Theor Appl Climatol (2011) 105:1–10
DOI 10.1007/s00704-010-0372-x

ORIGINAL PAPER

Human biometeorological evaluation of heat-related mortality in Vienna

Andreas Matzarakis · Stefan Muthers · Elisabeth Koch

Received: 26 August 2010 / Accepted: 27 October 2010 / Published online: 20 November 2010

Abstract The relationship between heat stress and mortality in the federal state of Vienna (Austria) was analyzed from 1970 to 2007. Long-term trends of mortality data and short-term adaptation to heat stress were considered by two complex approaches. The evaluation is based on the human biometeorological parameter, physiologically equivalent temperature. The results revealed a significant impact of heat stress on the human health, with a significantly higher sensitivity on women compared to men. Additionally, higher risks of deaths due to cardiovascular and respiratory diseases were found. During the long period of 38 years, some significant decreases of the sensitivity were found, especially in the medium heat stress levels. This could indicate active processes of long-term adaptation to the increasing heat stress.

1 Introduction

In summer of 2003, it was shown that there was a strong association between thermal stress and human health. Two heat waves occurred in June and August 2003 with the known effects of many thousands of deaths (Koppe et al. 2003; WHO 2003; Heudorf and Meyer 2005; Díaz et al. 2006; Robine et al. 2007), especially among older people (Díaz et al. 2002; Flynn et al. 2005; Laaidi et al. 2006; Barnett 2007; Hajat et al. 2007). The heat wave happened almost all over Western and Southern Europe. Although the effect of the heat waves in Austria was not found not to be extraordinary (Muthers et al. 2010a), still 130 additional deaths (Hutter et al. 2007) occurred during that time in Vienna.

After the heat waves in summer 2003, many countries in Europe forced to initiate the development of heat health warning systems (HHWS) in order to early inform and protect their citizens. An HHWS consists of different components. In general, in a meteorological aspect it is responsible for the identification of heat wave events with serious health impacts. In the public health arena, it initiates and coordinates measurements to mitigate the most serious health outcomes due to the heat wave effect (WHO 2004). The identification of heat wave effect on human health requires deep knowledge of the relationship between heat load and mortality in the specific region as it differs among various countries (Keatinge et al. 2000; Gosling et al. 2007; Kovats and Shakoor 2008; Lin et al. 2010), but is connected to the mean climate conditions of a specific region (Iñiguez et al. 2010). Moreover, social factors such as the demographic structure of the population or the state of the health systems need to be taken into account. Hence, the development of an HHWS should firstly involve an analysis of the specific relationship for this region, which identifies useful parameters, thresholds and the intensity of the heat load impact.

A brief description of HHWSs in Europe and the used meteorological factors or parameters is described in Koppe and Becker (2009). In most of the countries, a combination of daily air temperature (min, max, or mean) and sometimes air humidity were taken while a few countries used synoptic approaches, e. g., Italy. A more sophisticated approach based on the human energy balance and the derived perceived temperature (Jendritzky et al. 1979; Jendritzky 1990) is used in Germany. This approach also includes

A. Matzarakis (✉) · S. Muthers
Meteorological Institute, Albert-Ludwigs-University of Freiburg, Freiburg, Germany
e-mail: andreas.matzarakis@meteo.uni-freiburg.de

E. Koch
Central Institute for Meteorology and Geodynamics, Vienna, Austria

short-term adaptation processes in order to assess the different impacts of heat waves in the spring time or early summer (Koppe and Jendritzky 2005). Yet, in Austria, only the National Oceanic and Atmospheric Administration heat index was used until 2009.

The central idea of developing HHWS is to protect human lives and reduce health costs, individually and nationally. Despite the fact that the evaluation of HHWS is a complex topic, there is some evidence that HHWS were already able to reduce the health impact of heat waves (Fouillet et al. 2008; Chau et al. 2009).

In this paper, we present the results of the relationship between heat stress and all cause mortality in the densely populated city of Vienna (Austria), using a human biometeorological index, the physiologically equivalent temperature (PET).

2 Data and method

2.1 Climate data

The climate station of the Central Institute for Meteorology and Geodynamics at the "Hohe Warte" in Vienna was selected to represent the federal state of Vienna. Climatic parameters, including air temperature (°C), relative humidity (%), wind speed (m/s), and mean cloud cover (octas) were collected for the observation times of 7, 14 and 19 central European time (CET) during 1950 and 2007.

Since the thermal environment of the human body includes many different components—besides the air temperature and the air humidity also the radiation fluxes, the wind velocity, and non-meteorological parameters (age, sex, clothing insulation) are of importance—a physiologically relevant description of heat load must be based on human energy balance models (Höppe 1993). Hence, we selected the human biometeorological index PET, which provides the simulation of a core and the skin temperature by climatic parameters in the complex outdoor environment (Mayer and Höppe 1987). PET is calculated on the basis of the human energy balance model, Munich Energy Balance Model for Individuals (Höppe 1984) when considering a standardized person (male, 35 years; 1.75 m, 75 kg, clothing insulation of 0.9 clo) being exposed to the outdoor environment. The estimation was done applying the RayMan Model (Matzarakis et al. 2007; Matzarakis et al. 2010). PET describes the thermal situation by the air temperature of a reference environment, in which the core and the skin temperature is the same as in the complex outdoor environment. This reference environment is defined as a room with a wind velocity <0.1 m/s, a vapor pressure of 12 hPa and a mean radiation temperature that equals the air temperature (Mayer and Höppe 1987).

