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Modification of the Tourism Climatic Index to Central European climatic conditions – examples

Attila Kovács* and **János Unger**

Department of Climatology and Landscape Ecology, University of Szeged
P.O. Box 653, H-6701 Szeged, Hungary

**Corresponding author E-mail: kovacsattila@geo.u-szeged.hu*

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Abstract—Climate is a decisive tourism resource and plays key role in the attractiveness of tourist destinations and the seasonality in tourism demand. The suitability of climate for general tourism purposes (i.e., sightseeing, shopping, and other light outdoor activities) is most frequently expressed by the Tourism Climatic Index (TCI), which combines several tourism-related climatic elements. In this study, the original TCI is modified in two ways. On the one hand, one of the most popular and widely used bioclimatic indices, Physiologically Equivalent Temperature (PET) is applied instead of effective temperature (ET) in the part of the index related to thermal comfort conditions. Furthermore, the TCI is adjusted to a ten-day scale since it is more relevant to tourism than the original monthly averages of the climatic parameters. Using the modified TCI we characterize and compare climatically suitable or even unfavorable places and periods of the year in case of some Hungarian and two other relatively close tourist destinations as examples. Analytical results indicate that the most optimal climatic conditions are in the shoulder seasons in all investigated places. The summer period is more unpleasant for sightseeing activities mainly due to the instense heat load. There are some remarkable differences between the cities in the time of occurence of different tourism climatic conditions and, therefore, in the seasonality conditions.

Key-words: climatic conditions, tourism, modified Tourism Climatic Index, Physiologically Equivalent Temperature, Central Europe

1. Introduction

Tourism is one of the key sectors in Hungarian economy. In 2011, more than 41 million foreign tourists contributed with 1200 billion HUF to the tourism sector. Tourism related industries generate about 5.9% of national gross domestic product (GDP) and employ 8.4% of all workers in Hungary (*KSH,* 2012).

The attractiveness of a tourist destination is influenced by several factors. Together with geographical location, topography, landscape, flora and fauna, climate constitutes the natural tourism resource of a place (*de Freitas*, 2003). Climate can directly affect tourism in many ways. Climate may be a decisive factor in the choice of a destination by determining the time of the year, when climatic conditions are at their optimum, or by designating the area that offers the most suitable climatic conditions (*Mieczkowski,* 1985). Ultimately, it affects tourists' satisfaction with the destination area, thermal comfort, and climatic well-being of visitors. Inter-annual climate variability influences the length and quality of tourism seasons, and thus, the tourism demand (*Scott* and *McBoyle*, 2001; *Scott et al.*, 2008).

Mainly due to the increasing competition between tourist destinations, considerable effort has been put into defining an easily applicable metric in order to investigate the suitability of different tourist activities in terms of climatic conditions. It is generally accepted that tourists respond to the integrated effects of the atmospheric environment, therefore, a comprehensive tourism climatic metric has to integrate all three tourism-relevant aspects of climate identified by *de Freitas* (2003): thermal, physical, and aesthetic (*Matzarakis,* 2006; *Scott et al.,* 2008; *Yu et al.,* 2009; *Perch-Nielsen et al.*, 2010). An overview of these three different facets of climate and their significance to tourists is provided in *Table 1*.

One of the most comprehensive and widely used metrics in tourism climatology is the Tourism Climatic Index (TCI) (*Mieczkowski*, 1985), which attempts to reflect the destination's climatic suitability for "average" tourists engaged in light physical outdoor activities (e.g., sightseeing, shopping). TCI is also capable to characterize global or regional effects of climate change to tourism according to projected scenarios of future climatic conditions. For example, *Scott et al.* (2004) used the TCI to assess its temporal and spatial distribution and seasonal variability in the future focusing on destinations in North America, while *Amelung* and *Viner* (2006) and *Perch-Nielsen et al.* (2010) in Europe. *Zaninović et al.* (2010) studied the influence of climate change on summer tourism potential in the Pannonian lowland (great parts of Hungary and Croatia) by analysing the differences between future and present bioclimatic and tourism climatic conditions based on climate simulations focusing on the changes in single climatic parameters and Physiologically Equivalent Temperature (PET, see in Section 2). The results indicate diverse changes in summer tourism potential of the area due to the global warming. In addition, *Németh* (2013) analyzed the changes of the tourism climate potential in the Lake Balaton region of Hungary in detail during the last half-century based on the original TCI index. According to the results, the best climatic conditions for tourism purpose can be observed in the summer months. Between three climatological normal periods, significant changes in tourism climatic conditions cannot be detected in the last half-century.

Table 1. Various aspects of tourism climate, their impact, and significance (based on *de Freitas*, 2003)

Facets of climate	Impact, significance
Thermal	**Physiological impact**
integrated effects of air temperature, humidity, wind speed, short- and long-wave radiation, personal factors	heat sensation, thermal comfort, physiological stress
	climate therapy
Physical	**Physical impact**
wind	dust, sand, damage to property
rain	wetting, reduced visibility and enjoyment
snow	winter sports/activities
ice	personal injury, damage to property
air quality	health, allergies, well-being
ultraviolet radiation	health, suntan, sunburn
Aesthetic	**Psychological impact**
sunshine/cloudiness	enjoyment, attractiveness of site
visibility	enjoyment, attractiveness of site
day length	period of activities, convenience

The present study aims a modification of the original TCI in order to reduce its two current serious limitations and reflect a more current state of knowledge. We make an attempt to update the thermal comfort parts of the index and its original temporal scale to the Central European conditions. We present the behavior of the modified index while describing climatically suitable or even unfavorable periods of the year in case of some Hungarian and two relatively close tourist destinations as examples.

