Abstract This paper examines the influence of a medium-sized city (Szeged, Hungary) on the bioclimatological conditions of human beings. With the help of suitable indices for the available data set, differences in the annual and diurnal variation of human bioclimatic characteristics between an urban and rural environment are evaluated over a 3-year period. These indices are the thermohygrometric index (THI, defined by air temperature and relative humidity), the relative strain index (RSI, defined by air temperature and vapour pressure) and the number of “beergarden days” (defined by air temperature at 2100 hours). In urban and rural areas, “hot” THI conditions characterize 6% and 1% of the year, “comfortable” conditions 30% and 20%, “cool” conditions 10% and 12%, and “cold” conditions 54% and 66% respectively. Over longer periods (e.g. one, month) RSI remains below the threshold value for strong heat stress in the city. The monthly frequencies of beergarden days show that these days appear from May until October and the city has almost twice as many pleasant evenings as the rural areas. Consequently, the city favourably modifies the main climatological elements within the general climate of its region; periods likely to be comfortable are therefore found more frequently in the city than in rural areas.

Key words Bioclimatological indices · Temperature · Humidity · Medium-sized city

Introduction

Among local climates modified by man, the urban climate is the most obvious example. Our world is an increasingly urbanized one, which is why the special features of this local climate are becoming more apparent. Several mechanisms contribute to its development; the natural radiation balance is altered by changes in the properties of the underlying surface and air pollution; built-up areas are obstacles to the wind, modifying the natural flow and turbulence of the air; the water vapour balance is upset by the change from moist to dry surfaces; the combustion processes (heating, traffic, industry) emit artificial heat, water vapour and pollution to the atmosphere.

The atmospheric environment has a few meteorological parameters (temperature, humidity, air movement and radiation) that determine the bioclimatic conditions of someone out of doors. A complete assessment requires investigation of such further parameters as the insulating effects of clothing, metabolic heat produced by activity, occupation, age, acclimatization to the general climatic conditions prevailing in the region and the air quality. There are a lot of theoretical and empirical indices containing these parameters which can more or less evaluate the bioclimatic conditions for humans. Some of the indices use only one of the above parameters while others use two or more (Clarke and Bach 1971; Matzarakis and Mayer 1991; Mayer 1993). For example, to describe and characterize the Greek heatwaves in 1987 and 1988, Giles and Balafoutis (1990) used hourly values of air temperature and relative humidity with the help of psychrometric charts. Nowadays, more sophisticated procedures are at the disposal of researchers, which are based on human heat balance models and assess the thermal comfort of humans in a thermophysically relevant manner. They require more input data, for instance values of radiation processes and assumptions about the heat-transfer resistance of clothing as well as about human activity and internal heat generation. A fundamental energy-balance equation is Fanger’s “comfort equation” for an indoor climate, which allows the calculation of the “predicted man vote” (PMV) (Mayer 1993). This equation is incorporated in the Klima-Michel model, in which PMV is a suitable measure for assessing the thermal environment in different outdoor climates (Matzarakis and Mayer 1997). For example, Jendritzky and Nübler (1981) investigated the thermal environment in Freiburg, Germa-
ny, by determining of the spatial distribution of PMV values by day and at night. For urban planners and other people who have less knowledge of bioclimates, the “physiologically equivalent temperature” (PET) might be a more understandable and more useful measure. It is calculated from the Munich energy-balance model for individuals (MEMI). The idea behind PET is the transfer of the actual thermal conditions to an equivalent indoor environment in which the same thermal sensation is expected (Mayer and Höppe 1987). In the literature, several applications of PMV and PET and their comparison in the interpretation of the results can be found (e.g. Mayer and Höppe 1987; Matzarakis and Mayer 1991; Mayer 1993).

In the present study an attempt has been made to compare differences in human bioclimatological conditions between urban and rural environments in the case of a medium-sized city, using some simple appropriate measures from the data set available to us.

**Study area and measurement sites**

Szeged is situated in south-eastern Hungary (46°N, 20°E) at 79 m above sea level. The city and its surroundings are free from orographical effects (altitude differences inside and outside the city are only a few metres) and it is a long way from large bodies of water except for the River Tisza, which intersects the settlement (Fig. 1). Therefore its geographical situation is favourable for developing a relatively undisturbed urban climate. Szeged had about 178 000 inhabitants in the years under investigation (1978–1980) and its built-up area was approximately 46 km². The study area is in the climatic region Cf by Köppen’s classification (temperate warm climate with uniform annual distribution of precipitation) or in the climatic region D.1 according to Trewartha’s classification (continental climate with a long warm season) (Péczely 1979). In addition, the regional climate of Szeged has certain Mediterranean influences: in every 10 years approximately 3 years show Mediterranean characteristics in the annual variation of precipitation (Koppány and Unger 1992). The average meteorological parameters of the Szeged region are as follows:

- The mean annual temperature is 11.2°C with a mean annual range of 23.6°C.
- The mean January and July temperatures are –1.2°C and 22.4°C respectively.
- The mean annual precipitation is 573 mm.
- The mean annual relative humidity is 71%.
- The mean annual vapour pressure is 9.8 hPa.
- The mean annual wind speed is 3.2 ms⁻¹.
- The mean annual sunshine duration is 2102 h (Péczely 1979).