Furthermore, earlier studies have shown that a significant difference of the impact of heat waves exists between early summer and later summer (Kalkstein and Smoyer 1993; Hajat et al. 2002). This difference is probably a result of short-term adaptation processes. Hence, we used an approach developed by Koppe and Jendritzky (2005) to consider this effect. The Heath-Related Assessment of the Thermal Environment approach is taking different thresholds in categorizing different levels of thermal stress, based on the thermal conditions of the preceding 30 days. In case of warmer conditions, the threshold was adjusted upwards. In case of rather cold conditions, the threshold was lowered.

Threshold determination was according to the classification created by Matzarakis and Mayer (1996). Table 1 shows the levels of thermophysiological stress and the corresponding thresholds.

3 Mortality data

The daily mortality values for the period 1970 to 2007 were obtained from Statistik Austria. The data is classified by sex and cause of death according to the International Classification of Diseases-10 (ICD-10).

Figure 1 shows the daily absolute mortality in the federal state of Vienna for the period 1970 to 2007. Generally, the mortality has been reduced over time. The fitted Gaussian smooth extract the annual cycle with high values in the winter time and low values in summer. Additionally, a pronounced long-term trend from around 70 deaths per day in the 1970s to 50 in the first years of the twenty-first century is visible. The smaller segment in Fig. 1 displays the seasonal cycle for the year 1994 to 1997 and the high variability while peaks are exhibited in the winter months.

Long-term trends of the mortality data are influenced by mainly three factors, variations in the size of the population,

Table 1 Ranges of PET in °C for different levels of thermal perception by humans for 80 W activity and 0.9 clo clothing (Matzarakis and Mayer 1996)

PET	Thermal perception	Grade of physiological stress
4	Very cold	Extreme cold stress
8	Cold	Strong cold stress
13	Cool	Moderate cold stress
18	Slightly cool	Slight cold stress
23	Comfortable	No thermal stress
29	Slightly warm	Slight heat stress
35	Warm	Moderate heat stress
41	Hot	Strong heat stress
	Very hot	Extreme heat stress

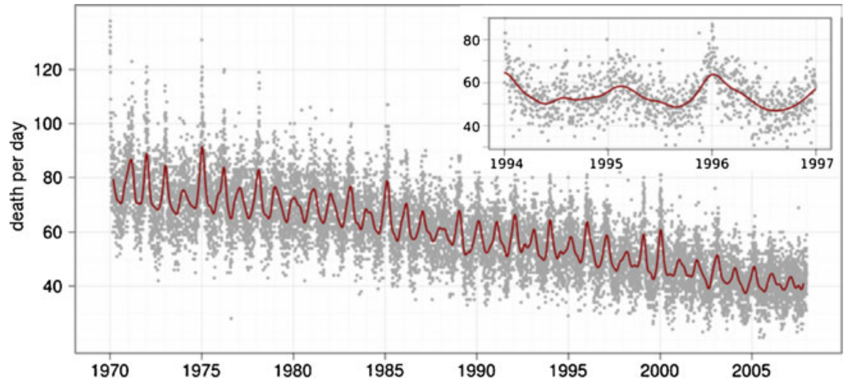

Fig. 1 Time series of the mortality data including a Gaussian smooth with a length of a half year

changes in the expectancy of life, and changes in the age structure of the population. The first factor was removed by dividing the absolute daily mortality by the size of the population. The result is the mortality rate, daily number of deaths by 100,000 inhabitants.

Therefore, annual information on the size of the population in the federal state of Vienna was used and the daily values were assessed by a linear interpolation of the annual values. The time course of the population size is shown in Fig. 2. The general size of the population in Vienna (solid line) was nearly constant during the period of investigation. For men (dashed line) and women (dotted line) there is a slightly different trend. Since 1990, there is a stronger increase in the male population and the difference between men and women becomes smaller. The size of the population determines also the quality of the results; the values are to a high degree influenced by noise. For a larger population, this noise is more and more superimposed by other influences, which are then easier to identify (Pascal et al. 2006). With a mean population of 1.6 million Vienna is large enough to expect sufficient results.

The other two disturbance variables are still included in the mortality rates. A society with a high number of older people shows higher mortality rates, compared to a younger society. Hence, the change towards an older society results in a rise of the mortality rates that could, by mistake, be assigned to other (external) causes. This fact is of particular importance since older people are known to be much more vulnerable to thermal stress than younger people (Flynn et al. 2005; Kovats and Shakoor 2008).

Figure 2 shows that the age structure of the society of Vienna changes significantly within the period of investigation. The figure presents the dependency rate (points) for specific years and the fraction of older people (60 years and more) relative to the number of people between 15 and 60 years for the period 1961 to 2008. At the beginning of the 1970s, the population in Vienna had a large fraction of old people, which decreased till the end of the 1990s. From then on, the fraction increased once again.

The effect of the changing age structure was removed by the use of a complex approach to calculate the baseline mortality (Koppe and Jendritzky 2005). Additionally, this approach removes the influence of the increased expectancy of life, which increased by 0.293 years per year for the men and 0.258 years for the women since 1970 (Gisser 2005). The approach makes use of a Gaussian smooth of a half year, which is not defined at the beginning and the end of our period of examination. Consequently, the first half of 1970 and the second half of the year 2007 is removed from our study period. The baseline mortality builds the basis to calculate the deviations of the daily mortality rates from this baseline. The deviations were described on a percentage basis relative to the baseline to consider long-term changes in the baseline level. These values are called relative mortality in the following.