2. The Tourism Climatic Index

TCI was developed by *Mieczkowski* (1985) based on previous research related to climate classifications for tourism and human biometeorology. In TCI, monthly averages of seven climate variables relevant for tourism are integrated into five sub-indices, listed in *Table 2*: daytime comfort index (CId), daily comfort index

(CIa), precipitation (R), sunshine (S), and wind (W). All of them are rated on different scales from 0 (unfavorable) to 5 (optimal) values while the thermal comfort sub-indices (CId and CIa) are rated from –3 to 5. By distinct weightings and then combining all weighted sub-indices, the overall TCI is calculated as follows:

$$TCI = 2 \times (4 \times CId + CIa + 2 \times R + 2 \times S + W)\,. \qquad (1)$$

Table 2. Summary of the sub-indices, their impact, and weigthing in TCI (based on *Scott* and *McBoyle*, 2001)

Sub-index	Monthly averages	Influence on TCI	Weighting
daytime comfort index (CId)	daily maximum temperature (°C) and minimum relative humidity (%)	represents thermal comfort when maximum tourist activity occurs (usually between 12 a.m. and 4 p.m)	40%
daily comfort index (CIa)	daily mean temperature (°C) and mean relative humidity (%)	represents thermal comfort over the full 24-hour period	10%
precipitation (R)	total precipitation (mm)	negative impact on outdoor activities and climatic well-being	20%
sunshine (S)	sunshine duration (hour)	positive impact	20%
wind (W)	wind speed (ms^{-1})	variable impacts depending on its value and the maximum temperature	10%

As all sub-indices have a maximum score of 5, *Mieczkowski* (1985) proposed a rating system of TCI with an overall maximum score of 100, where acceptable scores are above 40, good climatic conditions are above 60, and excellent scores are above 80 (*Table 3*).

Table 3. Tourism Climatic Index rating system (*Mieczkowski*, 1985)

TCI scores	Descriptive categories
90 – 100	ideal
80 – 89	excellent
70 – 79	very good
60 – 69	good
50 – 59	acceptable
40 – 49	marginal
30 – 39	unfavorable
20 – 29	very unfavorable
10 – 19	extremely unfavorable
< 10	impossible

Scott and *McBoyle* (2001) presented a conceptual framework of six possible types of annual TCI distributions; the tourism resource of all destinations can be classified into one of them (*Fig. 1*). In our study, this framework is used to characterize the tourism climatic conditions in the selected cities.

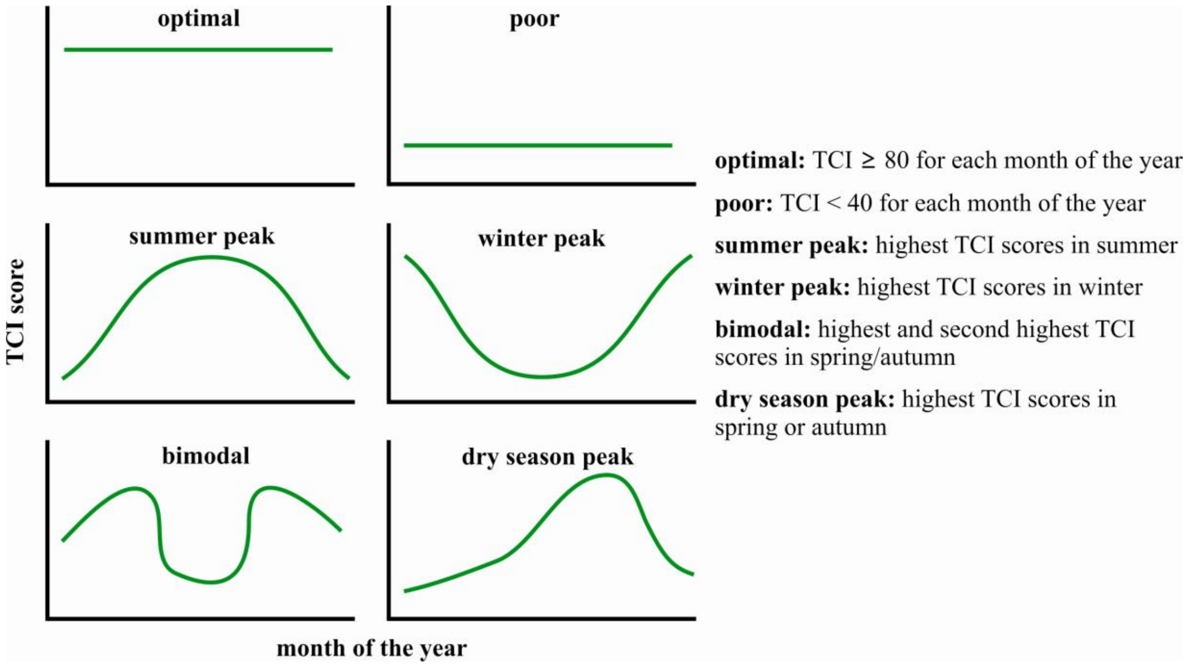

Fig. 1. Conceptual framework of annual tourism climate distributions (based on *Scott* and *McBoyle*, 2001).

The sub-indices of TCI expressing thermal comfort conditions (CId, CIa) are based on the effective temperature (ET), which is a simple empirical index of air temperature/relative humidity combinations (*Houghten* and *Yaglou*, 1923). The optimal comfort zone of ET is between 20 and 27 °C according to *ASHRAE* (1972) rated with maximum point 5. The rating scale then decreases on both sides of the optimal zone with 1 or 0.5 points. However, the rating points of the zones are based on the subjective opinion of the author, they are not empirically tested against the preferences of tourists (*de Freitas*, 2003; *de Freitas et al.*, 2008). A further important shortcoming of ET is that it does not include the effects of such thermal parameters as wind speed, short- and longwave radiation fluxes, in addition, it does not take into account such physiologically, and thus, bioclimatically relevant personal data as age, gender, height, weight, metabolic rate, and clothing. Therefore, it cannot evaluate the thermal conditions of the human body in a physiologically significant manner.

Instead of empirical indices, a full application of rationale indices based on the energy balance of the human body gives detailed information on the effect of thermal environment on humans (*VDI*, 1998). Such indices include all relevant thermophysiological parameters: air temperature, relative humidity, wind speed, short- and longwave radiation fluxes. One of the most popular and widely used rationale bioclimate indices is the Physiologically Equivalent Temperature (PET), which was developed typically for outdoor applications (*Mayer* and *Höppe,* 1987; *Höppe,* 1999). The interpretation of the index refers to indoor standard reference conditions and the evaluation of the thermal comfort conditions concerns a standardized fictive person. PET is defined as the air temperature at which, in a typical indoor setting, the heat budget of the body is balanced with the same core and skin temperature as those under the prevailing complex outdoor conditions (*Höppe,* 1999). The PET value categories were initially defined according to thermal sensations and physiological stress levels of Western and Central European people, where the thermally neutral heat sensation and stress are indicated by PET value range of 18–23 °C (*Fig. 2*) (*Matzarakis* and *Mayer*, 1996).