In 1977 a network of ten meteorological stations, was established in the city and it worked until July 1981. Air temperature, humidity, the maximum and minimum temperature and precipitation were measured. The stations were located in different parts of the city, namely the densely built-up city centre with medium wide streets, the housing estates, which contain tall concrete buildings with quite wide green areas, other zones that are characterized by detached houses, by the bank of River Tisza and by large parks, and the almost natural outskirts (Fig. 1). The influence of urban development was greatest at the measurement site in the city centre because of its central location, the high density of building and the large distance from the city perimeter. By contrast, the station at the outskirts was influenced least of all. This fact is supported by earlier studies on the urban heat island within Szeged (e.g. Unger 1996). As our aim was to compare typical and the most marked urban and rural environments in and around Szeged, in this study only the data sets of these two selected stations were examined.

Station 1 (a permanent station of the Hungarian Meteorological Service), which is free from any modifying effects of the urban climate, is situated 4.4 km to the west of the city centre. The surrounding area is agricultural, consisting of mainly non-irrigated wheat and maize fields, and it is considered to be a good example of the rural area. The sky-view factor of the rural site is almost 1. The temporary station 2 was located in the city centre in a paved square bounded by multi-storey buildings and this was chosen to be the urban station. Its surroundings are densely built-up and paved, and there are mainly three- to four-storey buildings; it is only occasionally interrupted by green (parks and river bank) and water (river) surfaces. The sky-view factor of the urban site is 0.54 (Fig. 1).

**Data and methods**

Wet- and dry-bulb measurements were taken four times a day (at 0100, 0700, 1300 and 1900 hours, Central
European thermometer shelters with Assman-type psychrometers with an accuracy of 0.1°C at a height of 2 m above ground level; these conditions mirror those in other earlier studies, which used data sets from standard synoptic stations (e.g. Bründl and Hörre 1984; Giles and Balafoutis 1990; Matzarakis and Mayer 1991). The relative humidity values were calculated with the help of the psychrometer table of the Hungarian Meteorological Service, which contains humidity values at temperatures between –40°C and +50°C. Our investigations utilized average monthly values of temperature, relative humidity and vapour pressure, and daily records of temperature between 1 January 1978 and 31 December 1980. These relatively old data have been previously used in different evaluations but not, until now, for their relevance to human biometeorology. For this reason it was necessary not lose these data and to choose appropriate ways of using them. The methods are relatively simple and not the most recent, because they are selected for the parameters available for us. However, we are sure that the methods applied reveal significant differences when human bioclimatological features in the centre and the surrounding area of the city are compared. The differences in the indices express the influence the city has on human bioclimatological conditions and the advantages and disadvantages of the altered physical environment of Szeged.

The effective temperature is defined as “an arbitrary index which combines into a single value the effect of temperature, humidity and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of the temperature of still, saturated air which would induce an identical sensation.” (Thom 1959) or “the temperature of a still, saturated atmosphere which will lead to the same thermal sensation as that existing and thus exposing the body to the same difficulties of adaptation” (Kyle 1994). The effective temperature takes account of wet- and dry-bulb temperatures and thus can be applied to locations that are both shaded and protected from the wind. One of the best indices estimating the effective temperature was developed by Thom (1959). This is also supported by later work (e.g. Clarke and Bach 1971; Giles et al. 1990). Thom’s discomfort index (DI) or, as we call it, the thermohygrometric index (THI) is secured by a simple linear adjustment applied to the average of the simultaneous dry-bulb \((t_d)\) and wet-bulb temperatures \((t_w)\). Its original form was:

\[
\text{THI (°F)} = 0.4(\text{t}_d + \text{t}_w) + 15
\]

Thom (1959) found that, at an index value lower than 70°F (21.1°C), no discomfort was essentially experienced, but as the index increased above 70°F an increasing proportion of individuals experienced discomfort. Half of the people tested were uncomfortable at an index value of 75°F (23.9°C), while at an index value over 80°F (26.7°C) most individuals were experiencing some sort of discomfort (Table 1). The same degree of discomfort can be caused by quite different conditions. For example at Las Vegas a dry-bulb temperature of 107°F (41.7°C) and a wet-bulb of 69°F (20.6°C, relative humidity 13%) were recorded (THI=84°F, 28.9°C) while at Indianapolis with the same index value the temperatures were 93°F and 80°F (33.9°C and 26.7°C; relative humidity 57%) respectively (Thom 1959).