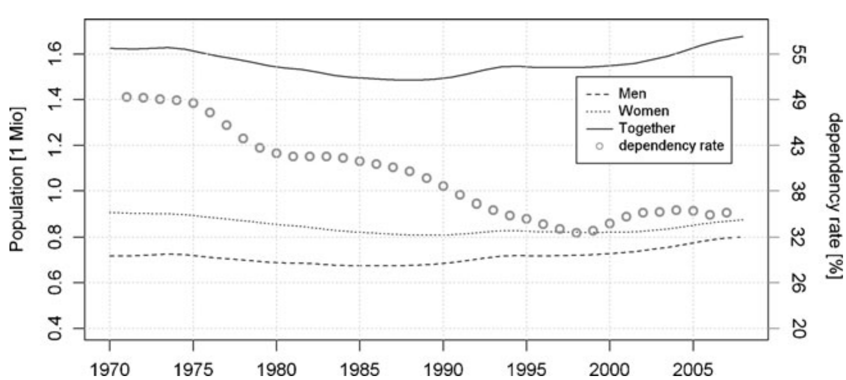

Fig. 2 Size and dependency rate of the population of Vienna in the period of examination

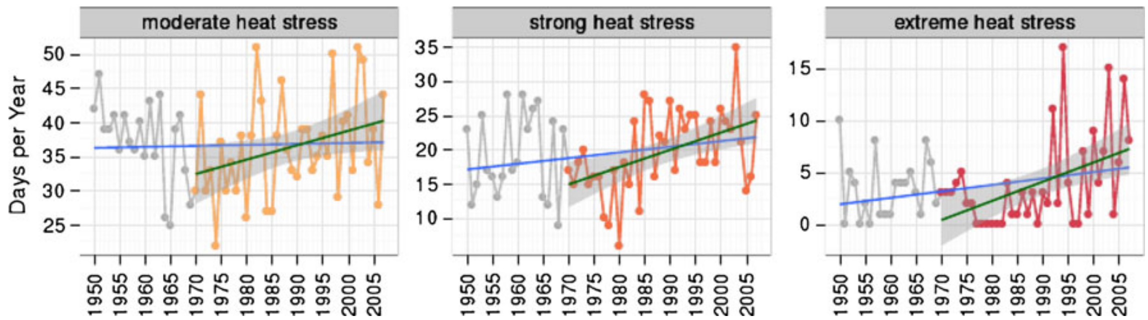

Fig. 3 Number of days per year for three heat stress levels for the period 1950–2007 (*gray*) including a linear regression line. The period of investigation is highlighted by the *colored* data points

The vulnerability of a population is a result of the combination of sensitivity (i.e., thermal comfort) and exposition (intensity and time of thermal stress situations) (Koppe 2005). The sensitivity is driven by demographic and physiologic factors and by behavioral processes. By the use of the complex approach to calculate the baseline mortality, the demographic component can be mostly excluded.

3.1 The relationship between heat stress and mortality

The relationship between thermal stress and human health was analyzed based on the levels of thermal stress mentioned above. In a first step, the full PET range was used. For each level, the mean value on the day, with thermal stress as well as on the following days and during heat waves, was assessed. Additionally, the confidence interval (CI) for the mean values was calculated, and the differences between the values were tested for significance using *t* tests. Later, the PET range was reduced to the thermal stress levels, relevant in the summer month, when heat stress is an issue. To include also early and late summer heat events, the summer months were defined by the period of April to October. For the identification of trends in the relationship between thermal stress and mortality, linear regressions were fitted and the significance was tested by *t* test for the slope of the regression line and the non-parametric Mann–Kendall test (Helsel and Hirsch 2002). For all the statistical tests used, a significance level of 95% was chosen, if not mentioned otherwise. All steps were done for the overall mortality (all causes of death and full population) as well as for men, women, and the cause of death group, cardiovascular and respiratory diseases (C+R).

4 Results

4.1 Climatic trends

Between 1971 and 2007 (1970 is not considered, since the observation time in the evening changed between 1970 and 1971 from 21 to 19 CET), the daily mean air temperature in Vienna amounts to 10.5°C (PET, 7.9°C). Assuming a linear development, the increase per decade was 0.37°C (PET, 0.45°C), which is mainly an effect of an air temperature increase in the months of April to October. According to Böhm (2009), this could be a result of a north shift of the subtropical belt of high pressure, which is characteristic for the Alpine region.

Consequently, there is also an increase in the days with heat stress, especially of days with strong (PET ≥30°C) and

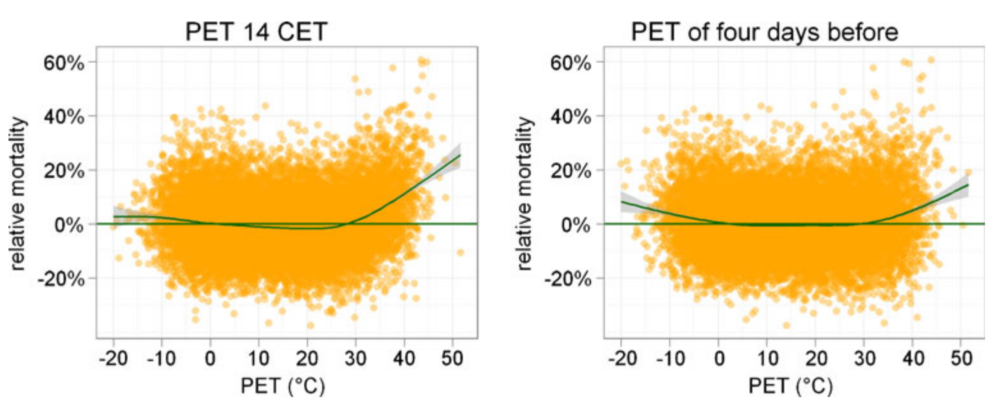

Fig. 4 Scatter plots of the input data. *Left side*: PET of 14 CET together with the relative mortality of the same day. *Right side*: same mortality data, but together with the PET of 4 days before. In both figures, a lowess smooth is overlaid (*green line*)

