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ORIGINAL ARTICLE

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Mortality and displaced mortality during heat waves in the Czech Republic

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Abstract The aims of this study were to assess impacts of hot summer periods on mortality in the Czech Republic and to quantify the size of the short-term displacement effect which resulted in lower than expected mortality after heat waves. The analysis covered the period 1982–2000 when several extraordinarily hot summers occurred in central Europe. Daily total all-cause mortality and mortality due to cardiovascular diseases (CVD) in the entire population of the Czech Republic (approximately 10 million inhabitants) were examined. The daily death counts were standardized to account for the long-term decline in mortality and the seasonal and weekly cycles. Heat-related mortality is better expressed if 1-day lag after temperature is considered compared to the unlagged relationship. With the 1-day lag, both excess total mortality and excess CVD mortality were positive during all 17 heat waves, and in 14 (12) heat waves the increase in total (CVD) mortality was statistically significant (P=0.05). The mean relative rise in total mortality during heat waves was 13%. The response was greater in females than males and similar regardless of whether total or CVD mortality was used. The largest relative increases, exceeding 20% in both total and CVD mortality, were associated with heat waves which occurred in early summer (the first half of July 1984 and June 1994). The mortality displacement effect played an important role since mortality tended to be lower than expected after hot periods. The mean net mortality change due to heat waves was estimated to be about a 1% increase in the number of deaths. The large relative increases during some heat waves were particularly noteworthy since the study (in contrast to most analyses of the heat stress/mortality relationship) was not restricted to an urban area and/or an elderly population.

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Introduction

Heat stress-related mortality is among main impacts of climatic extremes on human society. It has been reported and evaluated mostly in mid-latitude countries and cities, but also in the hot subtropical (Auliciems et al. 1997; Pan and Li 1995) and cold high-latitude environments (Donaldson et al. 2003). In Europe, analyses focusing on central and eastern European populations have been rare; studies have been most frequent for Great Britain (Rooney et al. 1998; Hajat et al. 2002; Donaldson et al. 2003), the Netherlands (Kunst et al. 1993; Mackenbach et al. 1997; Huynen et al. 2001), Belgium (Sartor et al. 1995, 1997), Germany (Laschewski and Jendritzky 2002), Finland (Keatinge et al. 2000; Donaldson et al. 2003), Spain (Alberdi et al. 1995; Díaz et al. 2002a,b), Portugal (Falcao and Valente 1997; Dessai 2002), Italy (Mammarella and Paoletti 1989; Zauli Sajani et al. 2002) and Greece (Katsouyanni et al. 1993; Matzarakis and Mayer 1991, 1997). Annual heat-related mortality was found to be similar in European countries with warm and cold summers, although it is observed at lower temperatures in colder climates (Keatinge et al. 2000).

The impacts of heat stress on mortality are most pronounced in the elderly, children and people whose health has already been compromised, particularly due to cardiovascular, cerebrovascular and respiratory diseases. However, the strongest weather-mortality relationships are usually found for total daily mortality rather than its stratified subsamples (Jones et al. 1982; Kunst et al. 1993). Some of the heat-related deaths are short-term displacements of the deaths of critically ill people who would have died soon even in the absence of oppressive weather conditions (Kalkstein 1993; Huynen et al. 2001; Braga et al. 2002).

The aims of this study were to analyze mortality during heat waves in the Czech Republic (central Europe) and to quantify the mortality displacement effect. The analysis covers the hottest summers ever observed in the area, particularly noteworthy for record-breaking 1-day temperatures, exceeding 40°C in 1983, and severe and long heat waves in 1992, 1994, 1998 and 2000 (Kyselý 2002a,b).

Materials and methods

Daily data on all-cause (total) mortality and mortality due to cardiovascular diseases (CVD; ICD-9 codes 390–459) in the Czech Republic (population of about 10 million inhabitants) were obtained from the Institute of Health Information and Statistics over the period 1982–2000. The data were stratified by gender. Excess daily mortality was established (separately for total and CVD mortality and for males and females) by calculating deviations of the observed number of deaths from an expected number of deaths for each day of the examined period. The expected number of deaths in each day over the period 1982–2000 was computed so that it takes into account the long-term trend in mortality (decreasing during the 1982–2000 period, particularly due to enhanced life expectancy after socio-economic changes which followed the 1989 "Velvet Revolution") as well as short-term variations due to the annual cycle (lower mortality in late than early summer, see similar results discussed in Lerchl 1998) and the weekly cycle (slightly lower mortality on weekends than weekdays, see a discussion in Wang et al. 2002 for possible reasons).