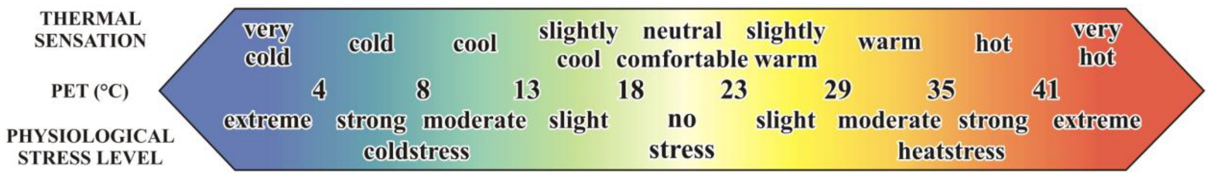

Fig. 2. Categories of the PET values (°C) for different grades of thermal sensation and physiological stress level of Western and Central European people (based on *Matzarakis* and *Mayer*, 1996).

3. Modification methods on Tourism Climatic Index

Despite the comprehensive nature and wide applications of TCI, a number of limitations were addressed and some modification possibilities were suggested by different studies (e.g., *de Freitas,* 2003; *Matzarakis,* 2006; *de Freitas et al.*, 2008; *Perch-Nielsen et al.*, 2010). The rating systems and the weightings of the sub-indices are partly based on human biometeorological literature, but also on the author's subjective opinions. A further important limitation is the application of ET, which was addressed by e.g., *Scott et al.* (2004), *Amelung* and *Viner* (2006) and *Perch-Nielsen et al.* (2010), therefore, they used apparent temperature (AT) (*Steadman*, 1979) instead of ET. However, AT is also based only on temperature/humidity combinations, and it is not really applied in recent human biometeorological research. A further important shortcoming of TCI is its temporal scale since monthly averages of the applied climatic parameters are considered, which are insufficient for tourism climatic purposes because tourists' length of stay during sightseeing is generally shorter (*de Freitas et al.*, 2008; *Scott et al.*, 2008; *Yu et al.*, 2009; *Perch-Nielsen et al.*, 2010).

Based on the above mentioned shortcomings, in the present study two modifications are performed in the structure of the original TCI, which means an initial step forward in the development of an updated index applicable at Central European climatic conditions. Firstly, in order to take into account human thermal comfort conditions more precisely in TCI, we attempted to integrate PET into the thermal sub-indices instead of ET, and for this purpose, a new rating system of PET has been developed, too. Secondly, the TCI is adjusted to a ten-day scale, i.e., ten-day averages of each climatic variables were rated, and then the values obtained in this way were taken at the index calculation.

The annual variations of the modified index and its sub-indices are presented and compared in case of four Hungarian and two other European cities: Szeged-Bajai út (46°15'N, 20°05'E), Siófok (46°54'N, 18°02'E), Debrecen (47°29'N, 21°36'E), Győr-Likócs (47°42'N, 17°40'E), Prague-Libus (50°0'N, 14°26'E), Thessaloniki-Airport (40°31'N, 22°58'E) (*Fig. 3*). The analysis concerns the periods of 1996–2010 and 2000–2010 in the first three and second three places, respectively.

Fig. 3. The investigated Hungarian and other European cities.

For the calculation of PET, hourly air temperature, relative humidity, wind speed, and cloudiness data of Hungarian Meteorological Service were used in the case of the Hungarien cities, while hourly and three-hourly synop report queries were utilized for Prague and Thessaloniki, respectively. PET was calculated by means of the bioclimate model RayMan (*Matzarakis et al.,* 2007). The measured wind speed data were transformed to the bioclimatological reference height of 1.1 m. Ultimately, the daytime (CId) and daily comfort (CIa) sub-indices of the modified TCI consist of the calculated daily maximum and daily average PET values holding the basic concept of *Mieczkowski* (1985) (see in *Table 2*). In addition to the data necessary for PET, daily precipitation and sunshine duration data obtained from the above mentioned databases were utilized. Concerning the parameters used for the calculation of PET, it is often difficult to access appropriate data, especially the radiation component of PET due to the lack of long-term or fine temporal scale (i.e., hourly) data sets. For example, application of global radiation instead of cloudiness data would be more appropriate, but its availability is often limited due to the uncertain measurement program and the lack of long-term data. Nevertheless, we could select several tourist destinations with complete data sets in different climatic regions, and evaluation and comparison are possible using these datasets representing these regions.

The original rating systems of wind speed (W), precipitation (R), and sunshine duration (S), and the weightings of all TCI sub-indices remained unchanged. (Note: Mieczkowski rated monthly precipitation on a scale from 0 to 5. Because of the ten-day averages, this scheme was changed by simply dividing the monthly values by 3, and these categories were rated by the original scores).

However, for the evaluation of PET, a new rating scheme had to be developed keeping in mind that the rating categories and scores should be based on objective, international standards, and subjective factors should be eliminated. The rating scores of PET were derived based on the principle that the comfortable thermal conditions should get higher scores while in case of intesifying warm or cold thermal stress conditions the values should decrease progressively on both sides of the comfort zone in an objective way.