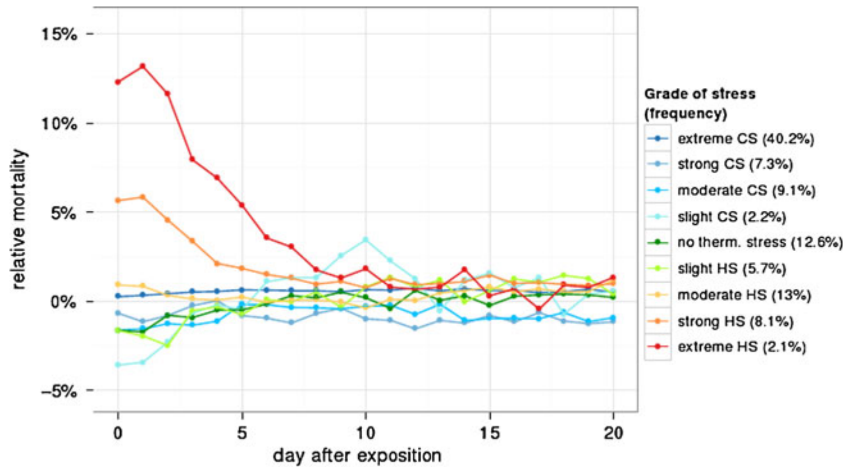

Fig. 5 Development of the mean relative mortality after different levels of thermal stress. The thermal conditions on day 0 builds the basis for the classification, afterwards the mean relative mortality for the days following the exposition was calculated

extreme (PET ≥35°C) heat stress. Given the months April to October and the PET of 14 CET, a significant increase in the number of days per year is found for all heat stress levels (Fig. 3). In the period of investigation, the mean number of days with moderate heat stress was 36 days per year with an increase of 0.21 days per year (CI, 0.002; 0.419), 19 days with strong heat stress were found (trends, +0.16 days per year; CI, 0.092; 0.413), and 3 days with extreme heat stress (trend, +0.18 days per year; CI, 0.066; 0.302). For the period since 1950, the trend is clearly smaller. For days with moderate heat stress an increase of 0.01 days per year (CI, −0.093; 0.121) was found, respectively, 0.08 days per year for days with strong heat stress (CI, −0.009; 0.175), and 0.06 days with extreme heat stress per year (CI, 0.002; 0.122).

4.2 The relationship between heat stress and mortality

Figure 4 (left) displays the relationship between the PET of 14 CET and the mortality of the same day for the period 1970 to 2007. The cloud of data points reveals a high variability over the whole PET range, but the lowess smooth (Cleveland and Devlin 1988) extracts the general tendency towards higher mortality values with higher PET. Additionally, a large range of thermal acceptability is visible, where the relative mortality is slightly below the baseline. With greater time lags, the rise of the lowess smooth for cold values becomes larger; Fig. 4 (right) displays the PET and the relative mortality of 4 days later.

The reaction of the human body to heat stress is more direct compared to cold stress (Keatinge 2002; Grass and Cane 2008; Muggeo and Hajat 2009). Hence, in the next step, the temporal reaction of mortality to different levels of thermophysiological stress is analyzed. The results are shown in Fig. 5, again based on the PET of 14 CET.

A pronounced increase of the relative mortality was found on days with strong and extreme heat stress (day 0). For the same day, the mean mortality reaches values of 12.3% (CI, 10.2; 14.4) and 5.6% (CI, 4.7; 6.6) for extreme and strong heat stress respectively. On the following day, the values are still higher (13.2% and 5.8%), but not significantly. From the third day onwards, the relative mortality decays and with day eight, the differences to the

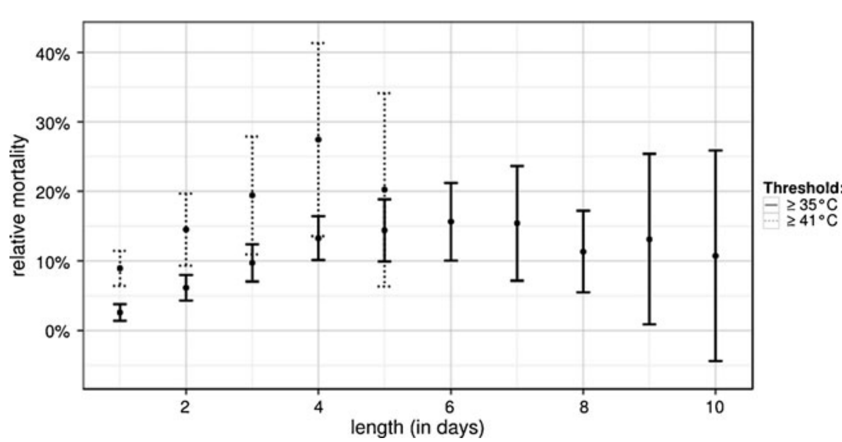

Fig. 6 Development of relative heat-related mortality during heat waves (multiple days in a row with PET of 14 CET ≥35°C (*solid line*, *point*) or ≥41°C (*dashed line*, *triangle*))

baseline are no longer significant. For moderate heat stress, the values are only slightly above the baseline.

On days with slight heat stress a relative mortality below the baseline was found (in the mean of 2.0%, with three significant days), the same applies to the days without thermal stress (1.3%, 4 days), slight (3.1%, 3 days), and moderate cold stress (1.4%, 5 days). Days with strong cold stress do not differ significantly from the baseline. Remarkable is the significantly positive peak around 10 days after a day with slight cold stress that can only be explained by random variations in the data set. The relative mortality after days with extreme cold stress stays significantly above the baseline for 20 days, without a pronounced variation. The mean relative mortality during this 20 days amounts to 0.6%.

