

ISSN 1732-4254 quarterly

BULLETIN OF GEOGRAPHY. SOCIO-ECONOMIC SERIES

journal homepages:
<http://www.bulletinofgeography.umk.pl>
<http://versita.com/bgss>

The accuracy of the heat index to explain the excess of mortality and morbidity during heat waves – a case study in a mediterranean climate

Ana Monteiro^{1, CDFMR}, Vânia Carvalho^{2, CDFMR}, Sara Velho^{3, CDFMR}, Carlos Sousa^{4, CDFMR}

University of Porto, Department of Geography, Institute of Public Health, Research Centre for Territory, Transport and Environment (CITTA), Geography and Regional Planning Centre (CEGOT), Via Panorâmica s/nº, 4150-564 Porto, Portugal;

¹phone: +351 919 698 402, fax: +351 226 077 150, e-mail: anamonteirosousa@gmail.com (*corresponding author*);

²phone: +351 918 235 406, fax: +351 226 077 150, e-mail: carvalho.vania@gmail.com; Institute of Public Health,

³phone: +351 916 904 594, fax: +351 226 077 150, e-mail: sara.ip.velho@gmail.com;

⁴phone: +351 919 541 149, fax: +351 226 077 150, e-mail: miguelsousa83@gmail.com

Monteiro, A., Carvalho, V., Velho, S. and Sousa, C., 2013: The accuracy of the heat index to explain the excess of mortality and morbidity during heat waves – a case study in a mediterranean climate. In: Szymańska, D. and Chodkowska-Miszczuk, J. editors, *Bulletin of Geography. Socio-economic Series*, No. 20, Toruń: Nicolaus Copernicus University Press, pp. 71–84, DOI: 10.2478/bog-2013-0012

Abstract. The aim of this contribution was to evaluate the accuracy of a well known human comfort index, the heat index, to anticipate the effects of the July 2006 heat wave in mortality (all causes) and morbidity (all causes, respiratory and circulatory disease). Our assessment was done to all citizens, to people of the 75+ cohort and to each gender, in Porto. For further statistical analysis, we calculated an expected number of admissions by averaging the admissions recorded during the comparison period. The 95% confidence interval was calculated, using a standard method based on the t-distribution, for differences between independent means with different population variances, using the Levene test to evaluate the variance's homogeneity. During the 2006 heat wave, a 52% mortality excess was registered relatively to the expected mortality ($p < 0.001$), for all cohorts of the population. The admissions excess for all ages included the admissions due to respiratory diseases ($p < 0.029$), pneumonia ($p < 0.001$) and chronic obstructive pulmonary disease ($p < 0.001$). For the 75+ cohort, the admissions due to respiratory diseases ($p < 0.017$), pneumonia ($p < 0.001$) and heart failure ($p < 0.610$) were also statistically high. The obtained results confirm that the heat index is a truthful method to anticipate the negative impacts of heat waves in human health even in climate contexts adapted to hot summers like at Porto – a Mediterranean tempered climate. The impacts of July 2006's heat wave in the increase of mortality (all causes) and in respiratory morbidity (all population and 75+ cohort) was evident.

Article details:

Received: 10 September 2012

Revised: 28 October 2012

Accepted: 04 January 2013

Key words:

Mediterranean area,
heat wave, heat index,
mortality, respiratory disease,
circulatory disease.

Contents:

| | |
|--|----|
| 1. Introduction | 72 |
| Materials and methods | 73 |
| 3. Research Results | 74 |
| 3.1. Total mortality and morbidity excess | 74 |
| 3.2. Excess morbidity by gender | 74 |
| 3.3. Excess morbidity for the 75+ cohort | 74 |
| 3.4. Excess morbidity the 75+ cohort by gender | 76 |
| 4. Discussion | 77 |
| 4.1. Number of heat wave days and daily temperatures | 77 |
| 4.2. Mortality/morbidity excess (all-ages) | 77 |
| 4.3. Morbidity excess by gender (all-ages) | 78 |
| 4.4. Morbidity excess in the 75+ cohort | 79 |
| 4.5. Morbidity excess in the 75+ cohort by gender | 80 |
| 5. Conclusions | 80 |
| Acknowledgements | 81 |
| References | 81 |

1. Introduction

All 21st climate scenarios produced by several global climate models anticipate a frequency increase in the duration and intensity of the heat waves (Plan-ton et al., 2008; Monteiro et al., 2012a, 2012b, 2012c) for temperate zone and in special for Mediterranean regions like Porto (Dessai, 2002, 2003; Díaz et al., 2002a, 2002b, 2006; Meehl, Tebaldi, 2004; Monteiro et al., 2012c).

Having this climate projections in mind, the negative impacts in human health caused by heat waves have been highly investigated either by climatologists or public health experts (Monteiro et al., 2011, 2012a, 2012b, 2012c) because the human adaptation capacity to adapt to this extreme events is still considerably low. The consequences of the several heat waves that occurred after the 90's in Europe (Rooney et al., 1998; Calado et al., 2004; Grize et al., 2005; Fouillet et al., 2006; D'Ippoliti et al., 2010; Monteiro et al., 2012a, 2012c), in United States (Semenza et al., 1999; Weisskopf et al., 2002) and in other places (Tan et al., 2007) in mortality and morbidity were highly investigated and all the conclusions claim for a greater concern with the need of innovative tools to anticipate the human health risks during extreme climatic episodes.

The research carried out on this particularly problematic had roughly two different approaches:

i) use of temperature as an isolated climatic variable and its effects in mortality and morbidity (Saez et al., 1995; Ballester et al., 1997; Hajat et al., 2002);
 ii) use of some climatic elements combination, such as temperature and relative humidity (Michelozzi et al., 2006; Schiffano et al., 2009; Almeida et al., 2010; Monteiro et al., 2012a, 2012c) and its consequences in human health deterioration. Steadman (1979a, 1979b, 1984) was an important example of these last ones, which constituted a remarkable starting point for the creation of the heat index, later on adjusted by the United States National Weather Service as an anticipation warning system for extreme heat events.

One subjacent concern to the majority of this type of investigation lies in the identification of the main vulnerable groups, namely, the elderly population (Díaz et al., 2002a), as it has a limited adaptation ability towards thermal stress factors (Jendritzky, 1993), requiring the creation of adequate preventive measures against heat waves. The negative impacts of intense heat in the elderly people by rising already existing physical weaknesses and sometimes leading even to death is recognised by several studies done in France 2006's heat wave (Fouillet et al., 2006; Rey et al., 2007), in Vienna (Hutter et al., 2007), in Holland (Huynen et al., 2001), in Spain (Borrel et al., 2006) and at Porto (Monteiro et al., 2011, 2012a, 2012b, 2012c). In the

majority of the studied cases the presence of chronic diseases are triggered and aggravated by the existing thermal discomfort during heat waves (Fouillet et al., 2006). Moreover, the individual vulnerability during extreme hot events is a composite equation where the age and the pre-existing diseases should be considered in combination with a vast list of other variables like gender (McGeehin, Mirabelli, 2001; Monteiro et al., 2012a).

