Specifics of temperature extremes under the conditions of urban climate

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Abstract: Urban climate causes intensive physical stress with negative impacts on health. One of the main risk factors is incidence of long-term period of high temperatures during the summer months, so-called heat waves. As a heat wave, a period of at least 3 consecutive days with maximum daily air temperature $\geq 30\,^{\circ}$C was considered. In this paper the heat-wave incidence and its dynamics are defined in the long-term monitoring in the cadastral of Brno. To determine the impact of urban heat island on observed characteristics, the temperature data series directly affecting the urban environment and temperature data series of non-urban area were evaluated. Urban climate is represented by Brno-Zabovresky station, and sub-urban climate by Brno-Turany station. Results are presented for the longest possible period, i.e. since 1987 when measurements in Zabovresky began till 2008 (22 years). For the evaluation, the homogenized data of daily maximum air temperature was used. The basis of the data was obtained by measurement at CHMI station network. The longest average length of the heat wave was recorded in 1994 (Zabovresky and Turany 8 days). The longest maximum length of the heat wave was recorded in 1994 (Zabovresky 19 days, Turany 17 days). The maximum number of heat waves per year was 6 at the station Brno-Zabovresky and 4 at Turany (1992, 1998 – Zabovresky and 2003 – Turany). The results showed significant specifics of urban climate as compared to suburban areas.

Key words: heat wave, urban area, high temperature, extremes, Brno

1. Introduction

Increased attention has been recently paid to the study of climate extremes not only for their own hazard (casualties, material damage) but also in relation to the threat of their prominence in the climate change. Negative consequences of possible climate change are changes in variability and occurrence of extreme events rather than changes in average temperature characteristics. The so-called heat waves belong to such extreme events *(Kyselý and Kalvová, 1998)*.

In addition to stronger conversion of the original landscape, the temperature in the center of heat island increases. Increased incidence of hot periods due to heat islands has been shown in the urban environment. In connection with the occurrence of temperature extremes, certain population groups, particularly the elderly and long-term sick, are most affected. In such situations, there is an increased mortality associated with chronic diseases, in particular cardiovascular, brain and vascular and respiratory tract diseases. It was found that for heat waves in summer, mortality was strongly associated with the duration of the heat wave *(Tan et al., 2007)*.

Urban area shows significantly higher temperatures than surroundings. *Hua et al. (2008)* analyzed one hundred and ninety one urban meteorological stations in China. Stations were categorized into three classes according to the urban population. A positive correlation between urban population and the rate of urban warming was found. These temperature differences are greater at night than during the day and in winter than in summer and most are in low wind or calm. Results showed that the urban environment caused great increase in local temperature at 2 a.m., 8 a.m. and 8 p.m. and small increase at 2 p.m. *(Liu et al., 2009)*. The main reason is the overlap of the original surface vegetation by infrastructure and buildings. Unlike higher plants, asphalt and concrete surfaces do not have the ability to utilize the incident solar radiation and convert it to chemical or other energy. Dark color of these surfaces also enhances absorption of light and heat radiation.

Near-surface climate was observed through temperature profiling from the surface to 2.47 m height in an urban vegetated park and its surroundings in central Stockholm, Sweden. Measurements were conducted during three summer days by mobile traverses. Air temperature differences between the built-up area and the park were in the range of 0.5–0.8 °C during the day and reached a maximum of 2 °C at sunset. *Jansson et al. (2007)* and *Lin et al. (2007)* employed a regional model to simulate the impact of urban expansion on monthly climate. Two experiments were performed by prescribing two different land covers: land cover represents vegetation in the 1970s, the other land cover represents the current urban conditions. Using the two land cover datasets, monthly climate of October 2004 (very dry season) was simulated. The results obtained from the numerical simulation show a distinct difference in simulated shelter-level temperature, humidity, surface fluxes and the height of planetary boundary layer with two different land cover data sets being specified.

In winter, the thermal energy supplied to individual houses and flats participates on the temperature increase in the cities. According to meteorological dictionary *(Sobíšek et al., 1993)* the area of increased air temperature in the limit and the ground layer of atmosphere above the city as compared to rural surroundings is defined as a heat island.