The equation for THI using air temperature \((t)\) measured in degrees Celsius and with \(f\) as the relative humidity is:

\[
\text{THI (°C)} = t – (0.55 – 0.0055f)(t – 14.5)
\]

The THI was used originally to determine the discomfort due to heat stress, therefore, it has been evaluated over a much wider range of conditions (Kyle 1994). As a result, the optimum occurs between 15°C and 20°C and that is the basis for defining comfortable conditions. Below a THI of 15°C, evaporation, which constantly takes place at the skin surface even in the absence of apparent perspiration, takes away heat from the body thus requiring defence against cooling. Hence, below a THI of 15°C there is a series of categories where increasing thermogenetic mechanisms are required to combat increasing cold stress. The opposite process occurs above a THI of 20°C because the perspiration system becomes effective as a cooling mechanism to prevent overheating. The higher the THI the more ineffective this mechanism becomes, so a series of categories have been introduced above the comfortable zone, where the heat stress is increasing (Table 2). It is similar to the classification of THI in Table 1, which is adapted for the thermal environment in summer. There are no significant differences between the two classifications; however, the one shown

### Table 1 Classification of the thermal environment in summer according to the discomfort index (DI) (= THI) (Matzarakis and Mayer 1991)

<table>
<thead>
<tr>
<th>DI classification</th>
<th>DI range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No discomfort</td>
<td>DI&lt;21</td>
</tr>
<tr>
<td>Under 50% population feels discomfort</td>
<td>21≤DI&lt;24</td>
</tr>
<tr>
<td>Over 50% population feels discomfort</td>
<td>24≤DI&lt;27</td>
</tr>
<tr>
<td>Most of population suffers discomfort</td>
<td>27≤DI&lt;29</td>
</tr>
<tr>
<td>Everyone feels severe stress</td>
<td>29≤DI&lt;32</td>
</tr>
<tr>
<td>State of medical emergency</td>
<td>DI≥32</td>
</tr>
</tbody>
</table>

### Table 2 The categories of the thermohygrometric index (THI) (Kyle 1994)

<table>
<thead>
<tr>
<th>THI category</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperglacial</td>
<td>(&lt;−40)</td>
</tr>
<tr>
<td>Glacial</td>
<td>−39.9 to −20</td>
</tr>
<tr>
<td>Extremely cold</td>
<td>−19.9 to −10</td>
</tr>
<tr>
<td>Very cold</td>
<td>−9.9 to −1.8</td>
</tr>
<tr>
<td>Cold</td>
<td>−1.7 to +12.9</td>
</tr>
<tr>
<td>Cool</td>
<td>+13 to +14.9</td>
</tr>
<tr>
<td>Comfortable</td>
<td>+15 to +19.9</td>
</tr>
<tr>
<td>Hot</td>
<td>+20 to +26.4</td>
</tr>
<tr>
<td>Very hot</td>
<td>+26.5 to +29.9</td>
</tr>
<tr>
<td>Torrid</td>
<td>+≥30</td>
</tr>
</tbody>
</table>
in Table 1 contains more detail when describing conditions of heat stress.

In order to take account of the effects of clothing and net radiation, the relative strain index (RSI) was developed for a sedentary standard man dressed in a business suit (healthy, 25 years old and not acclimatized to heat). For the conditions specified (internal heat production 100 Wm$^{-2}$, air movement 1 ms$^{-1}$, no solar radiation income) the index contains the simultaneously recorded air temperature ($t$°C) and vapour pressure ($e$hPa) (Kyle 1992):

$$\text{RSI} = \frac{t - 21}{58 - e}$$

A quarter of the people will be uncomfortable at an RSI of 0.2 and no one will be comfortable at an RSI of 0.3 (Table 3). For elderly and ill people the lower RSI of 0.2 represents the threshold above which they are subject to heat stress.

A further interesting measure when comparing thermal conditions between the city and its surroundings is the number of so-called beer garden days. This expression is defined as the number of days in a period when the air temperature at 2100 hours is above 20°C (Bründl and Höppe 1984; Höppe 1986). On such evenings people can sit in the open (in beer gardens, restaurants, confectioneries, open-air theatres, etc.) without feeling cold. These evenings are important from the point of view of leisure-time quality in climatic zones characterized by a longer cold season. In the present study, only the temperature records of the two stations at 1900 hours and 0100 hours were available, therefore the temperatures at 2100 hours were interpolated from the ones at 1900 hours and 0100 hours, assuming that temperature alters more or less uniformly between these two measurement times.