Figure 5 does not differentiate whether a day with extreme heat stress is the first or the fifth day of a heat wave. Therefore, Fig. 6 displays the development of mean relative mortality during heat waves of different lengths.

In Fig. 6, the mean relative mortality including confidence intervals during heat waves with a PET at 14 CET ≥35°C (solid line, point) and ≥41°C (dashed line, triangle) is shown. For heat waves with multiple days of PET ≥35°C in a row, the mean relative mortality on the first day is significantly above the baseline (2.6%; CI, 1.4; 3.8) and increases in the following days. The maximum is reached at the sixth day with 15.6% (CI, 10.1; 21.2), afterwards the mean relative mortality decreases and the confidence intervals become very large due to the low number of events (10-day events occurred nine times in the period of examination). During heat waves with PET ≥41°C, mortality increases also with the length of the event. On the first day, mean values of 8.9% (CI, 6.4; 11.5) were found and the maximum is reached on the fourth day with 27.4% (CI, 13.6; 41.3).

Very high relative mortality values in Vienna occur on and after days with moderate, strong, and extreme heat stress. Since our analysis focuses on heat stress and since extreme cold stress is not a problem in the summer months, there exists a large range from strong cold stress to slight warm stress with a relative mortality below the baseline. Hence, only four levels are examined in detail in the following: the three heat stress levels and a large level of thermal acceptability with a PET <29°C. Additionally, to remove the day to day variability and since the mortality of some levels rises on the second day, running 2-day mean values of the mortality are used.

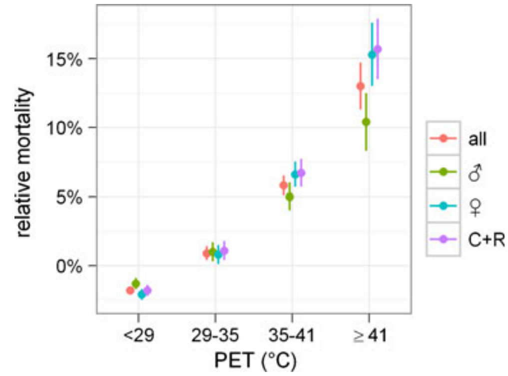

Fig. 7 Relative mortality including confidence intervals for different thermophysiological stress levels and different investigation groups for the period 1970 to 2007

The mean mortality for the four relevant levels is shown in Fig. 7. For the overall mortality (all causes of death and men and women together) the mean relative mortality on days with thermal acceptability (PET <29°C) is significantly negative (−1.8%; CI, −2.1; −1.5). In the heat stress levels, the mean relative mortality is higher in all cases, with 0.9% (CI, 0.4; 1.4) on days with moderate heat stress, 5.8% (CI, 5.0; 6.5) on days with strong heat stress, and 13.0% (CI, 11.1; 14.7) on days with extreme heat stress.

Besides the overall mortality, the mean mortality for men, women, and the cause of death group cardiovascular and respiratory diseases (C+R) is shown in Fig. 7. A slightly higher sensitivity to heat stress was found for women compared to men and C+R compared to the overall mortality. The mean relative mortality for all groups and levels is summarized in Table 2.

The mean values for the period 1970 to 2007 as shown in Fig. 7 and Table 2 were not constant during the period of investigation. As shown in Fig. 8, the variability between the years is very high and in all levels a trend towards lower values exists, as highlighted by the linear regression line,

Table 2 Mean relative mortality and confidence interval (percent) between 1970 and 2007 for different investigation groups (*C+R* cardiovascular and respiratory diseases) and different levels of thermophysiological stress (Muthers et al. 2010b)

Group	PET <29°C	PET 29–35°C	PET 35–41°C	PET ≥41°C
All causes	−1.8±0.3	0.9±0.5	5.8±0.7	13.0±1.7
Women	−2.1±0.4	0.8±0.7	6.6±0.9	15.3±2.3
Men	−1.3±0.4	1.0±0.7	5.0±1.0	10.4±2.1
C+R	−1.8±0.4	1.1±0.7	6.7±1.0	15.7±2.2
Women	−2.0±0.7	1.1±1.2	7.3±1.6	17.2±3.6
Men	−0.8±0.8	1.0±1.4	5.7±1.9	12.6±3.9