During heat waves events the effects in the health of individuals living in Mediterranean climates of Europe, special in cities where the Urban Heat Island effect is strong (Rooney et al., 1998; Gaffin et al., 2008; Metzger et al., 2010) and the ageing of the population is increasing like at Portugal (Almeida et al., 2010), it is very important to give also a special focus to the individual vulnerability, which means: (a) to estimate the impacts of the 2006 heat wave, according to the heat index, in terms of total mortality, total morbidity and morbidity due to circulatory and respiratory causes, in the Great Metropolitan Area of Porto (Portugal); (b) to identify the most vulnerable groups to the heat wave impacts, comparing the excess of mortality and morbidity for the total population, for the population by gender and for the population of the 75+ cohort.

2. Materials and methods

Study areas: Porto city, the hub of a Great Metropolitan Area (GAMP), represents the second larger Portuguese urbanized area. The location in the North-Western area of the Iberian Peninsula (41°N) close to the Atlantic Ocean and well exposed to the

arrival of the zonal westerly's after a long journey over the ocean from the east coast of the USA, explains the Mediterranean tempered climate context with mild and rainy winters and hot and dry summers. The GAMP has, approximately, 1.6 million people who, spatially distributed, represent the population density of 1,115 inhabitants per 1 km² (Instituto Nacional de Estatística, 2001).

Health and climate data: The health data analysed was obtained in Instituto Nacional de Estatística databases (mortality for January to December 2002–2007) and in Biostatistics and Medical Informatics and Health System's Central Administration databases (daily admissions due to all causes, to circulatory diseases and to respiratory diseases using All Patient Diagnosis Related Groups – Version 21 (ACSS, 2011)). The morbidity data were explored in four perspectives: i) all ages; ii) all ages by gender; iii) the cohort 75+; iv) the cohort 75+ by gender.

The heat index calculation, defined as an individually perceived air temperature given the humidity, was done with Porto's daily meteorological variables (Meteorological Observatory of Porto Serra do Pilar). The heat index measures the evaporative heat between a typical human and the environment, one of the appropriate measures to determine the effect of heat in the body, and better than temperature itself. The original estimation of the human-perceived equivalent temperature, proposed by Steadman (1979), comprised a group of parameters' calculations that were considerably simplified by Rothfus' model (1990), assuming several fixed magnitudes to some parameters like vapour pressure or dimensions of a human skin surface or clothing cover or clothing resistance to heat transfer or activity, etc.

$$HI = -42.379 + (2.04901523 \times T) + (10.14333127 \times R) - (0.22475541 \times T \times R) - (6.83783 \times 10^{-3} \times T^2) - (5.4481717 \times 10^{-2} \times R^2) + (1.22874 \times 10^{-3} \times T^2 \times R) + (8.5282 \times 10^{-4} \times T \times R^2) - (1.99 \times 10^{-6} \times T^2 \times R^2)$$

Where:

T = air temperature °C;

R = relative humidity %.

The calculation of the HI allows the classification of temperature (°C) according to four differ-

ent dangerousness levels, to which possible physical symptoms correspond (National Weather Service

Weather Forecast Office Summer Weather Safety and Survival Heat Index, 2011): (a) extreme danger ($HI \geq 54^{\circ}C$) – heat stroke or sunstroke; (b) danger ($41 < HI < 54$) – sunstroke, muscle cramps, and/or heat exhaustion; heatstroke due to prolonged exposure and/or physical activity; (c) extreme caution ($32 < HI < 41$) – sunstroke, muscle cramps, and/or heat exhaustion due to possible prolonged exposure and/or physical activity; (d) caution ($27 < HI < 32$) – possible fatigue due to prolonged exposure and/or physical activity.

Statistical methods: An *expected number of admissions* was calculated by determining the average number of admissions (2002 to 2007, except for 2006) recorded during three comparison weeks: the week previous to the heat wave (from July 3 to 10), the week of the heat wave (from July 11 to 18) and the following week (from July 19 to 26). From the *number of admissions observed* during the heat wave (from 11 to 18 July 2006) the *expected number of admissions* was subtracted to determine an excess or deficit in hospital admissions during the heat wave.

The 95% confidence interval was calculated, using the standard method based on the *t*-distribution for differences between independent means with different population variances, using the Levene test to evaluate the variance's homogeneity.

3. Research Results

3.1. Total mortality and morbidity excess

During the July 2006 heat wave, Porto registered an excess of 107 deaths which corresponds to an increase of 52% ($p < 0.026$) relatively to the expected mortality. At that time, the morbidity data due to all-causes did not evidence a statistically significant increase ($p < 0.938$).

The morbidity results due to circulatory and respiratory disease during the heat wave were fairly different. Morbidity due to all circulatory diseases did not reveal any statistical significant admission excess ($p < 0.562$). From the studied circulatory pathologies, the admissions due to myocardial infarction ($p < 0.353$) and heart failure ($p < 0.331$) did not reveal the admission excess during the studied extreme climatic episode.

The four hospitals admissions with respiratory diseases during the 2006 July heat wave show an excess of 67 admissions ($p < 0.029$), corresponding to an increase of 49% relatively to the expected respiratory morbidity. Moreover, some respiratory diseases evidence an even higher excess, namely the increase in pneumonia by 86% ($p < 0.001$) and chronic obstructive pulmonary disease by 100% ($p < 0.001$).

3.2. Excess morbidity by gender

Morbidity due to all-causes, like morbidity due to all circulatory causes, myocardial infarction, heart failure and chronic obstructive pulmonary disease did not present the admission excess by gender.

Morbidity due to all respiratory causes presented the admissions excess for the masculine gender by 43% ($p < 0.001$) and for the feminine gender by 58% ($p < 0.036$).

For admissions due to specific respiratory causes, only pneumonia revealed a statistically significant admission excess for the masculine gender ($p < 0.001$).

3.3. Excess morbidity for the 75+ cohort

The total morbidity of individuals from the 75+ cohort, despite revealing a slight increase during the heat wave period (22%), is not statistically significant ($p < 0.156$) for a confidence interval of 95%.