Therefore, in the derivation of rating scores of PET, we utilized the function relationship declared in *ASHARE* (2004) and *ISO* (2005) between two bioclimatic measures, predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) (*Fanger,* 1972). PMV derived from the comfort equation of *Fanger* (1972) predicts the mean values of the thermal votes of a large group of persons on a seven-point (later nine-point) thermal sensation scale (from –4 very cold to +4 very hot) based on the heat balance of the human body in an environment characterized by given thermal variables (air temperature, relative humidity, wind speed, mean radiant temperature) (*ASHRAE,* 2004; *ISO,* 2005). Individual votes are obviously scattered around this mean PMV value, i.e., thermal environment characterized by the same PET value does not necessarily evoke the same thermal sensation of all persons. However, the distribution of thermal votes as a function of PMV can be statistically predictable. PPD establishes a quantitative prediction of the ratio of thermally dissatisfied people who feel too cold or too warm, i.e., do not vote –1, 0, or +1 on the seven-point scale (*ASHRAE,* 2004; *ISO,* 2005). For example, in case of 0, PMV such thermal votes belong to only 5% of the given population, while 95% of them can be considered thermally satisfied. The relationship between PPD and PMV can be given as follows (*ASHRAE,* 2004; *ISO,* 2005) (*Fig. 4*):

$$PPD = 100 - 95 \times \exp(-0.03353 \times PMV^4 - 0.2179 \times PMV^2)\,. \qquad (2)$$

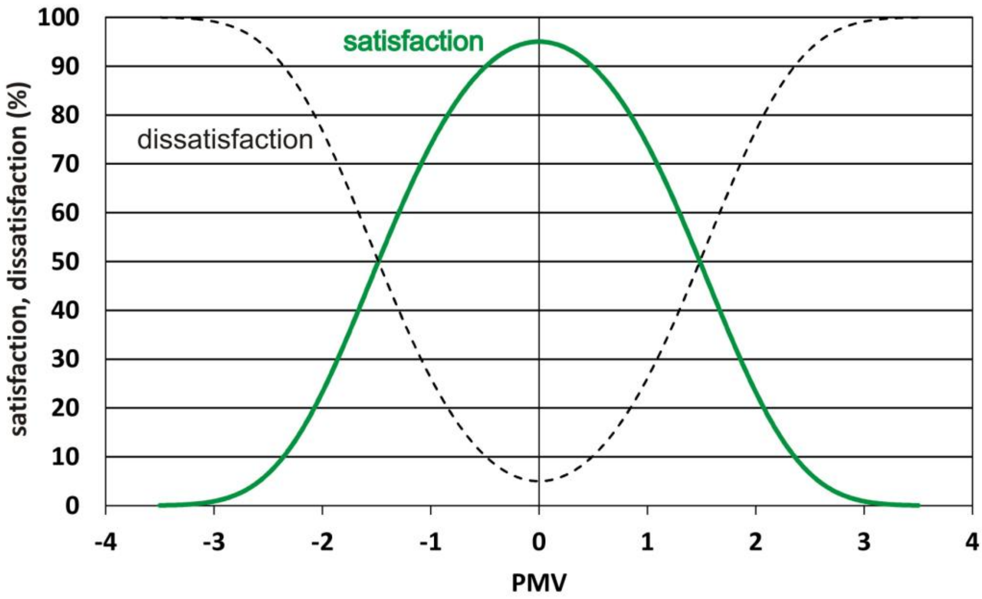

Fig. 4. Relationship between PMV and satisfaction-dissatisfaction with thermal conditions (based on *ASHRAE,* 2004; *ISO,* 2005).

In the derivation of the rating scores we utilized Eq. (2) and assumed that the TCI scores as a function of PET should decrease in the same way as the satisfaction with the thermal environment characterized by PMV declines. Our initial value was 0 PMV related to neutral thermal sensation, which was considered equivalent to the median value (20.6 °C) of the neutral PET category values (18.1–23.0 °C). Towards cold or warm discomfort conditions, decline of satisfaction associated with one-hundredth continuous PMV change was corresponded to decrease of TCI rating score associated with one-tenth PET change. Therefore, we obtained rating scores for all decimal PET values.

In this study, we utilized the widely used PET thermal sensation categories applicable in Western and Central European climatic conditions (*Fig. 2*), and these ranges were rated in case of the selected cities. All categories were characterized by an above derived rating score belonging to the median values of each PET categories. Thus, extreme cold conditions have lower rating scores than those of the warm extremities, because PET covers a larger range towards cold direction (*Table 4; Fig. 5*).

The above rating system was applied in the rating of the ten-day averages of both thermal comfort sub-indices in TCI.

Table 4. Rating system of PET-based sub-indices (CId, CIa) in the modified TCI (neutral PET category is marked with green)

PET categories (°C)	**Median of PET categories (°C)**	**Rating score**
35.1 – 41.0	38.1	1.9
29.1 – 35.0	32.1	3.5
23.1 – 29.0	26.1	4.7
18.1 – 23.0	20.6	5.0
13.1 – 18.0	15.6	4.7
8.1 – 13.0	10.6	3.9
4.1 – 8.0	6.1	2.8
0.1 – 4.0	2.1	1.6
–10.0 – 0.0	–5.0	0.3

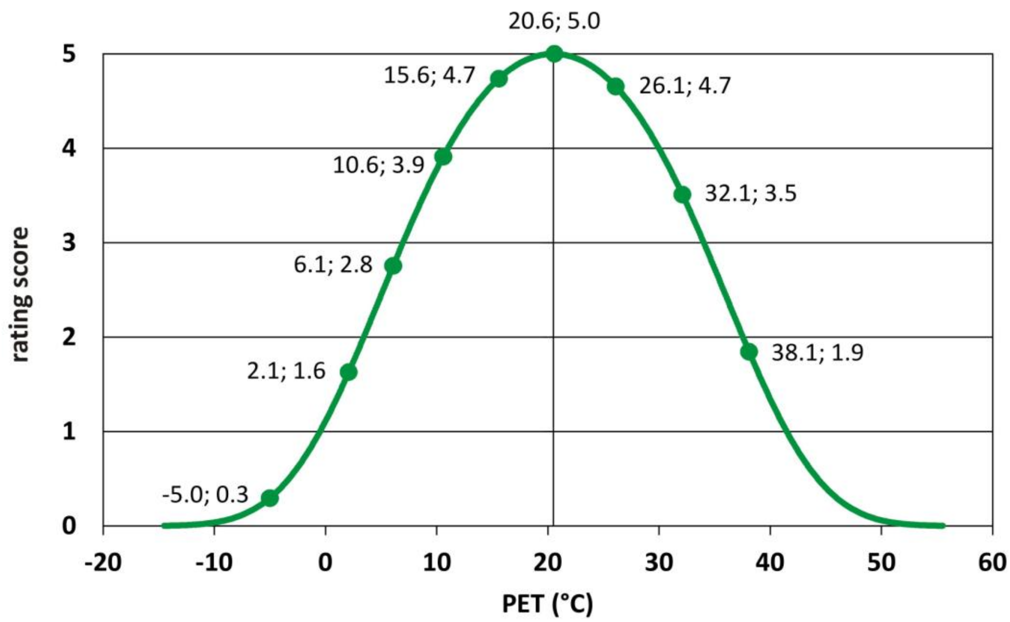

Fig. 5. Medians of PET thermal sensation categories (°C) and their obtained rating scores.

