DIE ERDE

Journal of the Geographical Society of Berlin

Vol. 145, No. 1-2 · Research article

Health heat stress in the Porto Metropolitan Area – a matter of temperature or inadequate adaptation?

Ana Monteiro[1], Sara Velho[2]

[1] University of Porto, Faculty of Arts, Geography Department, Via Panorâmica, s/n, 4150-564 Porto, Portugal, ISPUP (Institute of Public Health of Porto), Porto, Portugal, CITTA (Research Centre for Territory, Transports and Environment), Porto, Portugal, and Research Project FCT – ERA NET URBAN/0001/2009, anamt@letras.up.pt

[2] ISPUP (Institute of Public Health of Porto), Rua das Taipas nº 135, 4050-600 Porto, Portugal, and Research Project FCT - ERA NET URBAN/0001/2009, svelho@letras.up.pt,

Manuscript submitted: 29 June 2013 / Accepted for publication: 12 December 2013 / Published online: 2 September 2014

Abstract

The aim of this contribution is to understand the negative outcomes for human health during hot weather in a Mediterranean urban environment. Examining seasonal variations of thermal comfort in Porto, by Physiologically Equivalent Temperature (PET), and comparing expected and observed daily mortality (all causes) and morbidity (all causes, respiratory and circulatory diseases), suggests that in southern Europe, people's adaptation techniques for reducing heat stress and associated health risks need to be developed much further. Research already done in Porto shows that social and economic vulnerability must be included alongside with individual characteristics, like age, gender or genetics, when defining the thresholds above which negative health impacts begin to become severe. Findings from Porto show that a climate risk map is needed for every metropolitan area, with sufficient detail to give locally appropriate temperature thresholds taking into account both the local climate and the socio-economic conditions of every sector of the urban environment.

Zusammenfassung

In diesem Beitrag wird beabsichtigt, das Verständnis für die negativen Auswirkungen von Hitzeperioden auf die menschliche Gesundheit in einem mediterranen Ballungsgebiet zu verbessern. Die saisonalen Schwankungen des thermischen Wohlbefindens in Porto wurden ausgedrückt durch die physiologische Äquivalenztemperatur (PET). Daraus wurde die erwartete tägliche Mortalitätsrate berechnet und mit der tatsächlichen Mortalitätsrate verglichen (alle Ursachen), sowie mit der Morbiditätsrate (alle Ursachen von Atemwegs- und Kreislauferkrankungen). Die Ergebnisse deuten darauf hin, dass die Anpassungstechniken der Bewohner in Südeuropa deutlich weiter entwickelt werden müssen, um Hitzestress und die damit verbundenen Gesundheitsrisiken reduzieren zu können. Laufende Forschungsarbeiten in Porto (Portugal) zeigen auf, das soziale und ökonomische Verletzlichkeiten der Gesellschaft ebenso berücksichtigt werden müssen wie individuelle Veranlagung, Alter und Geschlecht, um robuste Schwellenwerte zu definieren zur Unterscheidung der besorgniserregenden Gesundheitsauswirkungen von anderen, nicht bedrohlichen negativen Gesundheitsauswirkungen. Ergebnisse aus Porto zeigen, dass eine Klima-Risikokarte für jeden Ballungsraum nötig ist, mit ausreichendem Detaillierungsgrad um lokal angepasste Schwellenwerte für Temperaturen bereitzustellen. Diese Risikokarten müssen sowohl das lokale Mikroklima wie die lokalen sozio-ökonomischen Rahmenbedingungen jedes Sektors des städtischen Umfeldes berücksichtigen.

Monteiro, Ana and *Sara Velho* 2014: Health heat stress in the Porto Metropolitan Area – a matter of temperature or inadequate adaptation? – DIE ERDE **145** (1-2): 80-95

DOI: 10.12854/erde-145-7

Keywords Health heat stress threshold criteria; mortality and morbidity; PET; Mediterranean cities

1. Introduction

Porto – 41° N and 8° W – is the second largest city of Portugal and the centre of a metropolitan area with more than 1.5 million inhabitants. It is located in the extreme southwest of the European continent, and it is the first part of Europe to face air masses coming across the Atlantic Ocean from the west (*Fig. 1*).

The area is affected by varied weather systems related to the complex air circulation in this zone, the nearby Azores Anticyclone and rapidly advancing depressions associated with movements of the Polar Front. The city is thus influenced by fluctuations of two markedly different types of air masses – warm and humid from the subtropics and colder and drier from the polar zone.