The heat wave is defined as a different long episode of extremely hot weather. Meteorological dictionary *(Sobíšek et al., 1993)* defines the heat wave as a few days lasting period of summer heat during which the daily maximum air temperatures reach 30 °C or more.

In Central Europe, the existence of heat wave is conditioned by advection of tropical air above the land or intensive radiological heating of polar air continuing above overheated land in the anticyclone area. Much attention is worldwide focused on studying the extreme temperature events. *Kukel et al. (1996)* studied the intense heat wave, which hit in Chicago, July 1995. *Kyselý and Kalvová (1998)* analyzed the incidence of heat waves in South Moravian region of the Czech Republic. Temporal variability of heat waves was described by *Kyselý (2003)* and analysis of mortality related to heat stress was studied by *Kyselý and Huth (2004).*

The term "heat wave" is relative due to climatic conditions of specific location. Temperatures which are considered normal for humans and other organisms in warmer areas tend to be regarded abnormal in colder areas. Therefore WMO recommends the heat wave to be defined as a period during which the daily maximum air temperature in five consecutive days is at least 5 °C higher than the normal average daily maximum for a given period (Heat Wave Duration Index HWDI) *(Frich et al., 2002).*

Kyselý and Kalvová (1998) defined the heat wave as a period that simultaneously satisfies the following three conditions: at least 3 days with daily maximum air temperature $\geq$ 30 °C, average daily maximum air temperature for the entire period $\geq$ 30 °C and daily maximum air temperature in all days $\geq$ 25 °C.

The Netherlands Royal Meteorological Institute defines the heat wave as a period of at least 5 days with daily maximum air temperature 25 °C and higher, which includes at least 3 days with daily maximum temperature 30 °C and higher *(Huynen et al., 2001).*

For the purposes of mortality analysis during the heat waves, *Kyselý and Huth (2004)* defined the heat wave as a continuous, at least three days period, during which the daily maximum air temperature is 30 °C or higher.

2. Material and methods

For the analysis of the heat waves incidence, the sites which lie in the potentially comparable climatic conditions but significantly different environmental conditions have been selected. One site is located in the city center, the second lies on the edge of the city out of reach of the urban environment effects.

For the purposes of the study, two climatic stations of Czech Hydrometeorological Institute (CHMI) were selected. Urban climate is represented by Brno-Zabovresky station and sub-urban climate by Brno-Turany station. Results are presented for the longest possible period, i.e. since 1987 when measurements in Zabovresky began till 2008 (22 years). Brno-Zabovresky station is located in the vicinity of the CHMI Brno branch. Brno-Turany station is located close to Brno airport on the outskirts of Brno.

For the evaluation, the homogenized data of daily maximum air temperature was used. The basis of the data was obtained by measurement at CHMI station network which has been checked for errors (by comparing with the surrounding stations, by comparing with the expected value calculated by geostatistical methods etc.) and then tested for the presence of inhomogeneities using statistical tests and the reference series with a subsequent correction of inhomogeneities. The missing values were substituted by using IDW method *(Štěpánek and Zahradníček, 2008).* The heat wave calculation was performed with the use of software ProClim *(Štěpánek, 2007).* As a heat wave, a period of at least 3 consecutive days with maximum daily air temperature $\geq 30\,^\circ$C was considered.

Analysed characteristics are as follows:

- Number of tropical days in the individual years (Fig. 3).
- Number of days in the heat waves (Fig. 4).
- Sum of effective temperatures in heat waves above 30 °C (Fig. 4).

Fig. 1. Aerial view of Brno-Zabovresky station.

Fig. 2. Aerial view of Brno-Turany station.

- Number of heat waves in the period (Fig. 6).
- Maximum and average duration of heat waves (Fig. 5).