4. Application of modified TCI in case of European examples

4.1. Annual variation of ten-day TCI

In the following, the annual variations of the modified TCI and its sub-indices are analyzed in the selected cities. In *Fig. 6*, the annual cycle of the ten-day TCI is presented. In all cities, bimodal type of distribution (see *Fig. 1*) was obtained, that is the most pleasant climate in terms of sightseeing activities in spring and autumn, while in summer, the climatic conditions are rather unfavorable. There are excellent climatic conditions (TCI > 80) in several ten-day intervals of spring and autumn, while in summer more unpleasant but still very good (70 < TCI < 80) conditions prevail. However, in the last decade of July and in early August, TCI often falls below 70 (except Siófok) but it still refers to good conditions. In Thessaloniki, this can be observed as early as mid-June and it lasts till mid-August.

During the winter season, generally unfavorable and marginal conditions (30 < TCI < 50) occur. From the last ten days of February, the climatic conditions are getting acceptable (TCI > 50), which lasts until the end of November or early December. It is remarkable that the conditions of Thessaloniki are suitable for sightseeing almost all winter (TCI > 60) (*Fig. 6*).

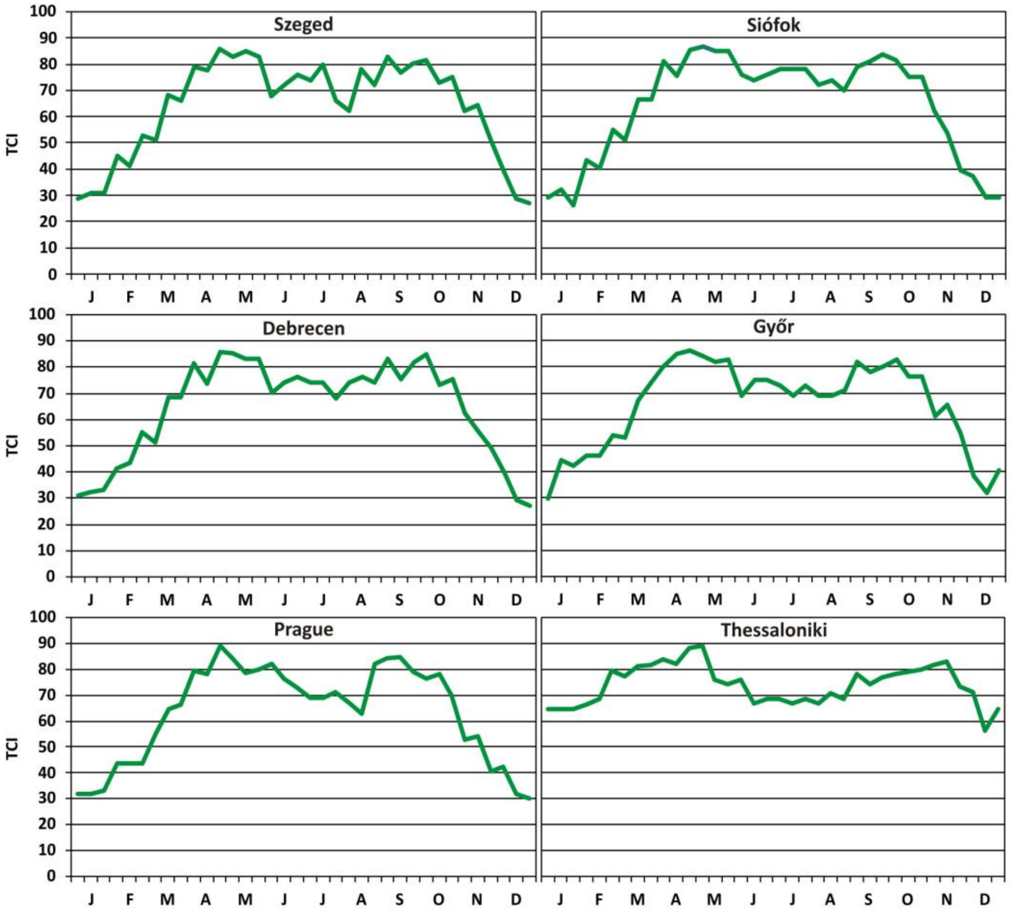

Fig. 6. Annual cycle of the modified ten-day TCI rating scores.

In order to analyze the differences between the cities and their possible causes in details, it is also necessary to examine the contribution of each sub-indices to the overall value of TCI (*Fig. 7*). It is obvious that the daily maximum PET sub-index (CId) is mainly responsible for the bimodal structure of TCI, because in the afternoon hours of summer ten-day intervals, when usually the maximum PET occurs, the prevailing heat stress (slight to strong stress conditions in *Fig. 2*) greatly reduces the rating scores in all cities, particularly in Thessaloniki. In summer and autumn, however, the average maximum values are closer to the comfort zone resulting higher rating scores. Furthermore, CId causes the plesant climate in winter in the Greek city (*Fig. 7*). In early August, a setback in CId in Szeged occurs, which is equal to the CId score of Thessaloniki. Therefore, overall TCI (62.2) barely indicates good climate in Szeged, and this warm load can particularly adversely affect the outdoor activities. It is interesting to note that the Greek city has somewhat higher TCI (66.6) in early August, which is caused by the higher average sunshine duration and lower precipitation conditions; however, the strong warm stress can reduce the comfort level of tourists to such an extent there, that this presumably cannot be fully compensated by the pleasant effects of sun and lack of rain.

The daily average PET (CIa) substantially contributes to TCI only from March to November in Hungary and Prague, while in the summer decades (in the Czech capital only in mid-summer) it falls into the comfort zone providing maximum score. In Thessaloniki, this is limited only to the second and third ten-day intervals of May, while in summer this sub-index indicates slight heat stress. However, CIa has significant effect also in the other periods, because it does not indicate such a level of cold stress conditions there as in the other cities (*Fig. 7*).