This climatological context produces a changing daily sequence of contrasting, stressful and demanding thermal conditions potentially affecting human health (*Monteiro* 1997, *Monteiro* et al. 2012a, 2012c, 2013a, 2013b, 2013c). This seasonal, monthly and daily thermal irregularity is aggravated by the indoor climatic unsuitability of many buildings and, with high socio-economic inequality, leads to a high probability of severe negative human health outcomes for some sec-

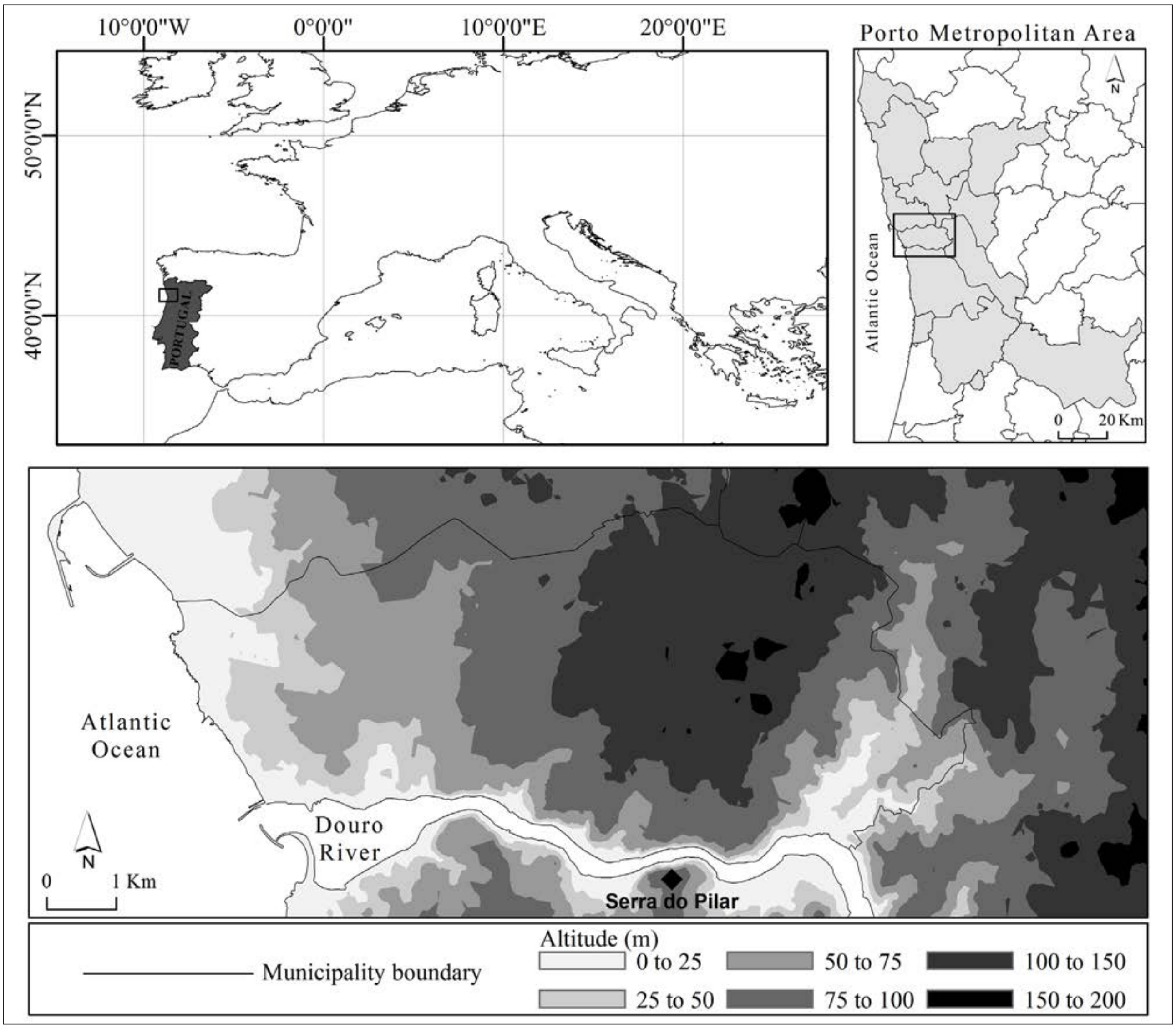

Fig. 1 Porto and Porto Metropolitan Area: geographical location

tors of the population during hot weather. However, the criteria for issuing a hot weather health warning adopted by the Portuguese authorities are either the WMO's definition of a heat wave: a sequence of at least 6 days with more than 5 °C above the average of the homologous period (WCDMP-No 47, WMO-TD, No 1071); or the Portuguese Meteorological Office's thresholds of days in Porto, when the maximum temperature is from 32 °C to 36 °C (yellow), from 37 °C to 38 °C (orange) and above 38 °C (red). However, both the considered temperature thresholds for triggering public health warning systems and the means of communicating the risk demonstrate that, in south European urban areas like Porto, extreme heat events are an underestimated hazard. The apparently moderate fluctuations of the temperature indicated by the analysis of the 100-year means obscure the day-to-day variety of thermal conditions and totally disregard the urban impact on local and regional temperature (*Monteiro* 1997, *Endlicher* et al. 2006).