The admission excess in the population of the elderly group during the studied extreme climatic episode occurred for the generality of respiratory (59%, $p < 0.017$), pneumonia (127%, $p < 0.001$), and chronic obstructive pulmonary disease (100%, $p < 0.013$).

Morbidity due to the generality of circulatory diseases, in elderly individuals, during the heat wave remained constant, with just a slight increase by 2%, statistically meaningless ($p > 0.875$). The total circulatory morbidity due to some specific causes, namely, due to acute myocardial infarction (-38%) and heart failure (-15%) decreased during the heat wave period. Morbidity due to vascular accident revealed a slight increase of 8%, however, statistically meaningless ($p < 0.665$).

Table 1. Mortality and internments excess during the heat wave from 11/07/2006 to 18/07/2006, calculated according to the heat index

| Diagnosis | A | B | C | D | E |
|---|-------------|-------|-------|-----------|-------|
| Mortality ^a | All-causes | 313 | 206 | 107 (52%) | 0.026 |
| All-Causes Morbidity (Total) | All-causes | 2,395 | 2,370 | 25 (1%) | 0.938 |
| All-Causes Morbidity (Men) | | 1,034 | 1,072 | -38 (-4%) | 0.813 |
| All-Causes Morbidity (Women) | | 1,361 | 1,266 | 95 (8%) | 0.567 |
| Respiratory Disease (Total) | GDC4 | 204 | 137 | 67 (49%) | 0.029 |
| Respiratory Disease (Men) | | 117 | 82 | 35 (43%) | 0.000 |
| Respiratory Disease (Women) | | 87 | 55 | 32 (58%) | 0.036 |
| Pneumonia (Total) | HDG 89;90 | 41 | 22 | 19 (86%) | 0.000 |
| Pneumonia (Men) | | 24 | 12 | 12 (100%) | 0.001 |
| Pneumonia (Women) | | 17 | 11 | 6 (55%) | 0.064 |
| Chronic Obstructive Pulmonary Disease (Total) | HDG 88 | 24 | 12 | 12 (100%) | 0.001 |
| Chronic Obstructive Pulmonary Disease (Men) | | 13 | 8 | 5 (63%) | 0.089 |
| Chronic Obstructive Pulmonary Disease (Women) | | 11 | 4 | 7 (175%) | 0.070 |
| Circulatory Disease (Total) | GDC5 | 232 | 218 | 14 (6%) | 0.562 |
| Circulatory Disease (Men) | | 111 | 110 | 1 (1%) | 0.933 |
| Circulatory Disease (Women) | | 121 | 108 | 13 (12%) | 0.384 |
| Acute Myocardial Infarction (Total) | HDG | 15 | 19 | -4 (-21%) | 0.353 |
| Acute Myocardial Infarction (Men) | 121;122;123 | 8 | 10 | -2 (-20%) | 0.484 |
| Acute Myocardial Infarction (Women) | | 7 | 9 | -2 (-22%) | 0.542 |
| Heart Failure (Total) | HDG 127 | 16 | 20 | -4 (-20%) | 0.331 |
| Heart Failure (Men) | | 11 | 9 | 2 (22%) | 0.461 |
| Heart Failure (Women) | | 5 | 12 | -7 (-58%) | 0.068 |
| Cerebral Vascular Accident (Total) | HDG 14;15 | 31 | 28 | 3 (11%) | 0.614 |
| Cerebral Vascular Accident (Men) | | 17 | 14 | 3 (21%) | 0.415 |
| Cerebral Vascular Accident (Women) | | 14 | 14 | 0 (0%) | 0.960 |

Explanation: ^a Mortality data by gender not available; GDC – Great Diagnostic Category; HDG – Homogeneous Diagnostic Groups; A – code; B – observed; C – expected; D – excess (95% CI); E – p-value

Source: PTDC/SAU-ESA/73016/2006

Table 2. Mortality and Internments excess in individuals from the 75+ cohort during the heat wave from 11/07/2006 to 18/07/2006, calculated according to the heat index

| Diagnosis | A | B | C | D | E |
|---|-------------|-----|-----|-----------|-------|
| Mortality ^b | All-causes | b | b | b | b |
| All-Causes Morbidity (Total) | All-causes | 484 | 397 | 87 (22%) | 0.156 |
| All-Causes Morbidity (Men) | | 187 | 172 | 15 (9%) | 0.660 |
| All-Causes Morbidity (Women) | | 297 | 224 | 73 (33%) | 0.000 |
| Respiratory Disease (Total) | GDC4 | 113 | 54 | 59 (109%) | 0.017 |
| Respiratory Disease (Men) | | 53 | 28 | 25 (89%) | 0.068 |
| Respiratory Disease (Women) | | 60 | 25 | 35 (140%) | 0.006 |
| Pneumonia (Total) | HDG 89;90 | 25 | 11 | 14 (127%) | 0.000 |
| Pneumonia (Men) | | 12 | 5 | 7 (140%) | 0.001 |
| Pneumonia (Women) | | 13 | 6 | 7 (117%) | 0.011 |
| Chronic Obstructive Pulmonary Disease (Total) | HGD 88 | 12 | 6 | 6 (100%) | 0.013 |
| Chronic Obstructive Pulmonary Disease (Men) | | 5 | 4 | 1 (20%) | 0.488 |
| Chronic Obstructive Pulmonary Disease (Women) | | 7 | 2 | 5 (250%) | 0.153 |
| Circulatory Disease (Total) | GDC5 | 63 | 62 | 1 (2%) | 0.875 |
| Circulatory Disease (Men) | | 27 | 25 | 2 (13%) | 0.678 |
| Circulatory Disease (Women) | | 36 | 37 | -1 (-3%) | 0.893 |
| Acute Myocardial Infarction (Total) | HDG | 5 | 8 | -3 (-38%) | 0.352 |
| Acute Myocardial Infarction (Men) | 121;122;123 | 1 | 3 | -2 (-67%) | 0.149 |
| Acute Myocardial Infarction (Women) | | 4 | 5 | -1 (-20%) | 0.638 |
| Insuficiência Cardíaca (Total) | HDG 127 | 11 | 13 | -2 (-15%) | 0.610 |
| Insuficiência Cardíaca (Men) | | 7 | 4 | 3 (75%) | 0.042 |
| Insuficiência Cardíaca (Women) | | 4 | 8 | -4 (-50%) | 0.146 |
| Cerebral Vascular Accident (Total) | HDG 14;15 | 14 | 13 | 1 (8%) | 0.665 |
| Cerebral Vascular Accident (Men) | | 7 | 5 | 2 (40%) | 0.273 |
| Cerebral Vascular Accident (Women) | | 7 | 8 | -1 (-13%) | 0.774 |

Explanation: ^a Mortality data by gender not available; GDC – Great Diagnostic Category; HDG – Homogeneous Diagnostic Groups; A – code; B – observed; C – expected; D – excess (95% CI); E – p-value

Source: PTDC/SAU-ESA/73016/2006

3.4. Excess morbidity the 75+ cohort by gender

During the July 2006 heat wave, the admission excess due to all causes was observed, having a statistical significance of only 33% ($p < 0.001$) for the feminine gender.