Employing this approach, the expected number of deaths $M_0(y,d)$ for year y (y=1982,···,2000) and day d (d=1,···,365) was set according to

$$M_0(y,d) = M_0(d)W(y,d)Y(y)$$

where $M_0(d)$ denotes the mean daily number of deaths on day d in a year (computed from the mean annual cycle disregarding the long-term trend; the mean annual cycle was smoothed by 7-day running means); $W(y,d)$ is a correction factor for the observed weekly cycle of mortality (equals to 1.005 for weekdays and 0.995 for weekends); and $Y(y)$ is a correction factor for the observed year-to-year changes in mortality and equals to the ratio of the number of deaths in year y and the mean annual number of deaths during the analyzed period. Hence, due to the long-term decline in mortality, $Y(y)$ is larger (smaller) than 1.0 in the first (latter) part of the period under study. More details on the method are given in Kyselý and Kříž (2003); a similar standardization procedure has been used previously, e.g., in Guest et al. (1999), Smoyer et al. (2000a) and Whitman et al. (1997).

Daily maximum air temperature was calculated as the mean from five meteorological stations representative for the area of the Czech Republic. Daily mean and minimum temperatures and heat index (apparent temperature; e.g., Davis et al. 2003; Smoyer et al. 2000b) were evaluated as well but are not discussed here as their relationships to excess mortality (in terms of unlagged and lagged correlations) are similar or weaker (Kyselý and Kříž 2003), and the daily maximum temperature is commonly employed both in formal heat wave definitions and the public perception of heat in the Czech Republic.

Heat waves are defined as consecutive periods of at least 3 days during which the daily maximum temperature is higher than or equal to 30.0°C. A similar definition of heat waves was used in a long-term study of heat wave occurrence in the Czech Republic (Kyselý 2002a) and in a heat-related mortality analysis in Huynen et al. (2001).

An alternative definition of heat waves as summer periods of 3 or more successive days with deviations of the daily maximum temperature from the seasonal cycle higher or equal to 6.0°C, which leads to the same number of heat waves being observed in the period analyzed, was also applied but is not discussed here because the heat-related mortality during periods so defined is less pronounced. This also indicates that the absolute (raw) values of temperature have more direct effects on mortality in summer than the relative anomalies from the seasonal course.

Since the relationship between summer temperatures and mortality is sometimes found to be stronger with a lag of 1 day compared to unlagged relationships (Auliciems et al. 1997; Díaz et al. 2002b; Ramlow and Kuller 1990; Sartor et al. 1995; Whitman et al. 1997; Davis et al. 2003), both the 0-day and 1-day lags between mortality and temperature were used in evaluating heat-related mortality.

The effects of the air pollution on mortality were not controlled for since the analysis was carried out for a population majority of which (67% in 2002) lived in cities with less than 50,000 inhabitants or in a rural environment where the air pollution impacts are not usually observed, while only a small portion (21%) lived in large cities with over 100,000 inhabitants (Czech Statistical Office 2003).

Results

Basic description and unlagged analysis

During the 1982–2000 period, 17 heat waves occurred (Table 1), all of them between the beginning of June and the end of August. Their duration was 3–5 days with the exception of the extraordinary July–August 1994 heat wave (Kyselý 2002a) which lasted 17 days. Examples of the relationship between mortality and temperature for two summer seasons, 1984 (with one pronounced heat wave only) and 1994 (with long periods of hot weather), are given in Fig. 1.

If the unlagged relationship is considered, the excess total mortality (excess CVD mortality) was positive during 16 (15) heat waves and in 12 (10) heat waves the increase was statistically significant (P=0.05). In females, the rise in all-cause mortality (CVD mortality) was significant in 12 (11) heat waves; significant increases were less frequent in males, appearing in 10 (4) heat waves only. In no event mortality was significantly lower than the expected value.

One-day lag analysis

The impacts of heat waves on mortality are even more pronounced if the 1-day lag of mortality after high temperature is considered (Table 1). The total number of excess deaths over the 17 heat waves was 2,972 (compared to 2,566 in the unlagged analysis), i.e., 39.6 excess deaths per day on the average. Both the excess total mortality and the excess CVD mortality were positive in all 17 heat waves, and in 14 (12) heat waves the increase in the total (CVD) mortality was statistically significant (P=0.05). In females, the rise in all-cause mortality (CVD mortality) was significant in 15 (11) heat waves; significant increases were again less frequent in males, observed in 10 (6) heat waves.