Moreover, Porto is located in a global zone where most 21st century GCM's scenarios anticipate a considerable temperature increase during this century (*Dessai* 2002, 2003; *Díaz* et al. 2002a, 2002b, 2006; *Meehl* and *Tebaldi* 2004, *Monteiro* et al. 2013a), which is already evident in the Porto data series (*Monteiro* et al. 2012c). Even if the rate of increase has not been similar during all months and seasons it is reasonable to anticipate that the duration and intensity of extreme heat events will increase in Mediterranean areas like Porto (*Planton* et al. 2008; *Rooney* et al. 1998; *Gaffin* et al. 2008; *Metzger* et al. 2010; *Monteiro* et al. 2012a, 2012b, 2013a).

With this climatic prediction and recognising the irregular and episodic behaviour of the climate system, it seems relevant for cities like Porto to evaluate, as accurately and completely as possible, the negative human health outcomes, as has already been done, since 1990, for other European areas (*Rooney* et al. 1998, *Calado* et al. 2004, *Grize* et al. 2005, *Fouillet* et al. 2006, *D'Ippoliti* et al. 2010, *Monteiro* et al. 2012b, 2013a). It is worth remembering, to cite just one example, that the well-known 2003 heat wave did not meet the official criterion of the required sequence of daily temperatures but provoked a significant morbidity and mortality excess (*Monteiro* et al. 2012b, 2013b). This indicates the importance of trying to select the best, most efficient and reliable criteria for defining the extreme heat event thresholds, considering the particular socio-economic and biophysical characteristics of the built environment of each individual urban area.

2. Materials and methods

The basic data sets employed in our analysis of Porto were yearly, monthly, daily and hourly cli-

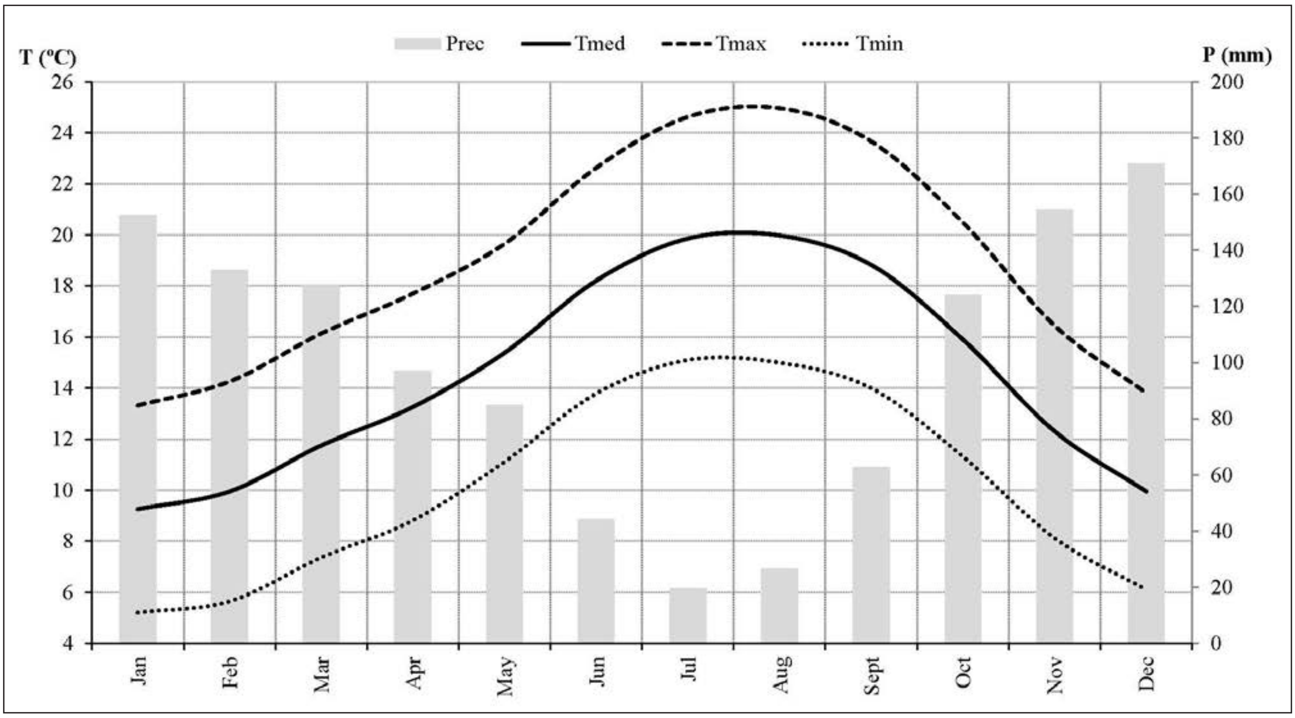

Fig. 2 Monthly average temperature and monthly total average rainfall in Porto, 1901-2007

Tab. 1 Extreme monthly and daily temperature records in Porto, 1901-2007

Highest monthly average temperature (1901-2007)		
Month	**T °C**	**Year**
Jan	12.0	1966
Feb	13.1	1998
Mar	16.2	1997
Apr	17.1	1997
May	18.6	1922
Jun	21.2	2004
Jul	22.7	2006
Aug	23.4	2006
Sept	21.8	1926
Oct	18.8	1989
Nov	17.5	1902
Dec	13.2	1989
YEAR	16.3	1997