The increase in the number of admissions for the generality of respiratory causes from individuals of the 75+ cohort was observed only for the feminine gender (140%, $p < 0.006$) during the July 2006 hot period.

This admission excess due to pneumonia in the eldest group occurred, for both genders, of

140% ($p < 0.001$) for men and 117% for women ($p < 0.011$).

In the case of the total number of admissions due to heart failure, in this age group a significant increase for men was observed ($p < 0.042$).

The total of admissions due to circulatory causes, acute myocardial infarction and cerebral vascular accident did not reveal significant increases between genders.

4. Discussion

4.1. Number of heat wave days and daily temperatures

The high heat index values seems to be well correlated with the mortality and respiratory admission excess during a heat wave episode, as in July 2006, characterised by the combination of very high temperatures (from 29°C to 37°C) and relative humidity moderate values (42% to 71%). Besides knowing that thermal sensation in man depends on much more factors than the only two considered here – temperature and relative humidity – we concluded that they are adequate to start a thermal discomfort evaluation. Thermal discomfort, which is liable of being observed (3 days of level II and 5 days of level III) can be explained by the combination of both climatic elements, from which the oscillating apparent temperature between 33 to 47°C resulted. The physiological symptoms associated to the level II of the heat index are sunstroke, muscle cramps, heat exhaustion due to possible prolonged exposure and physical activity, while those from the level III are similar to those from the previous level, with the possibility for the occurrence of heat stroke due to prolonged exposure and/or physical activity. In this study, the use of the heat index constituted an important criterion for the anticipation of respiratory morbidity. It is a warning system that combines temperature with humidity, generating the apparent temperature and respective physiological limits (Kovats, Ebi, 2006). Nevertheless, the human *susceptibility* to extreme events involves a puzzle of local bio-geophysical, social and economic variables that modifies considerably the accuracy of an in-

dex to a specific place. Sometimes those who predicts better the negative impacts in human health are the simpler ones that use only pre-established temperature thresholds (Koppe et al., 2003; Monteiro et al., 2012a, 2012c), while in other examples may be those that include synoptic methods associated to specific air masses or those presenting temporal series models (Kysely, 2004).

4.2. Mortality/morbidity excess (all-ages)

The mortality excess of 52% (107 admissions) and the all causes morbidity excess of 1% (25 admissions), as well as the respiratory morbidity excess of 49% (67 admissions) and circulatory morbidity excess of 6% (14 admissions) that occurred at the Great Metropolitan Area of Porto during the July 2006 heat wave, confirm previous results obtained in other places, namely, in chronic obstructive pulmonary disease and pneumonia (Mastrangelo et al., 2007; Monteiro et al., 2011, 2012b). It referred that the ideal conditions for increasing hospital admissions are gathered in the presence of a sequence of at least four consecutive hot and humid days, with humidex index above 40°C. As the author refers, from the physiological point of view, a respiratory difficulty occurs in result of the accumulation of heat and humidity during time. Simultaneously, the evaporative capacity becomes more reduced, making the organism's sudation and cooling function more difficult. Simultaneously, the evaporation capacity becomes smaller, making it difficult for the sudation and organism's cooling functions to occur (Frota, Schiffer, 1987).

Our results are also consistent with previous studies relating heat waves and mortality due to respiratory diseases (Monteiro et al., 2011, 2012a, 2012c). Some authors showed similar results while revealing the mortality excess due to respiratory causes, during heat wave episodes (Kilbourne, 1999; Rey et al., 2007). Similarly, Huynen et al. (2001) showed a clear relation between the respiratory mortality increase and different heat waves registered in Holland and Hertel et al. (2009) during the 2003 heat wave in Germany. Almeida et al. (2010), while studying the effect of apparent temperature in daily mortality, verified that during a hot season the increase of 1°C in daily average apparent temperature corresponded to the increase of 2.7% in respiratory causes mortality.

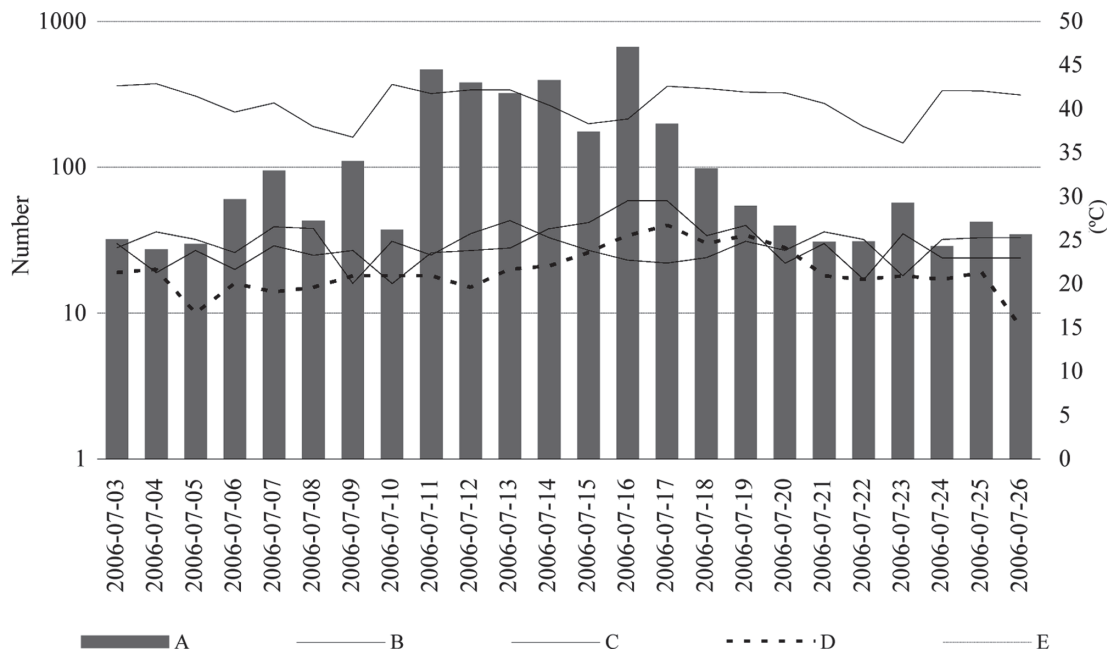


Fig. 1. Number of deaths and admissions for the total population occurred during the extreme heat event (from 11 to 18 July 2006), during the previous week (from 03 to 10 July 2006) and the following week (from 19 July to 26 July 2006)

Explanation: A – heat index; B – deaths, C – admissions (all-causes); D – respiratory admissions; E – circulatory admissions

Source: PTDC/SAU-ESA/73016/2006

4.3. Morbidity excess by gender (all-ages)

The significant admission excess for both genders during the 2006 heat wave, characterised by a high apparent temperature, was perceptible for the generality of the respiratory diseases. In pneumonia admissions, only the masculine gender revealed the hospital admission increase in relation to what would have been expected.