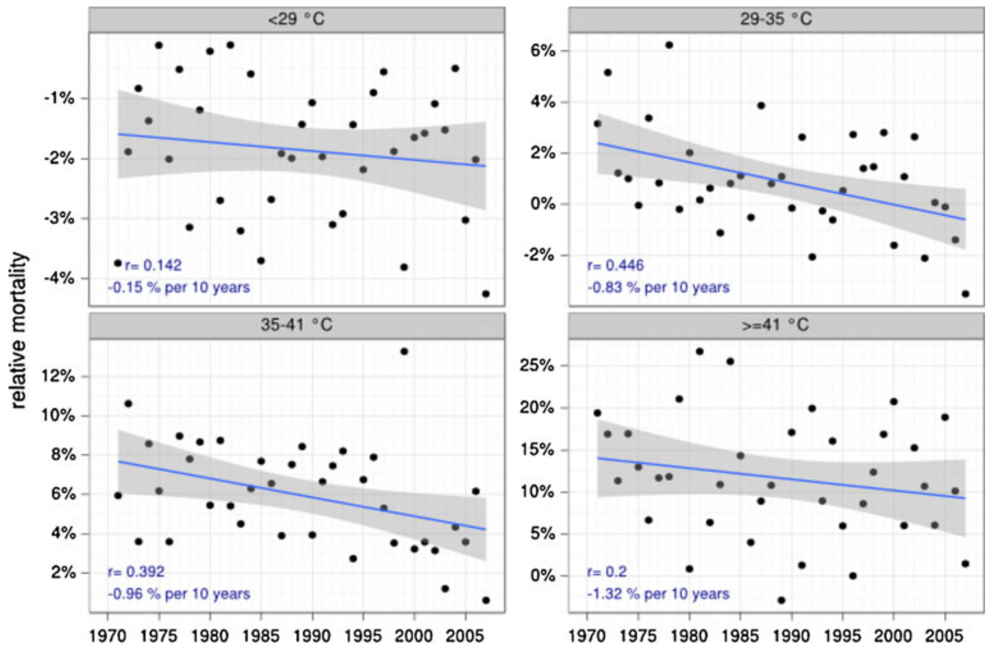

Fig. 8 Mean relative mortality per year for different levels of thermal heat stress. The *blue line* represents the fitted linear regression, including confidence interval. Additionally, the slope of the regression line (in percent per 10 years) and the Pearson correlation coefficient is shown in the lower left corner of each plot (according Muthers et al. 2010b)

including confidence interval. This trend is significant in the levels of moderate and strong heat stress. For moderate heat stress, the mean relative mortality decreases by −0.83% per 10 years (CI, −0.68; −0.97; p value of the slope of the regression line 0.006; Mann–Kendall, 0.018) and for days with strong heat stress by −0.96% (CI, −0.77; −1.16; p value, 0.016; Mann–Kendall, 0.006).

Responsible for this decrease is mainly a change in the sensitivity of women. The analysis for women reveals significant trends in the levels of moderate and strong heat stress, whereas the decrease for men is only significant in the levels of moderate heat stress and only on a significance level of 90%. For the C+R group, significant trends for moderate and strong heat stress were found too.

For an assessment of the absolute impact of the different heat stress levels during the summer, the mean relative mortality per level has to be combined with the number of occurrences for each level. This is done by a multiplication of the mean number of days (including confidence interval) and the mean relative mortality (including confidence interval). The product, the cumulated heat-related mortality describes the cumulated deviations of the relative mortality from the baseline for 1 year.

As seen in Fig. 9, the mean number of days for each level in the period of examination shows the opposite pattern compared to the mean relative mortality: the level with the highest occurrence is characterized by the lowest relative mortality and vice versa.

Based on the whole period of investigation, the days with strong heat stress are responsible for the majority of deaths (167%; CI, 132; 203), followed by the days with extreme heat stress (96%; CI, 62; 136). The days with thermal acceptability are on the other site characterized by pronounced negative cumulated heat-related mortality that does not compensate for the heat-related mortality. The same relation was found for men, women, and C+R. On a decadal basis (not shown), the days with strong heat stress become less important due to the decreasing relative mortality of this level. For the period 2001–2007, the level of extreme heat stress obtains the highest cumulated heat-related mortality.

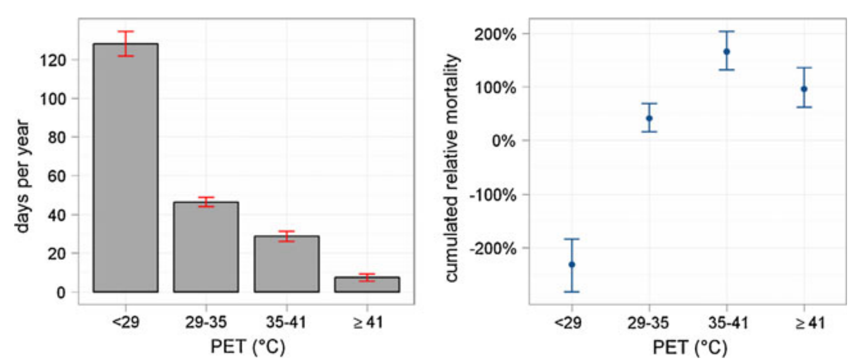

Fig. 9 Mean number of days per year and level of thermal stress (*left side*) and mean cumulated heat-related mortality (*right side*)

5 Discussion

A significant relationship exists between heat stress and the mortality of the population of Vienna, but the sensitivity changed in the last decades. The sensitivity changes are only significant in the levels of moderate and strong heat stress, but not in the level of extreme heat stress. The absence of significant trends in this level may be due to the fact that the absolute and mean thermal stress values increase in this level during the period of investigation contrary to the other heat stress levels.

Sensitivity changes were also found for other regions (Davis et al. 2003; Koppe 2005; Tan et al. 2007; Donaldson and Keatinge 2008). To some extent the decrease of sensitivity can be explained by the spread of air conditioning and fans (Braga et al. 2001; Davis et al. 2003; Donaldson et al. 2003).

A great advantage of this analysis was the use of a long period of investigation, which enabled the identification of long-term trends. Trends in the mortality data can be influenced by different demographic factors. These influences were removed by the use of a complex approach to calculate the baseline mortality and extract the relative mortality. Nevertheless, the demographic factors are of importance since they determine the height of the baseline. In the 1970s, Vienna's society had a large amount of older people and in the average, about 80 deaths per day occurred. In the following decades, the dependency rate changed towards more balanced values and the daily deaths decreased. For the future, the dependency rate is predicted to rise again (Statistik Austria 2009) and will reach the level of the 1970s in the year 2040. This is of importance for the absolute mortality values which are masked by the relative mortality in this study.

Additionally, the increase of heat stress situations is likely and Muthers et al. (2010b) therefore assessed the impact of climate change on the heat-related mortality in the twenty-first century by the use of regional climate model data. In any case, with and without long-term adaptation, an increase in the heat-related mortality is likely to occur mainly due to the days with extreme heat stress. Hence, further adaptation measurements are needed. HHWS can build a promising tool to reduce the impact heat waves.