The increase in mortality expressed as the total number of excess deaths was the highest during the exceptional 17-day July–August 1994 heat wave, but if calculated per day, it was close to the mean increase (Fig. 2). The relatively small pronounced mortality response to the long,

Table 1 Excess total mortality and excess mortality due to cardiovascular diseases (CVD) during heat waves, evaluated with a 1-day lag after the temperature measurement. The mortality increase (in number of deaths) is shown together with the 95% confidence interval. *M* (*F*) stands for males (females); M and F figures do not add up exactly to M + F in a few cases due to rounding off

No.	Heat wave			Total mortality			CVD mortality		
	Start	End	Duration (days)	M + F (deaths)	M (deaths)	F (deaths)	M + F (deaths)	M (deaths)	F (deaths)
1	2 Jun 1982	6 Jun 1982	5	249 (166 to 332)	141 (82 to 201)	108 (50 to 165)	119 (57 to 181)	64 (21 to 106)	55 (10 to 100)
2	16 Jul 1983	19 Jul 1983	4	125 (53 to 198)	33 (−19 to 85)	92 (42 to 142)	111 (57 to 164)	28 (−9 to 64)	83 (45 to 122)
3	26 Jul 1983	28 Jul 1983	3	130 (67 to 192)	78 (33 to 123)	51 (8 to 95)	62 (16 to 108)	30 (−2 to 62)	32 (−1 to 65)
4	10 Jul 1984	12 Jul 1984	3	297 (232 to 361)	132 (86 to 178)	164 (119 to 210)	175 (127 to 223)	58 (26 to 91)	117 (82 to 152)
5	3 Jul 1986	5 Jul 1986	3	54 (−9 to 117)	5 (−40 to 50)	49 (5 to 93)	37 (−10 to 84)	3 (−29 to 36)	34 (−0 to 68)
6	12 Aug 1990	14 Aug 1990	3	29 (−33 to 91)	33 (−11 to 78)	−5 (−47 to 38)	28 (−18 to 73)	23 (−9 to 54)	5 (−28 to 38)
7	29 Aug 1990	31 Aug 1990	3	81 (20 to 141)	24 (−19 to 68)	56 (14 to 98)	35 (−10 to 79)	4 (−27 to 34)	32 (−1 to 64)
8	1 Aug 1992	3 Aug 1992	3	93 (34 to 153)	22 (−20 to 65)	71 (29 to 112)	63 (19 to 106)	17 (−13 to 47)	46 (14 to 78)
9	6 Aug 1992	10 Aug 1992	5	246 (170 to 323)	88 (33 to 142)	159 (106 to 212)	131 (75 to 188)	18 (−21 to 57)	113 (72 to 154)
10	14 Aug 1993	16 Aug 1993	3	90 (31 to 148)	30 (−11 to 72)	59 (18 to 100)	24 (−19 to 66)	15 (−15 to 44)	9 (−22 to 40)
11	26 Jun 1994	29 Jun 1994	4	301 (231 to 371)	113 (64 to 163)	188 (138 to 237)	188 (136 to 240)	60 (24 to 95)	128 (90 to 166)
12	13 Jul 1994	17 Jul 1994	5	15 (−62 to 93)	13 (−42 to 68)	3 (−52 to 57)	12 (−46 to 69)	−11 (−50 to 27)	23 (−19 to 65)
13	22 Jul 1994	7 Aug 1994	17	596 (455 to 737)	266 (166 to 366)	330 (230 to 429)	384 (280 to 488)	97 (27 to 167)	287 (210 to 363)
14	8 Jul 1995	12 Jul 1995	5	234 (157 to 311)	105 (50 to 159)	129 (75 to 183)	150 (93 to 207)	71 (32 to 109)	79 (37 to 121)
15	5 Jun 1998	7 Jun 1998	3	156 (97 to 214)	73 (31 to 115)	83 (42 to 124)	116 (72 to 159)	31 (1 to 60)	85 (53 to 117)
16	20 Jun 2000	22 Jun 2000	3	118 (61 to 176)	43 (3 to 84)	75 (35 to 115)	51 (9 to 92)	9 (−19 to 37)	42 (12 to 72)
17	19 Aug 2000	21 Aug 2000	3	158 (103 to 213)	55 (16 to 94)	103 (65 to 142)	76 (36 to 115)	0 (−26 to 27)	75 (46 to 104)

severe July–August 1994 heat wave may seem surprising, but a short-term adaptability to hot weather which persisted since mid-June 1994 (see Fig. 1 and note the two earlier heat waves in 1994 in Table 1) together with mortality displacement are likely explanations.