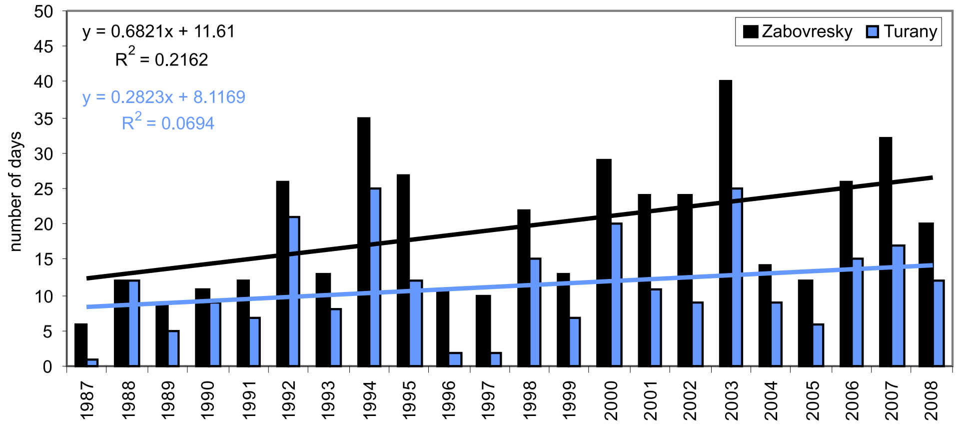

Fig. 3. Number of tropical days (interspersed with line of linear trend line and complemented by regression equation and R^2 value).

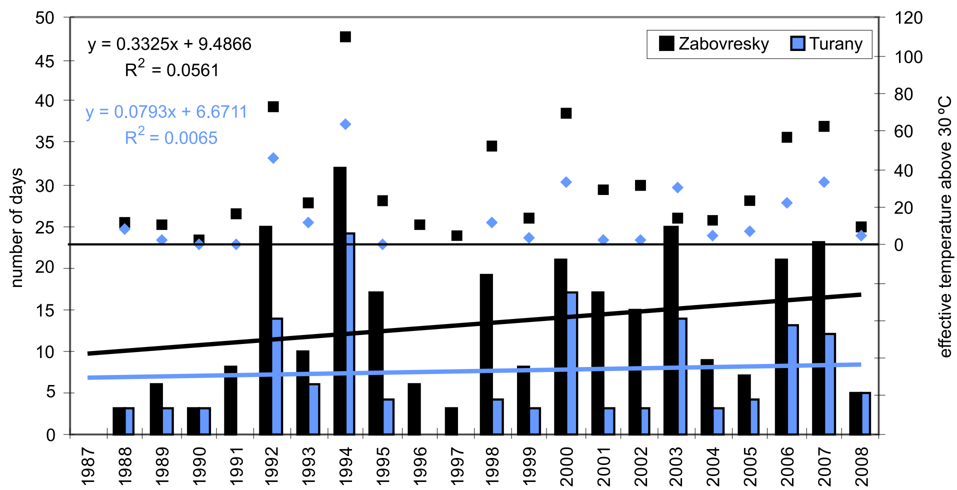

Fig. 4. Number of days of heat waves and their sum of effective temperatures above 30 °C (interspersed with linear trend line and complemented by regression equation and R^2 value).

All these characteristics were determined for the two selected stations (Turany and Zabovresky).

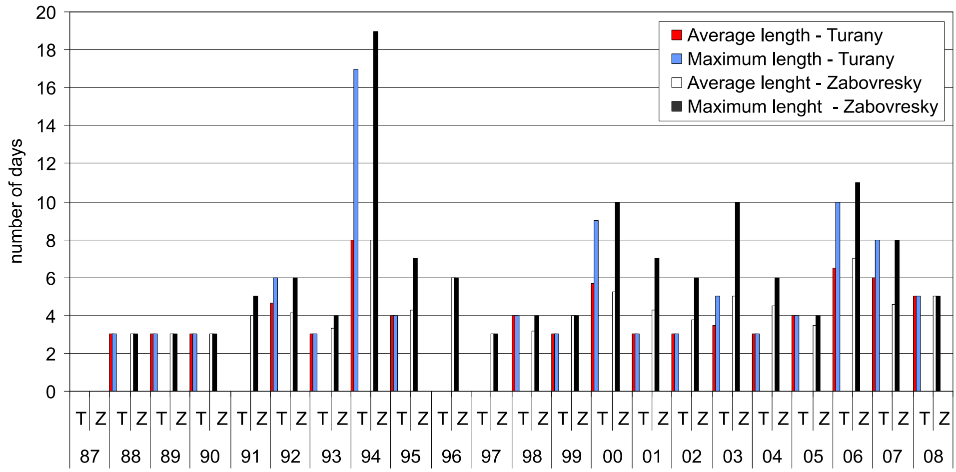

Fig. 5. Average and maximum length of heat waves.