Lowest monthly average temperature (1901-2007)		
Month	**T °C**	**Year**
Jan	6.5	1945
Feb	6.2	1956
Mar	9.2	1916
Apr	10.0	1986
May	12.8	1984
Jun	15.0	1972
Jul	17.2	1912
Aug	17.0	1912
Sept	16.2	1927
Oct	12.4	1974
Nov	8.5	1971
Dec	6.2	1933
YEAR	13.6	1932

Highest monthly average daily maximum temperature (1901-2007)		
Month	**T °C**	**Year**
Jan	15.1	1982
Feb	18.4	1998
Mar	23.3	1997
Apr	22.1	1997
May	23.7	1922
Jun	26.0	1981
Jul	28.1	1990
Aug	29.3	2006
Sept	28.3	1926
Oct	23.8	1962
Nov	21.4	1902
Dec	16.9	1953
YEAR	20.7	1997, 2006

Lowest monthly average daily minimum temperature (1901-2007)		
Month	**T °C**	**Year**
Jan	1.6	1954
Feb	1.0	1956
Mar	3.9	1970
Apr	5.7	1932
May	8.6	1972
Jun	10.6	1972
Jul	12.6	1965
Aug	13.0	1963, 1978
Sept	10.7	1952
Oct	7.1	1974
Nov	3.7	1934
Dec	1.5	1933
YEAR	8.9	1932, 1935

matic variables, daily hospital admissions and daily mortality data. The available daily and hourly climate data (temperature, humidity, wind velocity and direction, atmospheric pressure, insolation and solar radiation) of the two main climatological stations Porto-Pedras Rubras and Porto-Serra do Pilar were compared to define: i) the 100-year annual temperature trends; ii) the Physiological Equivalent Temperature (PET); iii) the most severe heat extreme events using different criteria. Porto's PET was estimated by SOLWEIG 2.3 software (*Lindberg* et al. 2008, *Lindberg* and *Thorsson* 2009), applied to Porto-Pedras Rubras climate hourly variables, from 2002 till 2007. The Porto PET thresholds were established according to the international thermal (dis)comfort classes (*Matzarakis* and *Mayer* 2000, *Matzarakis* and *Amelung* 2008, *Nastos* and *Matzarakis* 2008, *Monteiro* et al. 2012b).

