioclimate indices changed in an opposite way to autumn. After a heavy increase in the last 30-year period the winter averages were lower than in the antecedent period.

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REFERENCES

Bartholy J, Pongrácz R, Gelybó Gy, Szabó P (2008) Analysis of expected climate change in the Carpathian Basin using the PRUDENCE results. Időjárás 112:249-264

Blazejczyk K, Broede P, Fiala D, Havenith G, Holmér I, Jendritzky G, Kampmann B, Kunert A (2010) Principles of the new Universal Thermal Climate Index (UTCI) and its application to bioclimatic research in European scale. Miscellanea Geographica 14:91-102

Csima G, Horányi A (2008) Validation of the ALADIN-Climate regional climate model at the Hungarian Meteorological Service. Időjárás 112:155-177

Fiala D, Lomas KJ, Stohrer M (2001) Computer prediction of human thermoregulatory and temperature responses to a wide range of environmental conditions. Int J Biometeorol 45:143-159

Gulyás Á, Matzarakis A (2007) Selected examples of bioclimatic analysis applying the physiologically equivalent temperature in Hungary. Acta Climatol Chorol Univ Szegediensis 40-41:37-46

Gulyás Á, Matzarakis A (2009) Seasonal and spatial distribution of physiologically equivalent temperature (PET) index in Hungary. Időjárás 113:221-231

Gulyás Á, Unger J, Matzarakis A (2006): Assessment of the microclimatic and thermal comfort conditions in a complex urban environment: modeling and measurements. Build Environ 41:1713-1722

Höppe P (1984) Die Energiebalanz des Menschen. Dissertation. Wissenschaftlicher Mitteilung Nr. 49. Universität München

Höppe P (1999) The physiological equivalent temperature in an universal index for the biometeorological assessment of the thermal environment. Int J Biometeorol 43:71-75

Jendritzky G (1993) The atmospheric environment - an introduction. Experientia 49:733-738

Jendritzky G, Havenith G, Weihs P, Batchvarova E (eds) (2009) Towards a Universal Thermal Climate Index UTCI for assessing the thermal environment of the human being. Final Report COST Action 730

Jendritzky G, Bröde P, Fiala D, Havenith G, Weihs P, Batchvarova E, DeDear R (2010) The Universal Thermal Climate Index UTCI. Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg 20:184-188

Lin TP, Matzarakis A (2008) Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. Int J Biometeorol 52:281-290

Matzarakis A, Mayer H (1996) Another kind of environmental stress: Thermal stress. WHO Newsletters 18:7-10

Matzarakis A, Mayer H, Iziomon MG (1999) Applications of a universal thermal index: physiological equivalent temperature. Int J Biometeorol 43:76-84

Matzarakis A, Rutz F, Mayer H (2007) Modeling radiation fluxes in easy and complex environments – Application of the RayMan model. Int J Biometeorol 51:323-334

Németh Á, Mika J (2009) Climate as a risk factor for tourism. AGD Landscape & Environment 3(2):113-125

Németh Á, Schlanger V, Katona Á (2007) Variation of thermal bioclimate in the Lake Balaton Tourism Region (Hungary). In: Matzarakis A, de Freitas CR, Scott D (eds) Developments in Tourism Climatology, ISB Commission on Climate, Tourism and Recreation, Freiburg. 37-42

Szépszó G, Horányi A (2008) Transient simulation of the REMO regional climate model and its evaluation over Hungary. Időjárás 112:203-231

Unger J (1999) Comparisons of urban and rural bioclimatological conditions in the case of Central-European city. Int J Biometeorol 43:139-144

www.utci.org/cost.php