The mean relative increase in the total mortality (CVD mortality) in heat waves expressed as a % of expected mortality was 12.9% (13.6%; Fig. 2, Table 2). The relative mortality increase was positively correlated with the mean temperature during heat waves (Fig. 3) with a Pearson correlation coefficient of 0.55 for the total mortality rise if the 1-day lag after high temperature was taken into account. The total mortality increase was above 10% in all heat waves with a mean daily maximum temperature higher than or equal to 32.0°C. The largest relative increases, exceeding 20% in both total and CVD mortality, were associated with heat waves that occurred in early summer (the first half of July 1984 and June 1994). The maximum relative increase was 36.3% during the July 1984 heat wave, for CVD mortality in females. On individual days, the largest relative rise in total mortality (+37.2%) occurred on 1 August 1994.

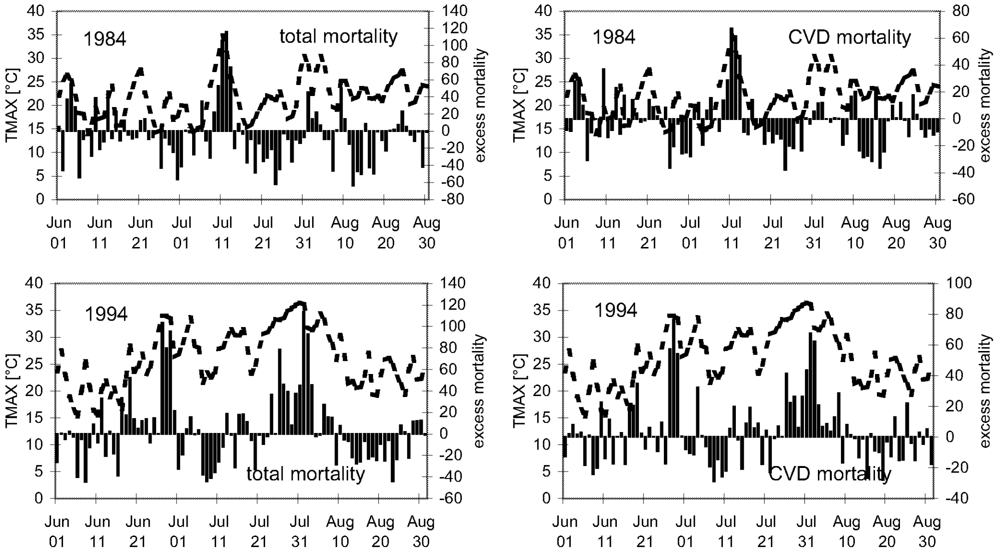
Mortality displacement effect

Since a hot period may have persisted for a longer time (e.g., it may have started to develop several days before a heat wave), the actual number of victims due to heat stress is likely to be slightly higher. On the other hand, the effect of a short-term mortality displacement (harvesting) accounts for a substantial part of the mortality increase during heat waves (see Fig. 1).

To evaluate its magnitude, the net effect on total mortality (either increase or decrease) was estimated for each heat wave by summing the daily excess mortality for the period of the heat wave (usually 3–5 days), considering the 1-day lag between mortality and elevated temperature, for several days preceding the heat wave when a positive excess mortality was observed (to include the development of a hot period) and for several days after the end of the heat wave during which a lower than expected mortality prevailed. To delimit the beginning and the end of the period over which the estimation of the net heat wave effect on mortality was calculated, a common criterion was applied: The first 3-day period with a *positive* mean excess mortality *before the heat wave* was chosen as the beginning while the last 3-day period with a *negative* mean excess mortality *after the heat wave* was chosen as the end. Hereafter, these periods are called "extended heat wave periods" (Table 3).

The difference between the net mortality change and the excess mortality gives an estimate of the magnitude of the displacement effect. However, mortality during and after each specific heat wave is influenced also by previous temperatures and a potential short-term physiological and behavioral adaptation, and the interpretation of the net mortality change is therefore not straightforward.