In the generality of circulatory diseases and admissions due to cerebral vascular accidents, a significant increase was observed neither for the total of admissions nor for admissions by gender, relatively to the expected admissions during the heat wave. The admissions due to myocardial infarction and heart failure suffered a decrease. These results seem to agree with other works which highlight a sub-dimensioning of circulatory causes. Studies made in London (Kovats, Ebi, 2006), Veneto (Mastrangelo et al., 2007), Chicago (Semenza et al., 1996; Whitman et al., 1997), Madrid (Linares, Díaz, 2007) and

Holland (Huynen et al., 2001) suggest that there is a short time gap between the exposure to heat and the death due to circulatory diseases. Therefore, the immediate effect of the heat in the human organism will contribute towards the reduction of the individual's hospitalisation.

Our results do not allow a clear distinction between the heat wave's effects by gender and for the generality of the population independently of age, except for the admission excess due to pneumonia for the masculine gender. Other studies (Ellis, Nelson, 1975, Ellis et al., 1975) regarding the evaluation of the effects in mortality in New York in the decade of the 1970s, do also refer the non-observance of differences between genders. However, the mortality excess in France during the 2003 heat wave (Pirard et al., 2005) and in Chicago during the 2005 heat wave (Whitman et al., 1997) were higher among women. Taking into account the differences between the results, the study's consensuality about the effects of heat waves by gender is still not recognised (Basu, Samet, 2002).

4.4. Morbidity excess in the 75+ cohort

Morbidity due to all causes presents an observed admission increase of 22% relatively to the expected in this age group, even though its significance level is reduced.

The results from this study also revealed a significant admission increase for the generality of respiratory diseases (109%), pneumonia (127%) and chronic obstructive pulmonary disease (100%) in the 75+ cohort during the heat wave period.

The hospital admission excess for individuals in this age group due to all circulatory causes, myocardial infarction, heart failure and cerebral vascular accident was not observed. The number of myocardial infarctions and heart failure during the July

2006 heat episode revealed a decrease. This morbidity behaviour in the most fragile individuals, such as the elderly, contributes to corroborate the idea that the intense heat will potentiate immediate death in individuals susceptible to the development of circulatory diseases (Mastrangelo et al., 2007). The heat wave episodes negative effects are more evident in the aged groups, due especially to the impact of temperature in the increase of the blood viscosity, which may produce thrombosis and a deficit in the thermoregulation function (Keatinge et al., 1986). However, other admission causes, such as the respiratory causes, characterised by a larger lag period between the development of the extreme heat episode and the effect produced in the human body evidence a higher vulnerability in individuals from the 75+ cohort.

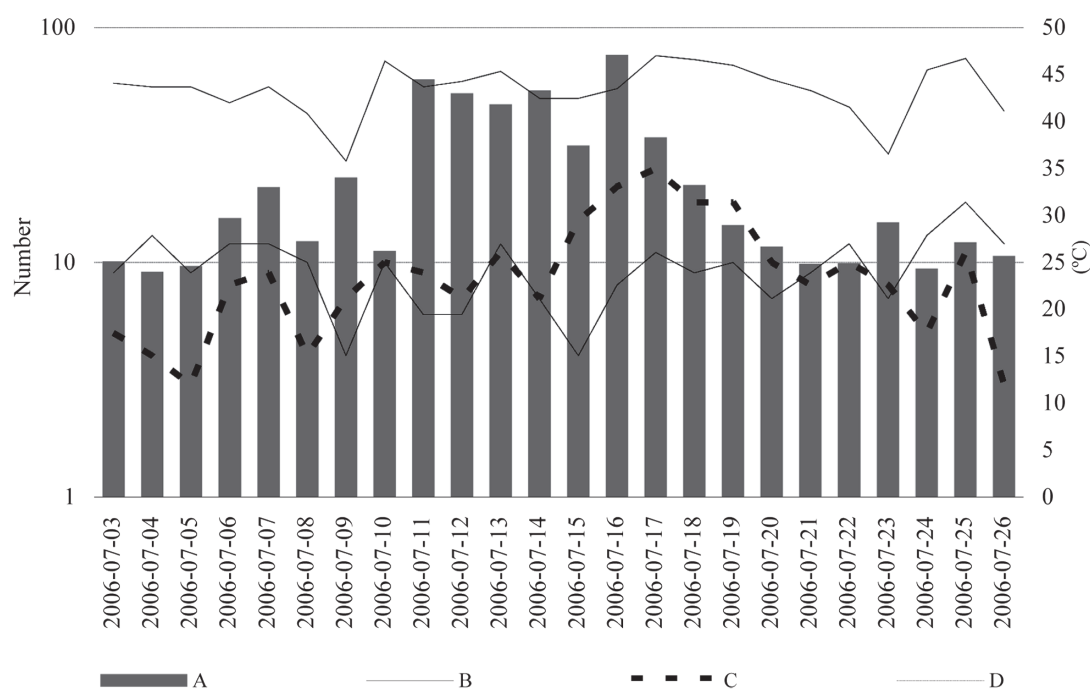


Fig. 2. Number of deaths and admissions in the population with age equal and above 75 years, occurred during the extreme heat event (from 11 to 18 July 2006), during the previous week (from 03 to 10 July 2006) and the following week (from 19 July to 26 July 2006)

Explanation: A – heat index; B – admissions (all-causes); C – respiratory admissions; D – circulatory admissions

Source: PTDC/SAU-ESA/73016/2006

4.5. Morbidity excess in the 75+ cohort by gender

The aged (75+ cohort) morbidity due to all causes is statistically significant for females. Numerous studies show also that the elderly women are the group with the highest mortality proportion in extreme heat situations (Klinenberg, 2002; Whitman et al., 1997). However, the women higher life expectancy than men may be one possible explanation for their higher mortality (Fouillet et al., 2006). Nevertheless, in our analysis this argument is not plausible, once we standardized the population by gender. Women from the 75+ cohort registered a significant increase in admissions for the generality of respiratory diseases and pneumonia. The masculine admission excess for this age group was only significant for admissions due to pneumonia and cardiac failure. One possible explanation for the cardiac failure excess in individuals with advanced age can be the fact that the filling during the left ventricular diastole decreases with age, limiting the cardiac debt and the cardiac frequency during a rest or during physical exercise (Schulman et al., 1992; Kenney, 1997). Other possibility is based on the fact that the age also contributes to the smaller activity of cutaneous vessels, limiting the body's capacity to deviate heat from the centre to the skin in moments of intense heat (Rooke et al., 1994). The risk for heart failure in the elderly from the masculine gender can be due to the fact that this group presents inadequate water consumption during high thermal stress conditions due to heat, which contributes towards a lower adaptation (Semenza et al., 1999).