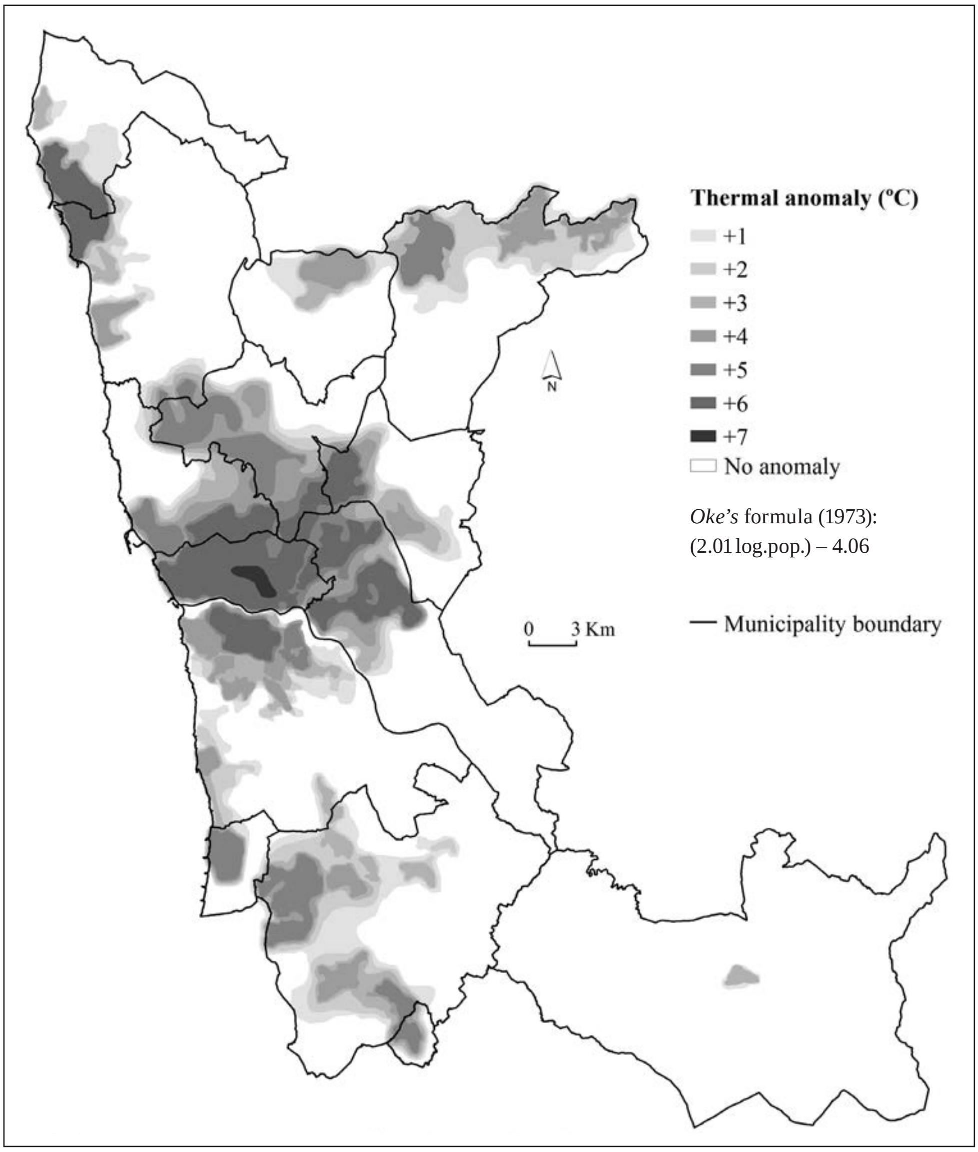

Fig. 3 Magnitude of urban heat anomalies in the Porto Metropolitan Area estimated according to Oke's (1973) formula for temperate climate zones and the methodologies explained in Monteiro et al. 2012c. Sources: IGEO-CAOP 2011; IGEOE Cartas Militares de Portugal, Série M888 (1998 and 1999); itinerant measurements in 1989, 1990, 1992 (Monteiro 1997); PTDC/SAU-ESA/73016/2006 (2012)

The extreme heat events were defined by four different international criteria already tested for Porto – WMO, Díaz, Thom's and Heat Index –, and a fifth criterion was added to define the most severe heat extreme episodes at Porto but having in mind their duration and intensity (*Monteiro* et al. 2012b, *Silva* 2012, *Monteiro* et al. 2013b, 2013c). The number of days they last and the intensity was calculated by the number of days with maximum and minimum temperature above the 90th percentile of the century dataset.

The daily hospital admissions from 2002 to 2007 were collected from the Health System's Central Administration (ACSS) and correspond to the Great Diagnosis Category of Respiratory Diseases (GDC 4) and Circulatory Diseases (GDC 5) in the Tenth Revision of the International Classification of Diseases, 2012. The morbidity data analysis used the daily admissions to the four public hospitals of the Porto Metropolitan Area (GAMP) with diagnosis GDC 4 and GDC 5, complemented by an analysis of admissions for bronchitis and asthma, COPD, pneumonia and pleurisy, myocardial infarction, stroke and heart failure.

The daily mortality data were gathered from the National Statistics Institute (INE) and include all causes of death from 2002 to 2007. The official data of daily mortality by parish are available only for all causes and since 2002.

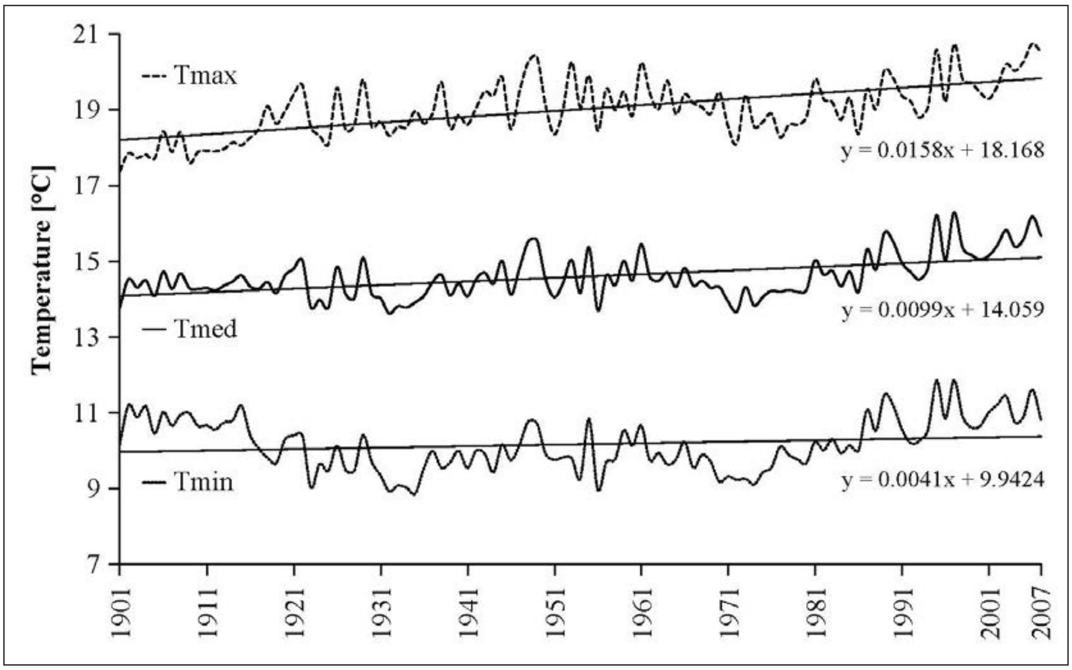

Fig. 4 Yearly average, maximum and minimum temperature in Porto, Portugal, 1901-2007