A topic discussed, which is controversial, is the existence of short-term displacement of mortality (harvesting effect). In this analysis, no evidence for the existence of this effect was found, but it was also not the focus of this work. In Fig. 5, a short-term displacement could be visible by a significant decrease of the mortality curve below the baseline, which was not found. Nevertheless, this topic should be analyzed with appropriate means more in details.

Moreover, other confounding variables, e.g., air pollution are known to be connected to the heat-related mortality (Hajat et al. 2002; O'Neill et al. 2005); however, air quality data suffers from the lack of long-term time series with acceptable data quality. Another important factor for the recovery after heat stress is the nighttime conditions (Nastos and Matzarakis 2008). An additional factor can be the location of the used station which is affected by the urban climate.

The first part of the analysis showed that the cold-related mortality is characterized by a longer time lag between exposure and reaction, and that the days with extreme cold stress are only characterized by a slight, but significant, higher mortality (+0.6%). Nevertheless, due to the large number of days with extreme cold stress (~40%) in Vienna, this fact is of particular importance, also in the context of climate change.

6 Conclusion

The use of long-term climate and mortality data, in combination with human biometeorological methods, which are more reliable because they include thermophysiology, revealed a clear relationship between heat stress and mortality. In addition, the long periods allow the determination of long-term trends in the sensitivity concerning heat stress.

The results show that further adaptation is needed to mitigate the impact of heat stress on the human health, especially in the context of climate change. Some positive developments, the long-term decrease in the thermal sensitivity, were already found for the past decades. The results build the basis for an implementation of a heat health warning system for Vienna. Further research should focus on the nighttime conditions, which are of particular importance for the regeneration of the human body after heat load. The use of human biometeorological parameters as well as the inclusion of short-term adaptation is recommended to achieve a realistic characterization of the thermal environment affecting the human body.

Acknowledgement The authors would like to thank the Austrian Federal Ministry for Science and Research for funding this study. Thanks to Ivy Shiue for proofreading the manuscript.

References

Barnett AG (2007) Temperature and cardiovascular deaths in the US elderly: changes over time. Epidemiology 18:369–372

Böhm R (2009) Geändertes Umfeld durch Klimawandel?/Modified environment due to climate change? Wildbach- und Lawinenverbau 163:34–50