5. Conclusions

The use of the heat index in the Mediterranean tempered climate, reflected similar effects to the extreme heat episodes in the behaviour of mortality and respiratory morbidity (Monteiro et al., 2012c). However, the circulatory morbidity was decreasing, unlike the respiratory mortality and morbidity. This fact suggests the necessity to investigate the consequences of these events according to their pathological causes, even for mortality or morbidity

simultaneously, once they might demand diversified intervention strategies.

This study still allowed the comprehension of some aspects which characterise the populations' individual vulnerability, namely, the differences observed between general population and the elderly population, as well as between men and women.

One of the constraints in this study results from the fact that it did not include mortality data specified by causes, what complicates the comprehension if the statistical insignificance relative to the admissions due to circulatory causes resulted in the mortality increase due to this type of cause. Accordingly, forward studies could try to understand the influence of high apparent days' temperature in the simultaneous behaviour for morbidity and mortality due to circulatory causes.

In conclusion, this study has demonstrated that, in the context of the Mediterranean tempered climate during high apparent temperature days, the mortality due to all causes and the morbidity due to all respiratory causes, pneumonia and chronic obstructive pulmonary disease significantly increased, not only for the 75+ cohort but also for the general population.

For the group including all ages, the differences between genders were not significant, with the exception for the masculine admission superiority in pneumonia.

Women from the 75+ cohort seem to be the population's most vulnerable group during these days, once morbidity due to all causes increased significantly. However, for this age group some significant differences between genders were registered. Women were the most affected by respiratory diseases as men were by heart failure.

The minimisation of vulnerability must include preventive measures which attribute a special importance to risk groups, which implies the knowledge of the local population's characteristics (Michelozzi et al., 2006). The information transmitted to public in general, and to the risk age groups in particular, assumes high importance. Naughton et al. (2002) suggest the necessity of informing the population about the main symptoms of heat in health. In the case of the population's most vulnerable groups, such as the elderly people and patients, it is fundamental to have daily surveillance to their physical conditions and their environmental context, by

family, neighbours or social assistants. The recognition of the effects of heat in health could contribute towards the modification of risk behaviours, as well as the awareness of physical symptoms in relation to heat could contribute to activate faster intervention mechanisms when emergency situations occur.

Acknowledgements

We would like to thank the support of Dr. Fátima Candoso (Health System Central Administration – HSCA), Dr. Fernando Lopes (São João Hospital – SJH) and Project PTDC/SAU-ESA/73016/2006 Research Fellow, Faculty of Medicine, University of Porto (FMUP).

References

- Almeida, S., Casimiro, E. and Calheiros, J.**, 2010: Effects of apparent temperature on daily mortality in Lisbon and Oporto, Portugal. In: *Environmental Health*, 9, (12), pp.1–7. DOI: 10.1186/1476-069X-9-12
- Ballester, F., Corella, D., Perez-Hoyos, S., Sáez, M. and Hervás, A.**, 1997: Mortality as a function of temperature: a study in Valencia, Spain, 1991–1993. In: *International Journal of Epidemiology*, 26, pp. 551–561. DOI: 10.1093/ije/26.3.551
- Basu, R. and Samet, J.**, 2002: Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. In: *Epidemiologic Reviews*, 24, pp. 190–202. DOI: 10.1093/epirev/mxf007
- Bioestatística e Informática Médica e Administração Central do Sistema de Saúde, 2011: The heat index “equation”. National Weather Service Technical Attachment P – Portal de Codificação dos GDH, available at: [portal-codgdh.min-saude.pt/index.php/All_Patient_Diagnosis_Related_Groups_\(AP-DRG\)](http://portal-codgdh.min-saude.pt/index.php/All_Patient_Diagnosis_Related_Groups_(AP-DRG)), DoA: 10 February 2011.
- Borrel, C., Dell’Olmo, M., Rodríguez-Sanz, M., Garcia-Olalla, P., Cayla, J., Benach, J. and Muntaner, C.**, 2006: Socioeconomic position and excess mortality during the heat wave of 2003 in Barcelona. In: *European Journal of Epidemiology*, 21, pp. 633–640. DOI: 10.1007/s10654-006-9047-4
- Calado, R., Nogueira, P., Catarino, J., Paixão, E., Botelho, J., Carreira, M. and Falcão, J.**, 2004: A onda de calor de Agosto de 2003 e os seus efeitos sobre a mortalidade da população portuguesa (The heat wave of August 2003 and its effects on mortality of the Portuguese population – in Portuguese). In: *Revista Portuguesa de Saúde Pública*, 22 (2), pp. 7–20.
- Clarke, J.**, 1972: Some effects of the urban structure on heat mortality. In: *Environmental Research*, 5, pp. 93–104.
- Dessai, S.**, 2002: Heat stress mortality in Lisbon Part I – model construction and validation. In: *International Journal of Biometeorology*, 47, pp. 6–12. DOI: 10.1007/s00484-002-0143-1
- Dessai, S.**, 2003: Heat stress mortality in Lisbon Part II –An assessment of the potential impacts of climate change. In: *International Journal of Biometeorology*, 48, pp. 37–44. DOI: 10.1007/s00484-003-0180-4
- Díaz, J., Garcia, R., Lopez, C. and Jordan, A.**, 2002a: Heat waves in Madrid 1986–1997: effects on the health of the elderly. In: *International Archives of Occupational and Environmental Health*, 75, pp. 163–170. DOI: 10.1007/s00420-001-0290-4
- Díaz, J., Garcia, R., Velasquez de Castro, F., Hernandez, E., Lopez, C. and Otero, A.**, 2002b: Effects of extremely hot days on people older than 65 years in Seville (Spain) from 1986 to 1997. In: *International Journal of Biometeorology*, 46, pp. 145–149. DOI: 10.1007/s00484-002-0129-z
- Díaz, J., Garcia-Herrera, T.R. and Linares, C.**, 2006: The impact of summer 2003 heat wave in Iberia: how should we measure it? In: *International Journal of Biometeorology*, 50, pp. 159–166. DOI: 10.1007/s00484-005-0005-8
- D’Ippoliti, D., Michelozzi, P., Marino, C., Donato, F., Menne, B., Katsouyanni, K., Kirchmayer, U., Analtis, A., Medina-Ramón, M., Paldy, A., Atkinson, R., Kovats, S., Bisanti, L., Schneider, A., Lefranc, A., Iñiguez, C. and Perucci, C.**, 2010: The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. In: *Environmental Health*, 9:37, pp. 1–9. DOI: 10.1186/1476-069X-9-37
- Ellis, F. and Nelson, F.**, 1975: Mortality in the elderly in a heat wave in New York City. In: *Environmental Research*, 978(15), pp. 504–512.
- Ellis, F., Nelson, F. and Pincus, L.**, 1975: Mortality during heat waves in New York City July, 1972 and August and September, 1973. In: *Environmental Research*, 10, pp. 1–13.

- Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellee, S., Guihenneue-Jouyaux, C.J., Jouglu, E. and Hémon, D.**, 2006: Excess mortality related to the August 2003 heat wave in France. In: *International Archives of Occupational and Environmental Health*, 80, pp. 16–24. DOI: 10.1007/s00420-006-0089-4
- Frota, A. and Schiffer, S.**, 1987: Manual de Conforto Térmico. 5ª Edição (Handbook of Thermal Comfort. 5th Edition – in Portuguese), São Paulo: Studio Nobel.
- Gaffin, S., Rosenzweig, C., Khanbilvardi, R., Parshall, L., Mahani, S., Glickman, H., Goldberg, R., Blake, R., Slosberg, R. and Hillel, D.**, 2008: Variations in New York City's urban heat island strength over time and space. In: *Theoretical and Applied Climatology*, 94., pp. 1–11. DOI: 10.1007/s00704-007-0368-3
- Grize, L., Hussa, A., Thommena, O., Schindlera, C. and Braun-Fahrländera, C.**, 2005: Heat wave 2003 and mortality in Switzerland. In: *Swiss Medical Weekly*, 135, pp. 200–205. DOI: 10.1007/s00484-012-0543-9
- Hajat, S., Kovats, R., Atkinson, R. and Haines, A.**, 2002: Impact of hot temperatures on death in London: a time series approach. In: *Journal of Epidemiology and Community Health*, 56, pp. 367–72. DOI: 10.1136/jech.56.5.367
- Hertel, S., Tertre, A., Jockel, K. and Hoffmann, B.**, 2009: Quantification of the heat wave effect on cause-specific mortality in Essen, Germany. In: *European Journal of Epidemiology*, 24, pp. 407–414. DOI: 10.1007/s10654-009-9359-2
- Hutter, P., Moshhammer, H., Wallner, P., Leitner, B. and Kundi, M.**, 2007: Heatwaves in Vienna: effects on mortality. In: *Wien Klin Wochenschr*, 119 (7–8), pp. 223–227. DOI: 10.1007/s00508-006-0742-7
- Huynen, M., Martens, P., Schram, D., Weijenberg, M. and Kunst, A.**, 2001: The Impact of heat waves and cold spells on mortality rates in the Dutch population. In: *Environmental Health Perspectives*, 109 (5), pp. 463–470. Instituto Nacional de Estatística (National Institute of Statistics), 2001: General Population and Northern Region's Housing Census, available at: <http://www.ine.pt>, DoA: 1 April 2011.
- Jendritzky, G.**, 1993: Human biometeorology, part I. In: *Experientia*, 499, pp. 733–740.
- Keatinge, W., Coleshaw, S., Easton, J., Cotter, F., Mattock, M. and Chelliah, R.**, 1986: Increased platelet and red cell counts, blood viscosity, and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis. In: *American Journal of Medicine*, 81, pp. 795–800.
- Kenney, W.**, 1997: Thermoregulation at rest and during exercise in healthy older adults. In: *Exercise and Sport Sciences Reviews*, 25, pp. 41–76.
- Kilbourne, E.**, 1999: The spectrum of illness during heat waves. In: *American Journal of Preventive Medicine*, 16 (4), pp. 359–360
- Klinenberg, E.**, 2002: Heat wave: A social autopsy of disaster in Chicago, Chicago: University of Chicago Press, p. 305, ISBN 0-226-44321-3.
- Koppe, C., Jendritzky, G., Kovats, R. and Menne, B.**, 2003: Heatwaves: impacts and responses, Copenhagen: World Health Organization.
- Kovats, R. and Ebi, K.**, 2006: Heatwaves and public health in Europe. In: *European Journal of Public Health*, 16 (6), pp. 592–599. DOI: 10.1093/eurpub/ckl049
- Kyselý, J.**, 2004: Mortality and displaced mortality during heat waves in the Czech Republic. In: *International Journal of Biometeorology*, 49, pp. 91–97. DOI: 10.1007/s00484-004-0218-2
- Linares, D. and Díaz, J.**, 2007: Impact of high temperatures on hospital admissions: comparative analysis with previous studies about mortality (Madrid). In: *European Journal of Public Health*, 18 (3), pp. 317–322. DOI: 10.1093/eurpub/ckm108
- Mastrangelo, G., Fedeli, U., Visentin, C., Milan, G., Fadda, E. and Spolaore, P.**, 2007: Pattern and determinants of hospitalization during heat waves: an ecologic study. In: *BMC Public Health*, 7, 200, pp. 1–8. DOI: 10.1186/1471-2458-7-200
- McGeehin, M. and Mirabelli, M.**, 2001: The potential impacts of climate variability and change on temperature related morbidity and mortality in the United States. In: *Environmental Health Perspectives*, 109 (Supplement 2), pp. 185–189.
- Meehl, G. and Tebaldi, C.**, 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. In: *Science*, 305, pp. 994–997. DOI: 10.1126/science.1098704
- Metzger, B., Ito, K. and Matte, T.**, 2010: Summer heat and mortality in New York City: How hot is too hot? In: *Environmental Health Perspectives* 118 (1), pp. 80–91. DOI:10.1289/ehp.0900906
- Michelozzi, P., Sario, M., Acetta, G., Donato, F., Kirchmayer, U., Ovidio, M. and Perucci, C.**, 2006: Temperature and summer mortality: geographical and temporal variations in four Italian cities. In: *Journal of Epidemiology and Community Health*, 60, pp. 417–423. DOI: 10.1136/jech.2005.040857