Fig. 1 Course of daily maximum temperature (T_{MAX}, *dashed curve*) and the excess total and CVD mortality (*columns*) during the summers of 1984 (*top*) and 1994 (*bottom*)



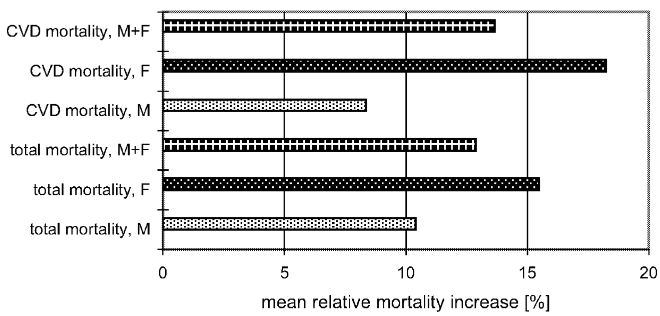


Fig. 2 Mean relative increases in mortality during heat waves

The net mortality change was clearly positive during the extended heat wave periods of the most severe heat waves, namely those of the August 1992 heat waves (the net mortality change for the two heat waves was +211 deaths), the June 1994 heat wave (+264 deaths) and the July–August 1994 heat wave (+294 deaths). The high value of +514 deaths for the August 2000 heat wave was achieved due to an extraordinarily long period of consecutive positive daily excess mortality following the heat wave that persisted for about 3 weeks. The net mortality change due to all heat waves was +963 deaths, or +3.6 excess deaths per day, which is slightly above 1.0% relative increase.

An alternative approach for the evaluation of the net effects of high summer temperatures is to sum the daily excess mortality over the June–August period in individual years (not shown). (The standardization procedure which controls for the long-term decline in mortality should not have a pronounced effect on these values since it considers all-year data on mortality.) The net summer mortality was positive in all years when two or more heat waves occurred (between 100 and 400 excess deaths); however, the highest net summer mortality was observed during the cold 1987 summer (the second coldest summer

Table 2 Relative increases in total and CVD mortality in heat waves. The 1-day lag of mortality after high temperature is considered. T_{MAX} denotes mean daily maximum temperature during the heat wave

Heat wave (no.)	Start	End	Duration (days)	T_{MAX} (°C)	Total mortality (%)	CVD mortality (%)
1	2 Jun 1982	6 Jun 1982	5	30.9	13.8	12.0
2	16 Jul 1983	19 Jul 1983	4	31.6	9.2	14.8
3	26 Jul 1983	28 Jul 1983	3	32.5	12.8	11.2
4	10 Jul 1984	12 Jul 1984	3	32.3	27.3	29.2
5	3 Jul 1986	5 Jul 1986	3	30.4	5.2	6.5
6	12 Aug 1990	14 Aug 1990	3	31.2	2.9	5.1
7	29 Aug 1990	31 Aug 1990	3	31.0	8.4	6.7
8	1 Aug 1992	3 Aug 1992	3	32.0	10.1	12.5
9	6 Aug 1992	10 Aug 1992	5	34.4	16.2	15.8
10	14 Aug 1993	16 Aug 1993	3	32.0	10.1	4.9
11	26 Jun 1994	29 Jun 1994	4	33.2	23.6	26.7
12	13 Jul 1994	17 Jul 1994	5	30.8	1.0	1.4
13	22 Jul 1994	7 Aug 1994	17	33.3	11.5	13.6
14	8 Jul 1995	12 Jul 1995	5	31.0	15.2	17.7
15	5 Jun 1998	7 Jun 1998	3	32.6	17.5	23.5
16	20 Jun 2000	22 Jun 2000	3	33.4	13.9	11.5
17	19 Aug 2000	21 Aug 2000	3	32.4	20.0	18.8
Mean					12.9	13.6

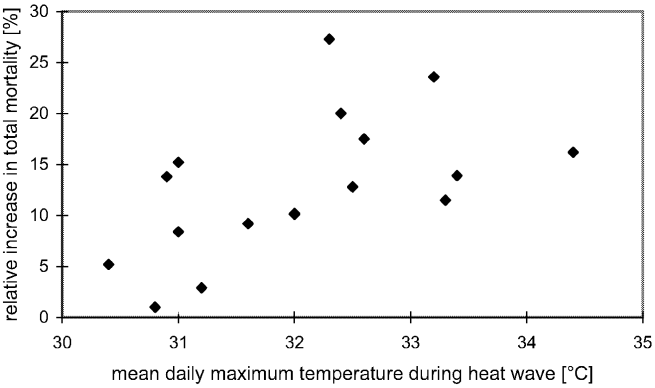


Fig. 3 Scatter-plot of relative increases in total mortality against mean temperature of heat waves