From May to August, relatively significant precipitation amount (R) is detected in terms of the ten-day averages in Hungary and Prague, which reduces tourism climatic conditions according to its rating system. Therefore, the contribution of precipitation is less in summer than in the other periods. Thus, in addition to CId, precipitation is also responsible for the bimodal structure shown in *Fig. 6*, even though it has smaller effect than CId because of its lower weight. Thessaloniki has very uneven distribution of rainfall, nevertheless, except in winter, less average precipitation can be detected compared to the other places, therefore it does not influence significantly the outdoor activities in most part of the year as shown in *Fig. 7*.

TCI score is increased the most obviously in summer and the least in winter by the sunshine (S). It should be noted that lower sunshine in Prague can affect adversely, while more hours of sunshine in the Greek city can influence favorably the attractiveness of the place. Significant differences cannot be explored in the averages of wind speed (W) during the year. Their rating scores are somewhat smaller in summer, but there are not any significant monthly or seasonal characteristics and differences between the cities (*Fig. 7*).

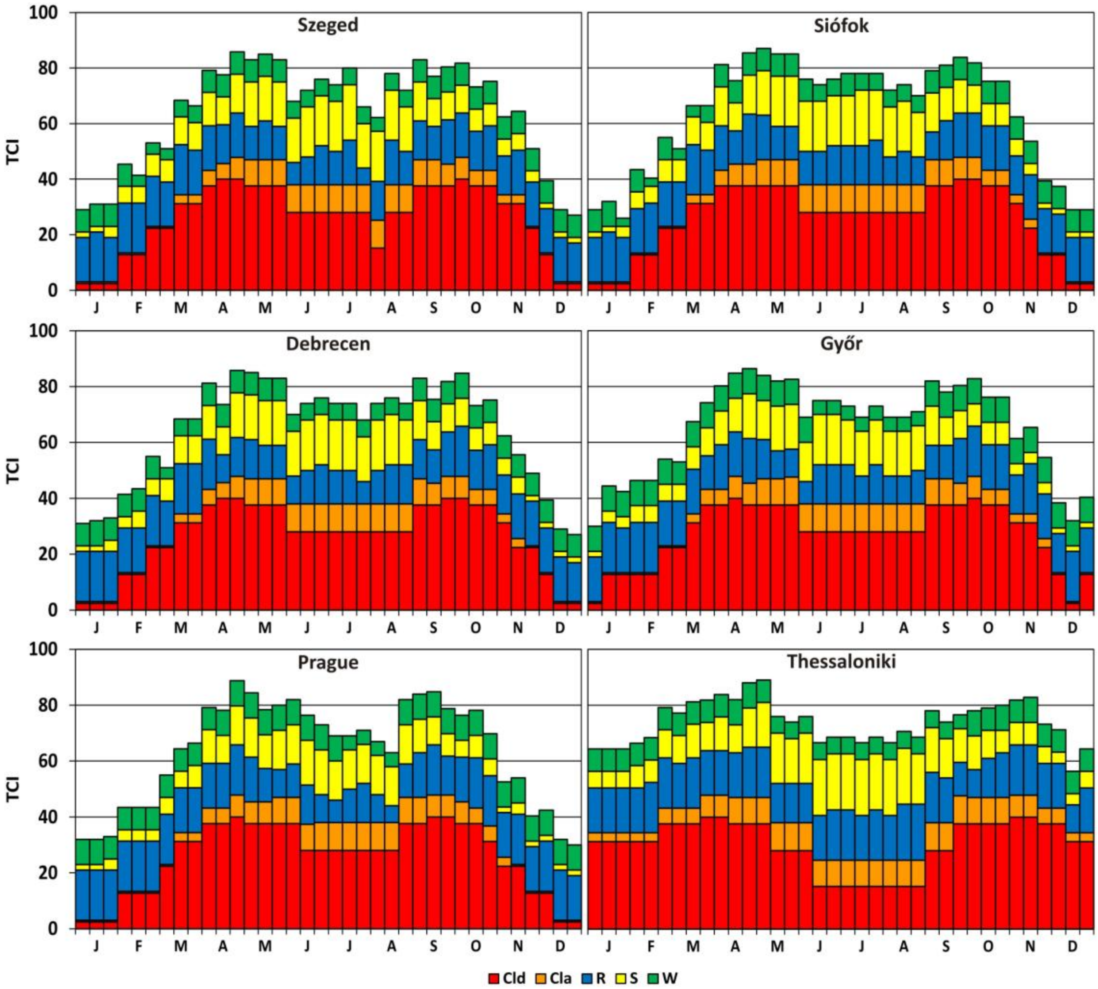

Fig. 7. Ten-day TCI sub-index rating scores (CId: daily maximum PET, CIa: daily mean PET, R: daily precipitation, S: daily sunshine duration, W: daily average wind speed).

4.2. Frequencies of TCI classes per ten-day intervals and seasonality

We have highlighted three distinctive threshold values of TCI (40, 60, 80), and the annual cycle of the average number of days (frequency) per ten-day interval above these thresholds was also investigated. As between the Hungarian cities there are not significant differences, the results are presented in case of Szeged, Prague, and Thessaloniki (*Fig. 8*). Climate is considered to be at least marginal/acceptable, good, and very good in terms of tourism above 40, 60, and 80, respectively.

In Szeged and Prague, all days are at least marginal (TCI > 40) from March to November, while this is valid for the whole year in Thessaloniki. In the distribution of the number of climatologically good days (TCI > 60), a bimodal structure can be recognized, particularly in Szeged. The Greek city has at least good days relatively uniformly throughout the whole year. The distribution of excellent days (TCI > 80) has some interesting characteristics, especially regarding the time of occurence. Bimodal structure remains in all three places, but while excellent days also occur already from the end of winter until the end of autumn in the Greek city, this starts later and ends earlier in Szeged and Prague. It is remarkable that in the shoulder seasons, one more excellent days can be expected in Prague and Thessaloniki than in the Hungarian city. In the summer period, decline in the number of excellent days can be observed in all cities, but there are significant differences in their temporal occurences. For example, in Thessaloniki, it decreases quickly in spring and reappears only in early autumn, while in Szeged some excellent days occur also in summer. However, in Prague, these rather unpleasant conditions are limited to a very short period in summer: excellent days can be expected even in June and already at the end of summer (*Fig. 8*).