Tab. 2 Yearly, seasonal and monthly temperature gradient in Porto during the last century (1901-2007)

	T_{med}	$T_{med\ max}$	$T_{med\ min}$
	Average gradient 1901-2007 (°C)	**Average gradient 1901-2007 (°C)**	**Average gradient 1901-2007 (°C)**
Year	0.009	0.015	0.004
Winter	0.01	0.014	0.007
Autumn	0.01	0.014	0.007
Spring	0.009	0.019	0.0000
Summer	0.011	0.018	0.004
January	0.009	0.011	0.006
February	0.013	0.017	0.008
March	0.016	0.028	0.005
April	0.006	0.015	0.002
May	0.006	0.014	0.002
June	0.011	0.02	0.0033
July	0.011	0.018	0.003
August	0.011	0.016	0.005
September	0.008	0.013	0.003
October	0.014	0.015	0.012
November	0.009	0.013	0.007
December	0.01	0.013	0.005

Higher values

The mortality and morbidity excess during the thermal heat stress events was calculated from the difference between the admissions and the deaths in the homologous period (i.e. the number of deaths in the same sequence of days of all the other considered years) and in the pre-defined extreme heat event periods (*Monteiro* et al. 2013b, 2013c).

Finally, on the basis of the obtained PET values during extreme heat events, the morbidity and mortality excess daily data during these periods, the new thresholds above which the mortality and morbidity starts to increase were established. As *Almeida* (2012) explained with detail it is possible to relate the obtained PET values to the air temperature.

In addition, a GIS project was conceived to calculate a deprivation index by parish, using a multi-level criteria analysis, in order to identify with the most possible precision the target population of this new extreme heat warning system in the Porto Metropolitan Area.

3. Results

The apparently agreeable moderate temperatures and rainfall volumes indicated by Porto's 100-year climatic averages (*Fig. 2*) hide the enormous daily variability in weather due to the high variability of local weather systems (*Tab. 1*).

The temperature extremes recorded at the climatological stations near the edges of the Porto urban area need to be modified to take account of positive thermal anomalies reported within the Metropolitan Area since 1990 (*Fig. 3*). Moreover, the positive trends of both minimum and maximum temperatures from 1901 to 2007 (*Fig. 4*) are the outcome of the combination of high yearly, seasonal and monthly gradients of temperature increase (*Tab. 2*). While the minimum temperature gradient is higher in autumn and winter, the maximum temperatures increase is greater in spring and summer (*Tab. 2*). March and October are the months with steepest maximum and minimum temperature gradients (*Tab. 2*). This variation in long-term trends, due to global weather changes and to local human activities, must cause great difficulties for much of Porto's human population, especially those who are most vulnerable to change, including the sick, poor, mentally ill, disabled, extremely young and aged, in their efforts to adapt to temperature extremes.

Calculation of Porto's PET confirms the impression, obtained from the basic analysis of the temperature, of a high frequency of stressful days for human health due to heat (*Fig. 5*). Although classified as a temperate climate type with a habitual warm and dry season, Porto's climate does not provide the city's human beings with comfortable temperatures every day of each year.

The PET, by month and by year, shows two or more extremely demanding hot days in terms of human health of over 35 °C each year (*Tabs. 3* and *4*). This happens most often, but not exclusively, during the