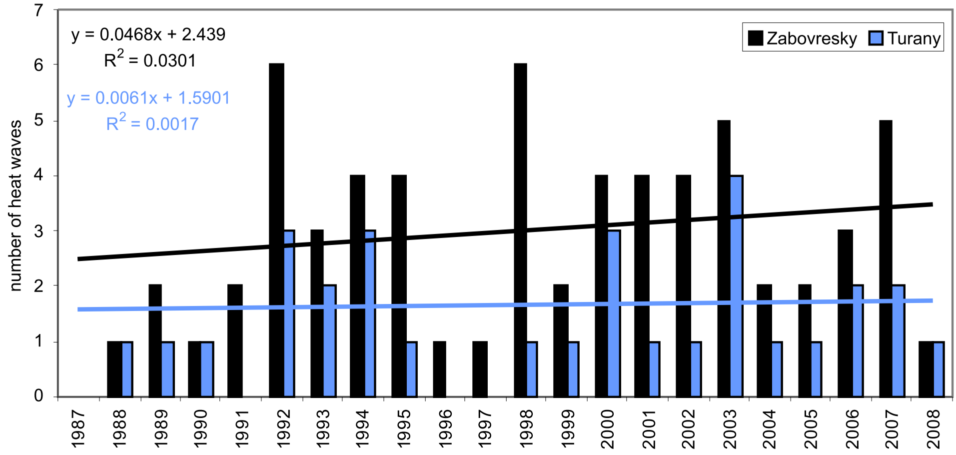

Fig. 6. Number of heat waves (interspersed with linear trend line and complemented by regression equation and R^2 value).

3. Results and discussion

The highest number of heat waves at Brno-Zabovresky station was found in 1992 and in 1998 and at Brno-Turany station in 2003. Maximum number of tropical days in the heat waves was reached in 1994 (Brno-Zabovresky – 32 days and Brno-Turany – 24 days). The average length of the heat wave in Zabovresky was 8 days and in Turany 7. The maximum length of heat wave occurs in 1994 – it was 19 days long in Zabovresky and 17 days in Turany. The maximum number of heat waves per year was detected in 1992 and 1998 at Zabovresky station and in 2003 at Turany station.

The results show that the values of monitored characteristics were significantly higher at Zabovresky station (representative of the urban environment) than at Turany station (sub-urban environment).

Table 1. Difference of monitored characteristics in individual years for Brno-Zabovresky station and Brno-Turany station

	number of tropical days	number of days in heat waves	average lenght of heat waves	maximum lenght of heat waves
1987	5	0	0.0	0.0
1988	0	0	0.0	0.0
1989	4	3	0.0	0.0
1990	2	0	0.0	0.0
1991	5	8	4.0	5.0
1992	5	11	-0.5	0.0
1993	5	4	0.3	1.0
1994	10	8	0.0	2.0
1995	15	13	0.3	3.0
1996	9	6	6.0	6.0
1997	8	3	3.0	3.0
1998	7	15	-0.8	0.0
1999	6	5	1.0	1.0
2000	9	4	-0.4	1.0
2001	13	14	1.3	4.0
2002	15	12	0.8	3.0
2003	15	11	1.5	5.0
2004	5	6	1.5	3.0
2005	6	3	-0.5	0.0
2006	11	8	0.5	1.0
2007	15	11	-1.4	0.0
2008	8	0	0.0	0.0
average	**8.1**	**6.9**	**0.8**	**1.8**