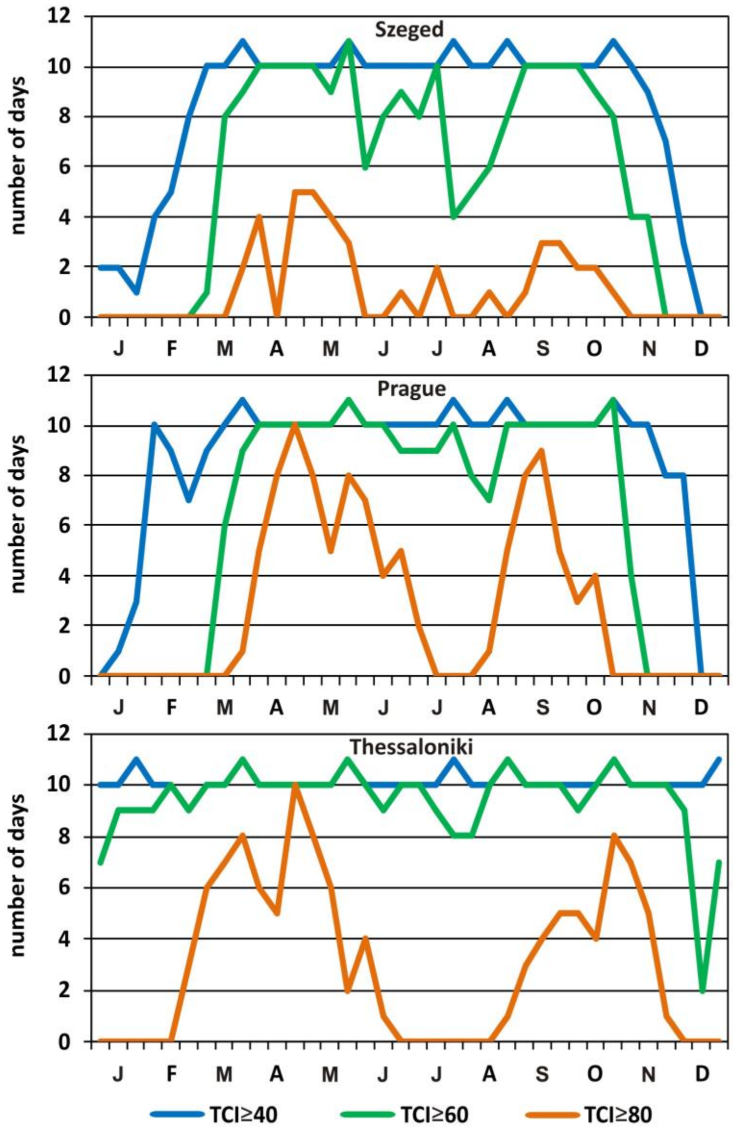

Fig. 8. Average number of days per ten-day interval above different TCI thresholds. At least marginal/acceptable, good, and excellent days are defined as having a TCI above 40, 60, and 80, respectively.

Fig. 9 illustrates the average relative frequencies of all TCI classes (see in *Table 3*) per ten-day interval resulted by the ratio of the average number of days belonging to a given class in a given ten-day interval and the number of days of that unit. According to *Fig. 9*, it can be definitely concluded that the best tourism climatic conditions in terms of the whole year can be observed in Thessaloniki, and the unpleasant climatic conditions occur most commonly in Szeged. In terms of ideal conditions, they appear the least frequently in Szeged and only in some periods of spring. In December and January, very and extremely unfavorable conditions can be often observed there. It should be noted that in summer acceptable and marginal conditions also appear in Szeged to a great extent besides the good categories, which indicates the frequent occurence of warm stress there. It can also be clearly detected that Thessaloniki has the most stable conditions in the whole year without significant diversities: there are almost only good, very good, and excellent days (*Fig. 9*).

The above findings and charts can be associated with the seasonality in tourism, which is one of the most worrisome yet least understood facets of the tourism industry (*Jang,* 2004). We used the ”seasonality ratio” (SR), a simple indicator to measure the seasonality in tourism. SR expresses seasonality in a single value, therefore, it is easy to use in tourism climatology. It was initially defined in relation to the ratio of tourist flows (*Yacoumis*, 1980), and the concept was then applied in the context to climate resources characterized by TCI. It is calculated by simply dividing the mean number of good days (TCI > 60) per month by the number of good days in the month with maximum good days (the „best" month) (*Perch-Nielsen et al.*, 2010). The lower the value, the stronger the seasonality, while value 1 indicates equal distribution of good days across all months. We applied this concept in ten-day resolution. SR illustrated in *Fig. 9* indicates approximately moderate seasonality in Prague (SR=0.56) and a slightly higher seasonality in Szeged (SR=0.52) due to their winter and summer conditions. However, Thessaloniki is essentially free of seasonality (SR=0.85), therefore, its SR also confirms that this city offers relatively stable climatic conditions throughout the year.

5. Discussion and conclusions

The applied modifications of Tourism Climatic Index are an initial but significant step towards developing the index for use in Central European climatic conditions. By integrating the PET index into TCI, the thermal comfort sub-indices of TCI are based on more advanced knowledge of bioclimatology than in case of the original index. During the development of the rating system of PET, objective and international standards related to the evaluation of thermal environment were utilized. We assumed that the standardized relationship between the heat sensation of large number of persons evoked by thermal environment, and their resulting satisfaction with the environment may be appropriate for the rating of the thermal environment of the tourists characterized by PET. The rating system of PET was derived based on this relationship, and the PET thermal sensation ranges used in Western and Central European climatic conditions were applied. By using ten-day averages instead of monthly ones, the climatic conditions can be described suiting better to tourists' length of stay during sightseeing.