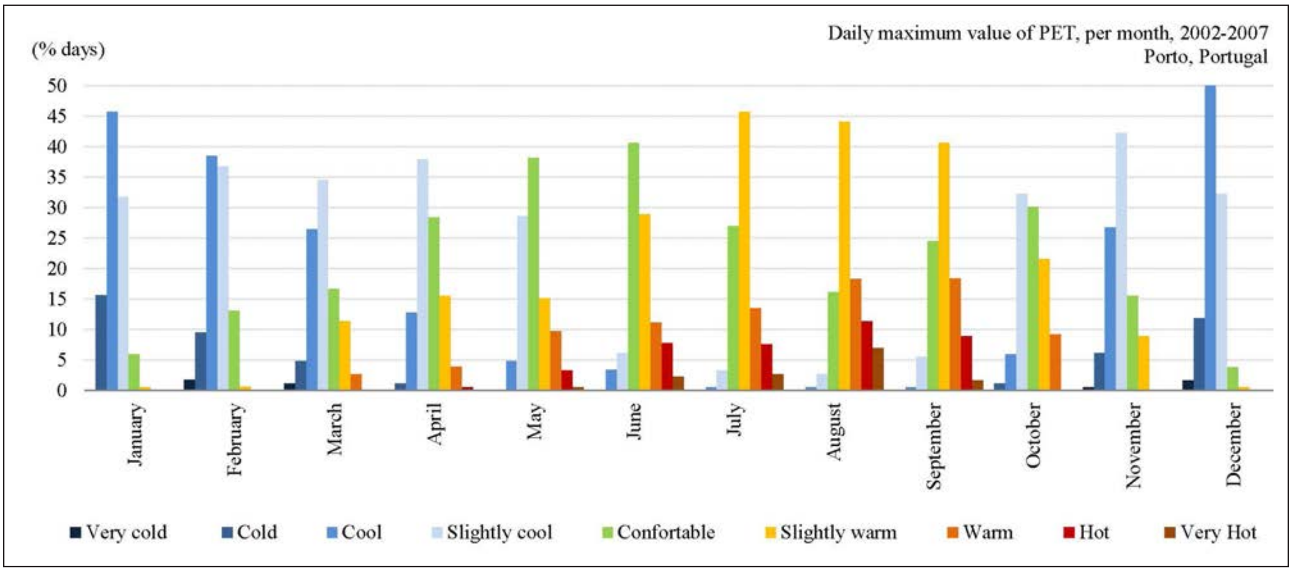

Fig. 5 Porto's PET comfort classes: frequencies per month, 2002-2007

Tab. 3 Yearly distribution of days with maximum PET, by comfort class, 2002-2007

Level	Number of days per year (%) by PET class in Porto					
	2002	2003	2004	2005	2006	2007
Very Cold < 4 °C	1	1	0	0	0	1
Cold 4 °C – 8 °C	3	5	4	4	4	4
Cool 8 °C – 13 °C	22	19	18	19	15	14
Slightly cool 13 °C – 18 °C	28	21	27	23	24	24
Comfortable 18 °C – 23 °C	23	23	17	23	20	24
Slightly warm 23 °C – 29 °C	16	20	22	18	21	21
Warm 29 °C – 35 °C	6	5	8	7	7	9
Hot 35 °C – 41 °C	2	4	2	4	5	3
Very Hot > 41 °C	0	2	0	2	3	1
	100	100	100	100	100	100

> 20%

Tab. 4 Monthly distribution of days with maximum PET, by comfort class, 2002-2007

Level	Number of days per month (%) by PET class in Porto (2002-2007)											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Very Cold < 4 °C	0	2	1	0	0	0	0	0	0	0	1	2
Cold 4 °C – 8 °C	16	9	5	1	4	0	0	0	0	1	6	12
Cool 8 °C – 13 °C	46	38	26	13	5	3	1	1	1	6	27	50
Slightly cool 13 °C – 18 °C	32	37	34	38	28	6	3	3	6	32	42	32
Comfortable 18 °C – 23 °C	6	13	17	28	38	41	27	16	24	30	16	4
Slightly warm 23 °C – 29 °C	1	1	11	16	15	29	46	44	41	22	9	1
Warm 29 °C – 35 °C	0	0	3	4	10	11	13	18	18	9	0	0
Hot 35 °C – 41°C	0	0	0	1	3	8	8	11	9	0	0	0
Very Hot > 41 °C	0	0	0	0	1	2	3	7	2	0	0	0
	100	100	100	100	100	100	100	100	100	100	100	100

> 20%

warm season (July to September). Between 2002 and 2007, there were more hot and very hot days, according to PET classes, in 2006.

To portray the effects of unusually hot weather in the warmest part of the year, it is important to select the most appropriate indicator of the potential for human heat discomfort. Different indicators use varying criteria (*Tabs. 5* and *6*). Previous work in Porto suggests the most suitable indicator is that of Díaz as it is less demanding about the number of days of excessive heat, but considers the importance of both the diurnal and the nocturnal thermal environment (*Monteiro* et al. 2012b, *Silva* 2012).

So, following the Díaz criteria, with a minor adaptation considering the sequences of at least two days in Porto, with the 70th, 90th and 97th percentiles of minimum and maximum temperature as potential thresholds for a high probability of negative health outcomes in vulnerable human beings, the worst heat events from 2002 to 2007 were found to be in July-August 2003, July 2006 and August 2006 (*Tab. 7*).

For each event the observed and expected mortality and morbidity were calculated, revealing a considerable excess of mortality and morbidity increase during each extreme heat event compared to more normal seasonal conditions (*Tab. 8*).

During these three extreme heat events, the behaviour of mortality (all causes) and morbidity by respiratory diseases (all causes, circulatory, bronchitis and asthma, COPD, pneumonia and pleurisy), circulatory diseases (all causes, stroke and heart failure) shows an excess of occurrences, reaching as much as 118 % of normal for COPD (*Tab. 8*). The analysis of daily records for some of these events shows that negative health impacts arose during the excessive heat episode and continued for the 2 to 5 days afterwards (*Monteiro* et al. 2012b, 2012d).

In this paper we aim to go further and try to understand whether such exceptional events have similar negative health impacts in all socio-economic groups, demographic categories and built environments. Initially we examined the mortality rate

Tab. 5 Heat events in Porto according to WMO, Díaz, Thom's and Heat Index criteria by decade (all months)

	WMO criteria	**Díaz criteria**	**Thom's criteria**	**Heat Index criteria**
	Number of events			
1901-1910	0	21	no data	no data
1911-1920	3	20	no data	no data
1921-1930	3	20	no data	no data
1931-1940	2	18	no data	no data
1941-1950	5	22	no data	no data
1951-1960	3	16	no data	no data
1961-1970	5	17	no data	no data
1971-1980	2	16	7	11
1981-1990	2	25	8	14
1991-2000	6	30	6	12
2001-2007	6	31	10	14
1901-1910	0	21	no data	no data
Total	**37**	**236**	**31**	**51**

Tab. 6 Heat events in Porto according to WMO, Díaz, Thom's and heat Index criteria by decade (hot season months – May to September).