For a detailed presentation of heat-wave occurrence, two extreme years 1994 and 2003 were selected. The first heat wave at Zabovresky station was detected from 26th June to 29th June 1994. The first heat wave at Turany station occurred from 27th June to 29th June. Two heat waves in Turany were detected in July 1994, specifically from 14th to 17th July and from 22nd July to 7th August (lasted for 17 days). Even longer heat wave than the one in Turany occurred in 1994 in Zabovresky and lasted from 21st July to 8th August (in total 19 days). The beginning of the first heat wave at Zabovresky station was recorded on 4th June 2003, the wave lasted till 8th June. The first heat wave at Turany station started on 11th June and lasted till 13th June. At this time, the second heat wave of current year which lasted from 10th June to 13th June was already recorded at Zabovresky station. Heat wave occurred also from 20th July to 22nd July 2003 in Zabovresky. There was no heat wave in July in Turany anymore.

August 2003 was the most extreme from this viewpoint. Already at the beginning of the month a very long heat wave that lasted from 1st to 10th August was recorded in Zabovresky and two shorter in Turany: from 1st to 5th August and from 8th to 10th August. At both stations one heat wave lasting 3 days from 12th to 14th August was found. The highest maximum daily air temperature was measured on 13th August (Zabovresky 37.8 °C and Turany 37.1 °C). The longest average length of the heat wave was recorded in 1994 (both Zabovresky and Turany for 8 days). The longest maximum length of the heat wave was recorded in 1994 (Zabovresky for 19 days, Turany for 17 days). The maximum number of heat waves per year was detected at Brno-Zabovresky station in 1992, 1998 and Brno-Turany in 2003 (Fig. 6).

At both stations the highest number of tropical days was found in 2003. From the perspective of all other monitored characteristics year 1994 appears as an extreme one, and only the number of heat waves at Brno-Zabovresky station was found highest in 1992 and 1998 and for Brno-Turany in 2003.

The results show that the monitored characteristics for Brno-Zabovresky station (representative of the urban environment) reach significantly higher values than for Brno-Turany station (sub-urban environment).

The highest number of tropical days for Brno-Zabovresky station was 40 while for Brno-Turany station only 25 (2003). Maximum number of days in the heat waves was 32 for Brno-Zabovresky and 24 for Brno-Turany (1994). Sum of effective temperatures above 30 °C reaches 110.3 °C in Zabovresky while in Turany only 63.9 °C (1994). The average length of the heat wave was 8 days in Zabovresky and 7 days in Turany and the maximum length was 19 days in Zabovresky and 17 days in Turany (1994). Maximum number of heat waves per year has been determined as follows: 6 for Brno-Zabovresky station (1992, 1998) and 4 for Turany (2003).

For the period from 1997 to 2008 at Brno-Turany station there occur about 8 tropical days less than at Brno-Zabovresky station. On average, the number of tropical days of heat waves differs in about 7 days. Average heat wave in Turany is about one day shorter, in maximum about two days.

Figures 7 a 8 display a course of maximum air temperature during "extreme" years 1993 and 2004 at both monitored stations in comparison with long-term course (1997–2008) of daily maximum temperature.

Frequency, intensity and duration of heat waves did not increase generally during the 20^{th} century. But in the 21^{th} century, especially in the second half, the situation will be altered dramatically *(Hupfer et al., 2009).*

Wider impacts may include effects on the retail industry, ecosystem services and tourism. Adapting to more frequent heat waves should include soft engineering options and where possible, avoid the widespread use of air conditioning which could prove unsustainable in energy terms *(McGregor et al., 2007).*

4. Conclusion

Among negative consequences of possible climate change the changes in variability and occurrence of extreme events are included. Extreme events, the so-called heat waves, are defined as a different long episode of extremely hot weather. Urban area shows significantly higher temperature than the surroundings. For the analysis of the heat waves incidence the locations in the center (Zabovresky station) and on the edge (Turany station) of Brno city were selected. For the evaluation, homogenized CHMI data of the daily maximum air temperature for the period of 1987–2008 (22 years) were used.