Braga F, Zanobetti A, Schwartz J (2001) The time course of weather-related deaths. Epidemiology 12:662–667
Chau P, Chan K, Woo J (2009) Hot weather warning might help to reduce elderly mortality in Hong Kong. Int J Biometeorol 53:461–468
Cleveland WS, Devlin SJ (1988) Locally weighted regression: an approach to regression analysis by local fitting. J Am Stat Assoc 83:596–610
Davis RE, Knappenberger PC, Michaels PJ, Novicoff WM (2003) Changing heat-related mortality in the United States. Environ Health Perspect 111:1712–1718
Díaz J, García R, de Castro VF, Hernández E, López C, Otero A (2002) Effects of extremely hot days on people older than 65 years in Seville (Spain) from 1986 to 1997. Int J Biometeorol 46:145–149
Díaz J, García-Herrera R, Trigo RM, Linares C, Valente MA, De Miguel JM, Hernández E (2006) The impact of the summer 2003 heat wave in Iberia: how should we measure it? Int J Biometeorol 50:159–166
Donaldson GC, Keatinge WR (2008) Direct effects of rising temperatures on mortality in the UK. In: Kovats RS (ed) Health effects of climate change in the UK 2008: an update of the Department of Health report 2001/2002. Department of Health, UK, pp 81–90
Donaldson GC, Keatinge WR, Nayha S (2003) Changes in summer temperature and heat-related mortality since 1971 in North Carolina, South Finland, and Southeast England. Environ Res 91:1–7
Flynn A, McGreevy C, Mulkerrin EC (2005) Why do older patients die in a heat wave. Int J Med 98:227–229
Fouillet A, Rey G, Wagner V, Laaidi K, Empereur-Bissonnet P, Le Tertre A, Frayssinet P, Bessemoulin P, Laurent F, De Crouy-Chanel P, Jougla E, Hémon D (2008) Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave. Environ Epidemiol 37:309–317
Gisser R (2005) Recent demographic trends in Austria until 2004. In: Vienna yearbook of population research. Verlag der Österreichischen Akademie der Wissenschaften, Vienna, pp. 237–242
Gosling SN, McGregor GR, Páldy A (2007) Climate change and heat-related mortality in six cities part 1: model construction and validation. Int J Biometeorol 51:525–540
Grass D, Cane M (2008) The effects of weather and air pollution on cardiovascular and respiratory mortality in Santiago, Chile, during the winters of 1988–1996. Int J Climatol 28:1113–1126
Hajat S, Kovats RS, Atkinson RW, Haines A (2002) Impact of hot temperatures on death in London: a time series approach. J Epidemiol Commun H 56:367–372
Hajat S, Kovats RS, Lachowycz K (2007) Heat-related and cold-related deaths in England and Wales: who is at risk? Occup Environ Med 64:93–100
Helsel DR, Hirsch RM (2002) Statistical methods in water resources. U.S. Geological Survey, techniques of water-resources investigations book 4, chapter A3. http://www.epa.gov/earth1r6/6pd/qa/qadevtools/mod4references/supplemental/twri4a3-new.pdf Accessed 16 June 2009
Heudorf U, Meyer C (2005) Gesundheitliche Auswirkungen extremer Hitze—am Beispiel der Hitzewelle und der Mortalität in Frankfurt am Main im August 2003. Gesundheitswesen 67:369–374
Höppe P (1984) Die Energiebilanz des Menschen. Münchener Universitätsschriften, Meteorol. Inst., Wiss. Mitt. 49
Höppe P (1993) Heat balance modelling. Experientia 49:741–746
Hutter H, Moshammer H, Wallner P, Leitner B, Kundi M (2007) Heatwaves in Vienna: effects on mortality. Wien Klin Wochenschr 119:223–227
Iñiguez C, Ballester F, Ferrandiz J, Pérez-Hoyos S, Sáez M, López A (2010) Relation between temperature and mortality in thirteen Spanish cities. Int J Environ Res Public Health 7:3196–3210
Jendritzky G (1990) Methodik zur räumlichen Bewertung der thermischen Komponente im Bioklima des Menschen—Fortgeschriebenes Klima-Michel-Modell. Beitr Akad f Raumforsch u Landschaftspl 114:7–69
Jendritzky G, Sönning W, Swantes HJ (1979) Ein objektives Bewertungsverfahren zur Beschreibung des thermischen Milieus in der Stadt- und Landschaftsplanung ("Klima-Michel-Modell"). Beitr Akad f Raumforsch u Landschaftspl 28:1–85
Kalkstein LS, Smoyer KE (1993) The impact of climate change on human health: some international implications. Cell Mol Life Sci 49:969–979
Keatinge WR (2002) Winter mortality and its causes. Int J Circumpolar Health 61:292–299
Keatinge WR, Donaldson GC, Cordiolo E, Martinelli M, Kunst AE, Mackenback JP, Nayha S, Vuori I (2000) Heat-related mortality in warm and cold regions of Europe: observational study. Brit Med J 321:670–673
Koppe C (2005) Gesundheitsrelevante Bewertung von thermischer Belastung unter Berücksichtigung der kurzfristigen Anpassung der Bevölkerung an die lokalen Witterungsverhältnisse. Dissertation, Albert-Ludwigs-University of Freiburg (Germany)
Koppe C, Becker P (2009) Comparison of operational heat health warning systems in Europe. In: Matthies F, Menne B (eds) Preparedness and response to heat waves in Europe, from evidence to action. Public health response to extreme weather events. WHO Regional Office for Europe, Copenhagen
Koppe C, Jendritzky G (2005) Inclusion of short-term adaptation to thermal stresses in a heat load warning procedure. Meteorol Z 14:271–278
Koppe C, Jendritzky G, Pfaff G (2003) Die Auswirkungen der Hitzewelle 2003 auf die Gesundheit. DWD Klimastatusbericht 2003:152–162
Kovats S, Shakoor H (2008) Heat stress and public health: a critical review. Annu Rev Public Health 29:41–55
Laaidi M, Laaidi K, Besancenot J (2006) Temperature-related mortality in France, a comparison between regions with different climates from the perspective of global warming. Int J Biometeorol 51:145–153
Lin T, Matzarakis A, Hwang R (2010) Shading effect on long-term outdoor thermal comfort. Build Environ 45:213–221
Matzarakis A, Mayer H (1996) Another kind of environmental stress: thermal stress. WHO Newsletter 18:7–10
Matzarakis A, Rutz F, Mayer H (2007) Modelling radiation fluxes in simple and complex environments—application of the RayMan model. Int J Biometeorol 51:323–334
Matzarakis A, Rutz F, Mayer H (2010) Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. Int J Biometeorol 54:131–139
Mayer H, Höppe P (1987) Thermal comfort of man in different urban environments. Theor Appl Climatol 38:43–49
Muggeo VM, Hajat S (2009) Modelling the non-linear multiple-lag effects of ambient temperature on mortality in Santiago and Palermo: a constrained segmented distributed lag approach. Occup Environ Med 66:584–591
Muthers S, Matzarakis A, Koch E (2010a) Summer climate and mortality in Vienna—a human-biometeorological approach of heat related mortality during the heat waves in 2003. Wien Klin Wochenschr 122:525–531
Muthers S, Matzarakis A, Koch E (2010b) Climate change and mortality in Vienna—a human biometeorological analysis based on regional climate modeling. Int J Environ Res Public Health 7:2965–2977
Nastos PT, Matzarakis A (2008) Human-biometeorological effects on sleep disturbances in Athens, Greece: a preliminary evaluation. Indoor Built Environ 17:535–542
O'Neill M, Hajat S, Zanobetti A, Ramirez-Aguilar M, Schwartz J (2005) Impact of control for air pollution and respiratory

epidemics on the estimated associations of temperature and daily mortality. Int J Biometeorol 50:121–129

Pascal M, Laaidi K, Ledrans M, Baffert E, Caserio-Schönemann C, Le Tertre A, Manach J, Medina S, Rudant J, Empereur-Bissonnet P (2006) France's heat health watch warning system. Int J Biometeorol 50:144–153

Robine JM, Cheung SL, Le Roy S, Van Oyen H, Herrmann FR (2007) Report on excess mortality in Europe during summer 2003. EU Community Action Programme for Public Health: Grant Agreement 2005114

Statistik Austria (2009). Bevölkerungsvorausschätzung 2008–2050. Statistik Austria

Tan J, Zheng Y, Tang X, Guo C, Li L, Song G, Zhen X, Yuan D, Kalkstein A, Chen H (2007) Heat wave impacts on mortality in Shanghai, 1998 and 2003. Int J Biometeorol 51:193–200

WHO (2003) The health impacts of 2003 summer heat waves—Briefing note for the Delegations of the 53rd session of the WHO Regional Committee for Europe, 8 Sept 2003, Vienna

WHO (2004) Heat-waves: risks and responses. World Health Organization, Copenhagen