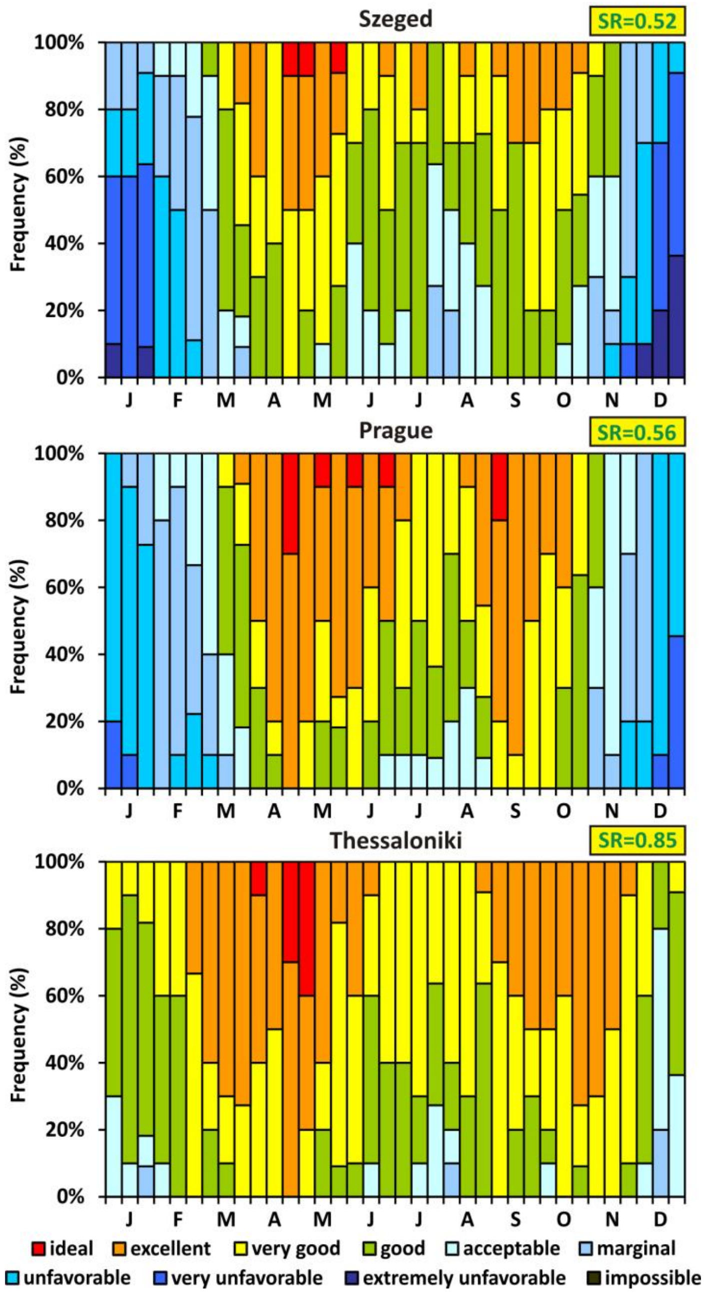

Fig. 9. Average relative frequencies of TCI categories per ten-day interval (see *Table 3* for details). SR indicates the "seasonality ratio".

Our results clearly show the optimal or even unfavorable periods for outdoor (sightseeing) tourism activities in a given place or the comparability of places in a given period. According to the bimodal structure of TCI, summer period has slightly less favorable climatic conditions in all six investigated cities mainly due to the heat load in the afternoon hours, therefore, the shoulder seasons may be the best times for sightseeing. Unlike the other places, in Thessaloniki, winter can also offer suitable climatic conditions. Between the four Hungarian cities only small differences are found, significant and characteristic differences can be detectable only in larger spatial scale. Considering the entire year, Thessaloniki is suitable for sightseeing activities throughout the year without significant seasonality, and it provides pleasant conditions most frequently. Szeged and Prague have higher seasonality and show unfavorable conditions more frequently, but except for winter, these cities are also appropriate for outdoor activities without any doubt, though in Szeged (moreover slightly in Prague, too) warm stress often can impair the level of thermal comfort and well-being of tourists in summer.

It should be noted that it is not sufficient to consider only the overall TCI itself, but it is desirable to analyze individually the contribution of all sub-indices. As an example, Thessaloniki has only a slightly less favorable conditions in summer according to its overall TCI, but if considering each sub-indices, PET sub-indices indicate worse thermal stress conditions by 1–2 categories compared to the other cities, which has a substantial negative impact on the comfort level and well-being of tourists. Presumably, these discomfort conditions cannot be fully compensated by the pleasant (physical-aesthetic) effects of more sunhine and less precipitation there.

During the analysis, basically three drawbacks of the index were identified which would, therefore, need to be changed in order to reflect more accurately and realistically the tourism climatic conditions. Firstly, the precipitation sub-index – particularly in case of convective rainfall – substantially distorts the value of TCI in some ten-day intervals in the calculation of the many-year and ten-day averages, therefore it has such a low rating score compared to other intervals that it rates too unfavorably and unrealistically the climatic conditions. Moreover, such heavy but short rainfalls usually do not have a great effect from a tourist perspective. Some annual differences in rating scores of precipitation can be noticed due to the definite maximum amount in summer and minimum in winter. Nevertheless, if possible, it would be worth changing the applied precipitation variable and its rating system.

Secondly, in the structure of the original TCI, wind speed is rated by means of different scales depending on the value of average maximum temperature and wind speed (as seen in *Table 2*). In case of very cold conditions and high wind speeds, a wind chill rating system has to be used but its rating scores downgrade significantly the relevant ten-day intervals compared to the others. We used this original rating system in this study, but it was developed mainly according to the thermal effects of wind, which is already expressed by PET in our study, therefore, rather the physical (mechanical) effects of wind should be taken into account in a modified and simplified rating system.

Finally, it would be reasonable to exclude the night hours from the study currently covering the whole day due to the negligible tourist activities at night and to use only the daytime periods, for example the hours between the average sunrise and sunset. Nevertheless, as after sunset the tourist activities often remain significant for a few hours, particularly in summer, this period after sunset would worth being investigated separately.

Our further analysis will be directed to the application of new PET thermal sensation ranges according to an outdoor field survey revealing subjective estimations of thermal environment carried out in Szeged, south Hungary (*Kántor et al.,* 2012). As it is expected, it will provide information on the differences in bioclimatic and tourism climatic conditions of European places for travellers visiting these places but living in south Hungary, therefore accustomed to the thermal conditions prevailing there. By means of the ranges reflecting the thermal sensation of the south Hungarian people, we can compare the results based on the original and new ranges.

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