Table 3 Net mortality change over extended heat wave periods. The values shown account for the mortality increase during the heat wave development and the decline after the hot period due to the harvesting effect, but not for the previous temperature course. The 1992 heat waves are treated together as one case

Heat wave (no.)	Net mortality change (deaths)	Duration of the extended heat wave period (days)
1	34.2	18
2	29.3	12
3	−145.2	15
4	−26.4	23
5	−180.9	13
6	−145.5	11
7	126.0	18
8+9	211.1	18
10	−25.0	7
11	264.1	8
12	−16.7	11
13	293.5	36
14	237.1	10
15	−106.1	16
16	−101.1	11
17	514.5	41

in 1982–2000) without heat waves. This demonstrates the difficulties involved in the interpretation of excess mortality over extended periods.

Discussion

The relative mortality increases during heat waves in the Czech Republic compare well with results of other European studies despite the different methodologies and definitions of heat stress episodes. Laschewski and Jendritzky (2002) found increases in mortality of up to 25% in Baden-Württemberg (southwestern Germany) during heat waves (compared with 37% in the Czech Republic) for the most oppressive 1-day weather conditions, but the net mortality change due to heat waves was only about 0.2% (compared with 1% in the Czech Republic). The mean relative increase in the total mortality of 12% (compared with 13% in the Czech Republic) was reported by Huynen et al. (2001) during heat waves in the Netherlands, with the largest excess of about 24% for the 1994 heat wave (compared with 12% during the same heat wave in the Czech Republic, and 27% during the heat wave with the largest mortality increase). Their results for the short-term mortality displacement were inconclusive; during some heat waves the harvesting effect was not observed. Here, it is the case particularly for the August 2000 heat wave, but generally the displaced deaths make a substantial part of the total number of victims of heat waves. The relative mortality increase during heat waves in London was up to 31% during the severe 1976 heat wave, and between −3% and 17% for other heat waves, results which were mostly statistically insignificant (Hajat et al. 2002). The slightly greater response to heat waves in the population of the Czech Republic compared to western European countries may result from the lower socio-economic state of this less prosperous communist and post-communist (since 1989) country.

Mortality during the summer of 1994, of which the July–August hot period was the most severe and longest heat wave in Prague since 1775 (Kyselý 2002a), was dealt with in Sartor et al. (1995) for Belgium and Huynen et al. (2001) for the Netherlands. Because of different time periods analyzed, different courses of temperature during the heat waves as well as during the preceding and subsequent periods, and the different data used (stratified by age in Sartor et al. 1995; Huynen et al. 2001), a direct comparison is not possible. However, the relative mortality increases were of a similar magnitude in all three regions.

Females are more sensitive to heat stress than males, a result reported by other studies in European populations as well (Díaz et al. 2002a,b; Mackenbach et al. 1997; Rooney et al. 1998). The difference between the genders is more pronounced for CVD than for total mortality in the Czech Republic. It is likely to be connected with the age structure of the population, which has a higher percentage of women living alone, and a greater physiological and behavioral vulnerability of women to an oppressive thermal environment.

The higher sensitivity to early-summer heat waves, when the population has not become acclimatized to hot weather, is also in agreement with other analyses (Hajat et al. 2002; Kalkstein and Smoyer 1993; Laschewski and Jendritzky 2002).

Future plans concerning the analysis and prediction of heat stress-related mortality in the Czech Republic include the development of the synoptic (air mass-based) approach (Smoyer et al. 2000a; Kyselý and Huth 2004) and of time-series models describing the relationship between weather and mortality in a more comprehensive way. Complex biophysiological comfort indices and models (Höppe 1999; Laschewski and Jendritzky 2002) are also likely to yield better results although their widespread use is hindered by the need for more extensive input data.

Despite its limitations, this analysis clearly shows that heat stress leads to a considerably elevated all-cause mortality and CVD mortality in the Czech Republic, although a substantial portion of the victims would have died in the short term without the added stress of extreme heat. The large relative increases in mortality, exceeding 20% during some heat waves, are particularly noteworthy since this study, in contrast to most analyses of the heat stress/mortality relationship, was not restricted to an urban area and/or an elderly population. A development of a similar heat-watch-warning system which has mitigated the impacts of heat waves on mortality in US cities (Kalkstein et al. 1996; Kalkstein 2000) as well as other intervention measures leading to a better preparedness and awareness of the population, and particularly of its vulnerable groups, towards extreme heat should be considered also for central European conditions.

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