The number of tropical days in the individual years, the number of days in the heat waves, the sum of effective temperatures in heat waves above

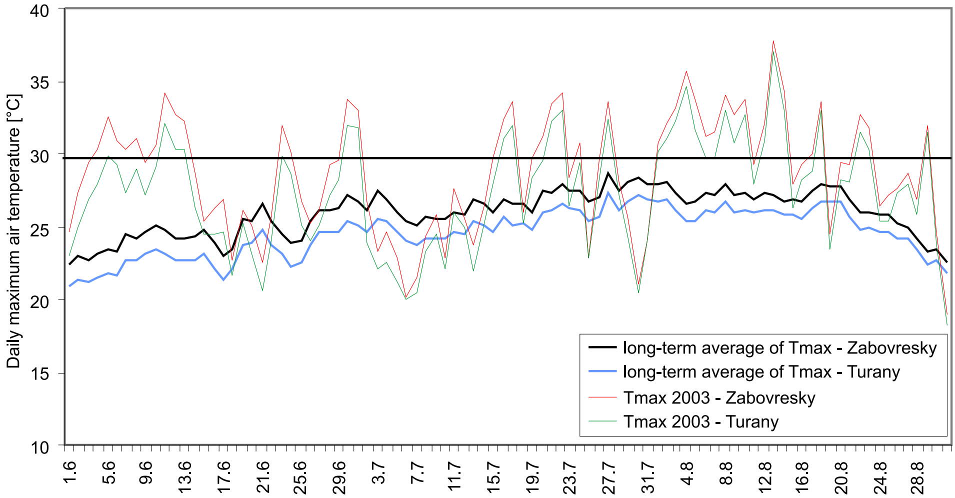

Fig. 7. Comparison of daily maximum air temperatures at Brno-Turany and Brno-Zabovresky stations in 2003 along with their long-term average 1997–2008.

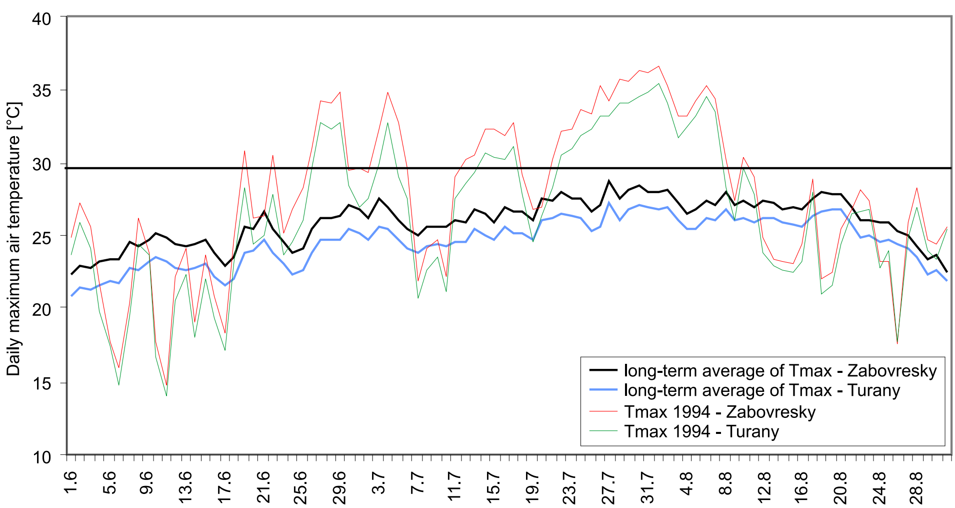

Fig. 8. Comparison of daily maximum air temperatures at Brno-Turany and Brno-Zabovresky stations in 1994 along with their long-term average 1997–2008.

30 °C, the number of heat waves in the period and the maximum and average duration of heat waves were analysed.

The longest average length of the heat wave was recorded in 1994 (Zabovresky and Turany 8 days). The longest maximum length of the heat wave was recorded in 1994 (Zabovresky 19 days, Turany 17 days). The maximum number of heat waves per year was 6 at Brno-Zabovresky station and 4 at Turany (1992, 1998 – Zabovresky and 2003 – Turany). The results showed a significant specific of urban climate as compared to sub-urban areas.

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