**Results and discussion**

The average monthly THI values were counted for each observation time at stations 1 and 2 representing rural and urban areas respectively. When the isopleths from these values are drawn the daily and annual distribution of THI in rural and urban areas can be seen (Fig. 2). The figure shows that the year encompasses four THI categories (hot, comfortable, cool and cold) in the city centre and five (the previous ones and very cold) outside the city. Comparison of the isopleths identifies the following main features of the differences in human bioclimatological effects between the city centre and the surroundings.

Considering a whole year as 100%, for the urban area, 6% of the year is in the “hot” THI category, which occurs in the summer months from about noon to the evening hours with a maximum of 22.8°C in August; rural areas only just enter this highest category (for 1% of the year) at about noon in the summer months with a maximum of 21.6°C.

The most important “comfortable” conditions dominate in the city centre for nearly one-third of the year (30%), mainly from May until September, during the whole day, except for the afternoon hours in summer mentioned above (hot). In rural areas these conditions pertain for 20% of the year, also from May until September but only in the daylight and in the evening hours.

There is no significant difference in percentage of the year where conditions are “cool” (10% in urban and 12% in rural areas), but while this occurs in the inner city only in April–May and September–October, in rural areas, it also occurs in summer in the nocturnal and morning hours.

<table>
<thead>
<tr>
<th>RSI</th>
<th>Proportion of persons unstressed/distressed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>100 unstressed</td>
</tr>
<tr>
<td>0.20</td>
<td>75 unstressed</td>
</tr>
<tr>
<td>0.30</td>
<td>0 unstressed</td>
</tr>
<tr>
<td>0.40</td>
<td>75 distressed</td>
</tr>
<tr>
<td>0.50</td>
<td>100 distressed</td>
</tr>
</tbody>
</table>

Table 3 The relative strain index (RSI) classification (Kyle 1992)

**Fig. 2** Isopleths of the mean rural and urban thermohygrometric index (THI, °C) in Szeged (1978–1980). Conditions: 1 hot, 2 comfortable, 3 cool, 4 cold, 5 very cold
hours. The relatively small proportion of the year experiencing cool conditions is easy to understand because of the relatively narrow range of possible THI values for this category (only 2°C).

The most dominant bio climatic type in both locations is the “cold” one, having a wide range of possible values (approx. 15°C). In the city centre it prevails from October to April during the whole day (54% of the year), while in the rural areas it appears even in June and August in the nocturnal hours (66% of the year). Here, in January also, the “very cold” bio climatic type can be demonstrated at about 0700 hours with a minimum of –2.5°C, but it is negligible as a proportion of the year as a whole (<1%).

It can be established that, according to this measure (THI), the urban environment has more advantageous effects on the thermal conditions of humans than disadvantageous ones because of the more frequent occurrence of comfortable conditions and the smaller proportion of cold and cool periods. Nevertheless, the longer hot period in the city centre is a disadvantage for people staying in the urban environment in summer. However, as the classification in Table 1 shows, because of the relatively low value of the maximum THI in summer, less than 50% of the population feels any discomfort.

This is supported by the investigation of monthly mean RSI values in the four observation times, because this revealed that, in the climatic region of Szeged, we cannot reckon on strong heat stress even in the summer months. In the city the index reaches its maximum value (0.10) in June, July and August at 1300 hours and in the rural areas this occurs in July and August (0.07 and 0.08), implying no distress even for the elderly. The results show that for a longer period (e.g. one, month) the RSI values remain below the thresholds of heat stress mentioned above (0.2 for the elderly and 0.3 for the young). On certain days in summer the threshold values can be exceeded, but the period of distress does not last long.

There is a very significant difference between the numbers of beergarden days in the city and the country. The absolute numbers of these days in the city centre and in the surroundings during the three years under investigation were 250 and 133 respectively. This means that the city has almost twice as many pleasant evenings as the rural area. The average monthly relative frequencies of beergarden days show that they are found from May until October with the maximum in July (Fig. 3). In the case of the rural station, the frequencies in September and October are rather low (2% and 1%). From June to September the differences are always higher than 19%, the maximum difference being 36% in September. In the rural areas the beergarden days account for less than half of the days in the summer, while in the centre they exceed two-thirds and even three-quarters of the summer months. The temperatures at 2100 hours are almost always between 20°C and 26°C, exceeding 26°C in only a few cases.

Consequently our medium-sized city (Szeged) modifies the main climatological elements within the general climate of its region during every hour of the year. These modifications are mostly favourable from the human bioclimatological point of view because the comfortable periods within a year are found more frequently for those (sedentary people wearing standard clothing) living in the city than for those living in rural areas. We have to emphasize that our results and the above-mentioned effects on individuals apply only in this part of Europe, and also presumably in those parts of temperate zones the world over that are characterized by similar climatic conditions to those of south-eastern Hungary, as mentioned in the section “Study area and measurement sites”.

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