- Monteiro, A., Fonseca, L., Almeida, M., Sousa, C., Velho, S. and Carvalho, V.**, 2012a: Atlas da saúde e da doença – vulnerabilidades climáticas e socioeconómicas na Grande Área Metropolitana do Porto e Concelho do Porto (Atlas of health and sickness–climatic and socio–economic vulnerabilities in the Greater Metropolitan Area of Porto and Concelho Port – in Portuguese). Available at: https://www.dropbox.com/sh/2jad5pdf1hf978x/_MsLVsdvsp, DoA: 13 February 2011.
- Monteiro, A., Velho, S. and Góis, J.**, 2012b: A importância da fragmentação das paisagens urbanas na Grande Área Metropolitana do Porto para a modelização das ilhas de calor urbano – uma abordagem metodológica (The importance of fragmentation of urban landscapes in the Greater Metropolitan Area of Porto to the modeling of urban heat islands – a methodological approach – in Portuguese). In: *Revista da Faculdade de Letras – Geografia. Universidade do Porto*, série III, 1, pp.123–159. Available at: <http://ler.letras.up.pt/uploads/ficheiros/10548.pdf>, DoA: 13 February 2011.
- Monteiro A., Carvalho, V., Oliveira T. and Sousa, C.**, 2012c: Excess mortality and morbidity during July 2006 Heat Wave in Porto, Portugal. In: *International Journal of Biometeorology*, 57:1, pp. 155–67. DOI: 10.1007/s00484–012–0543–9
- Monteiro, A., Carvalho, V., Velho S. and Sousa, C.**, 2011: Assessing and monitoring urban resilience using COPD in Porto. In *Science of the Total Environment*, 414, pp.113–119. DOI: 10.1016/j.scitotenv.2011.11.009
- National Weather Service Weather Forecast Office Summer Weather Safety and Survival. Heat Index, available at: <http://www.weather.gov/>, DoA: 10 February 2011.
- Naughton, M., Henderson, A., Mirabelli, M., Kaiser, R., Wilhelm, J., Kieszak, S., Rubin, C. and McGeehin, M.**, 2002: Heat–related mortality during a 1999 heat wave in Chicago. In: *American Journal of Preventive Medicine*, 22 (4), pp. 221–227.
- Planton, S., Déqué, M., Chauvin, F. and Terray, L.**, 2008: Expected impacts of climate change on extreme climate events. In: *Comptes Rendus Geoscience*, 340, pp. 564–574. DOI:10.1016/j.crte.2008.07.009
- Pirard, P., Vandentorren, S., Pascal, M., Laaidi, K., Le Tertre, A., Cassadou, S. and Ledrans, M.**, 2005: Summary of the mortality impact assessment of the 2003 heat wave in France. In: *Euro Surveill*, 10 (7). Available at: www.eurosurveillance.org/ViewArticle.aspx?ArticleId=554; DoA: 13 February 2011.
- Rey, G., Jougl, E., Fouillet, A., Pavillon, G., Bessemoulin, P., Fraussin, P., Clavel, J. and Hémon, D.**, 2007: The impact of major heat waves on all–cause and cause–specific mortality in France from 1971 to 2003. In: *International Archives of Occupational and Environmental Health*, 80, pp. 615–626. DOI: 10.1007/s00420–007–0173–4
- Rooney, C., McMichael, A., Kovats, R. and Coleman, M.**, 1998: Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. In: *Journal of Epidemiology and Community Health*, 482 (52), pp. 482–486.
- Rooke, G., Savage, M. and Brengelmann, G.**, 1994: Maximal skin blood flow is decreased in elderly men. In: *Journal of Applied Psychology*, 77, pp. 11–14.
- Rothfus, L.**, 1990: The heat index “equation”, National Weather Service Technical Attachment (SR 90–23).
- Saez, M., Sunyer, J., Castellsagué, J., Murillo, C. and Antó, J.**, 1995: Relationship between weather temperature and mortality: a time series analysis approach in Barcelona. In: *International Journal of Epidemiology*, 24, pp. 576–582.
- Schiffano, P., Cappai, G., Sario, M., Michelozzi, P., Marino, C., Bargagli, A. and Peruci, C.**, 2009: Susceptibility to heat wave–related mortality: a follow–up study of a cohort of elderly in Rome. In: *Environmental Health*, 8:50, pp.1–14. DOI: 10.1186/1476–069X–8–50
- Schulman, S., Lakatta, E., Fleg, J., Lakatta, L., Becker, L. and Gerstenblith, G.**, 1992: Age related decline in left ventricular filling at rest and exercise. In: *American Journal of Psychology*, 263, pp. 1932–1938.
- Semenza, J., Carol, M., Rubin, H., Kenneth, M., Falter, H., Selanikiom J., Flanders, D., Howe, H. and Wilhelm, J.**, 1996: Heat–related deaths during the July 1995 heat wave in Chicago. In: *New England Journal of Medicine*, 335 (2), pp. 84–90.
- Semenza, J., McCullough, J., Flanders, W., McGeehin, M. and Lumpkin, J.**, 1999: Excess hospital admissions during the July 1995 heat wave in Chicago. In: *American Journal of Preventive Medicine*, 16 (4), pp. 269–277.
- Steadman, R.**, 1979a: The assessment of sultriness. Part I: A Temperature–Humidity Index based on human physiology and clothing science. In: *Journal of Applied Meteorology*, 18 (7), pp. 861–873.
- Steadman, R.**, 1979b: The assessment of sultriness. Part II: Effect of wind, extra radiation, and barometric

- pressure on apparent temperature. In: *Journal of Applied Meteorology*, 18 (7), pp. 874–884.
- Steadman, R.**, 1984: A universal scale of apparent temperature. In: *Journal of Climate and Applied Meteorology*, 23 (12), pp. 1674–1687.
- Tan, J., Zheng, Y., Song, G., Kalkstein, L., Kalkstein, J. and Tang, X.**, 2007: Heat wave impacts on mortality in Shanghai, 1998 and 2003. In: *International Journal of Biometeorology*, 51, pp. 193–200. DOI: 10.1007/s00484-006-0058-3
- Weisskopf, M., Anderson, H., Foldy, S., Hanrahan, L., Blair, K., Török, T. and Rumm, P.**, 2002: Heat wave morbidity and mortality, Milwaukee, Wis, 1999 vs 1995: An improved response? In: *American Journal of Public Health, Research and Practice*, 92 (5), pp. 830–833.
- Whitman, S., Good, G., Donoghue, E., Benbow, N., Shou, W. and Mou, S.**, 1997: Mortality in Chicago attributed to the July 1995 heat wave. In: *American Journal of Public Health*, 87 (9), pp. 1515–1518.