	WMO criteria					Díaz criteria					Thom's criteria					Heat index criteria				
	May	**Jun**	**Jul**	**Aug**	**Sep**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
1901-1910											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1911-1920											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1921-1930											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1931-1940											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1941-1950											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1951-1960											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1961-1970											n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
1971-1980																				
1981-1990																				
1991-2000																				
2001-2007																				

Number of events

0 [1-2] [3-4] [5-7]

Tab. 7 The three worst heat events in Porto in terms of intensity and duration, 2002-2007

30 July – 12 August 2003		11-18 July 2006		3 – 13 August 2006	
	Length: 14 days		Length: 8 days		Length: 11 days
Tmax	5 days > P99 (35.2 °C)	Tmax	3 days > P99 (35.2 °C)	Tmax	5 days > P99 (35.2 °C)
	2 days > P98 (33.9 °C)		3 days > P97 (33.0 °C)		1 day > P98 (33.9 °C)
	1 day > P95 (31.7 °C)		1 day > P95 (31.7 °C)		2 days > P97 (33.0 °C)
	2 days > P93 (30.6 °C)		1 day > P90 (29.1 °C)		1 day > P95 (31.7 °C)
	1 day > P68 (24.4 °C)	Tmin	6 days > P98 (19.2 °C)		2 days > P93 (30.6 °C)
	1 day > P73 (25.1 °C)		1 day > P97 (18.7 °C)	Tmin	7 days > P99 (20.0 °C)
	1 day > P80 (26.4 °C)		1 day > 90 (17.1 °C)		1 day > P98 (19.2 °C)
	1 day > P82 (27.0 °C)				1 day > P97 (18.7 °C)
Tmin	5 days > P99 (20.0 °C)				1 day > P96 (18.3 °C)
	2 days > P98 (19.2 °C)				1 day > P94 (17.8 °C)
	1 day > P97 (18.7 °C)				
	1 day > P96 (18.3 °C)				
	1 day > P95 (18.0 °C)				
	1 day > P94 (17.8 °C)				
	1 day > P93 (17.6 °C)				
	2 days > P92 (17.4 °C)				

Tab. 8 Observed and expected mortality and morbidity in Porto from 2002 to 2007 (adapted from Monteiro et al. 2012a and 2013b).

Extreme heat event	Observed (o) [no.]	Expected (e) [no.]	(o-e) [no.]	(o-e)/ e *100 [%]	PET
Mortality					
30 July – 12 August 2003	490	365	126	34 %	27-47 °C
11 – 18 July 2006	313	226	87	39 %	31-45°C
3 – 13 August 2006	351	281	70	25 %	31-45°C
Morbidity					
Respiratory diseases (all causes)					
30 July – 12 August 2003	288	229	60	26 %	27-47°C
11 – 18 July 2006	204	144	60	42 %	31-45°C
3 – 13 August 2006	237	173	64	37 %	31-45°C
Circulatory diseases (all causes)					
11 – 18 July 2006	232	215	17	8 %	31-45°C
Bronchitis and asthma					
3 – 13 August 2006	26	12	14	112 %	31-45°C
Chronic disease obstructive					
11 – 18 July 2006	24	11	13	118 %	31-45°C
3 – 13 August 2006	26	15	11	76 %	31-45°C
Pneumonia and plearisy					
11 – 18 July 2006	41	24	17	68 %	31-45°C
3 – 13 August 2006	39	25	14	56 %	31-45°C
Stroke					
11 – 18 July 2006	31	29	2	7 %	31-45°C
Heart failure					
3 – 13 august 2006	29	25	4	15 %	31-45°C

among the people over 64 years old, as the elderly are more likely to die from causes independent of the indoor and outdoor climatic conditions (*Fig. 6*).

Through a hierarchical multi-criteria analysis of all variables, using a GIS containing the most detailed available health, demographic and geographical data, we derived a deprivation index under extreme heat events. The analysis considers as variables affecting the health of the isolated elderly: inadequacy and age of the dwellings, overcrowding in terms of living space, unemployment rate, income, illiteracy, sun exposure and slope (*Fig. 7*).

4. Discussion

The results obtained from Porto confirm findings from other European temperate zone cities. As in Berlin during the August 2003 heat wave, there is a vital need to find more efficient solutions that consider the complexity of the combined effects of "... heat waves, thermal stress, rapid urbanisation, growing number of elderly people and global climate change ..." (*Endlicher* et al. 2008: 277, also *Gabriel* and *Endlicher* 2011, *Philips* et al. 2013). They also underline the importance of every urban built form and structural design option in understanding the local (dis)comfort areas inside

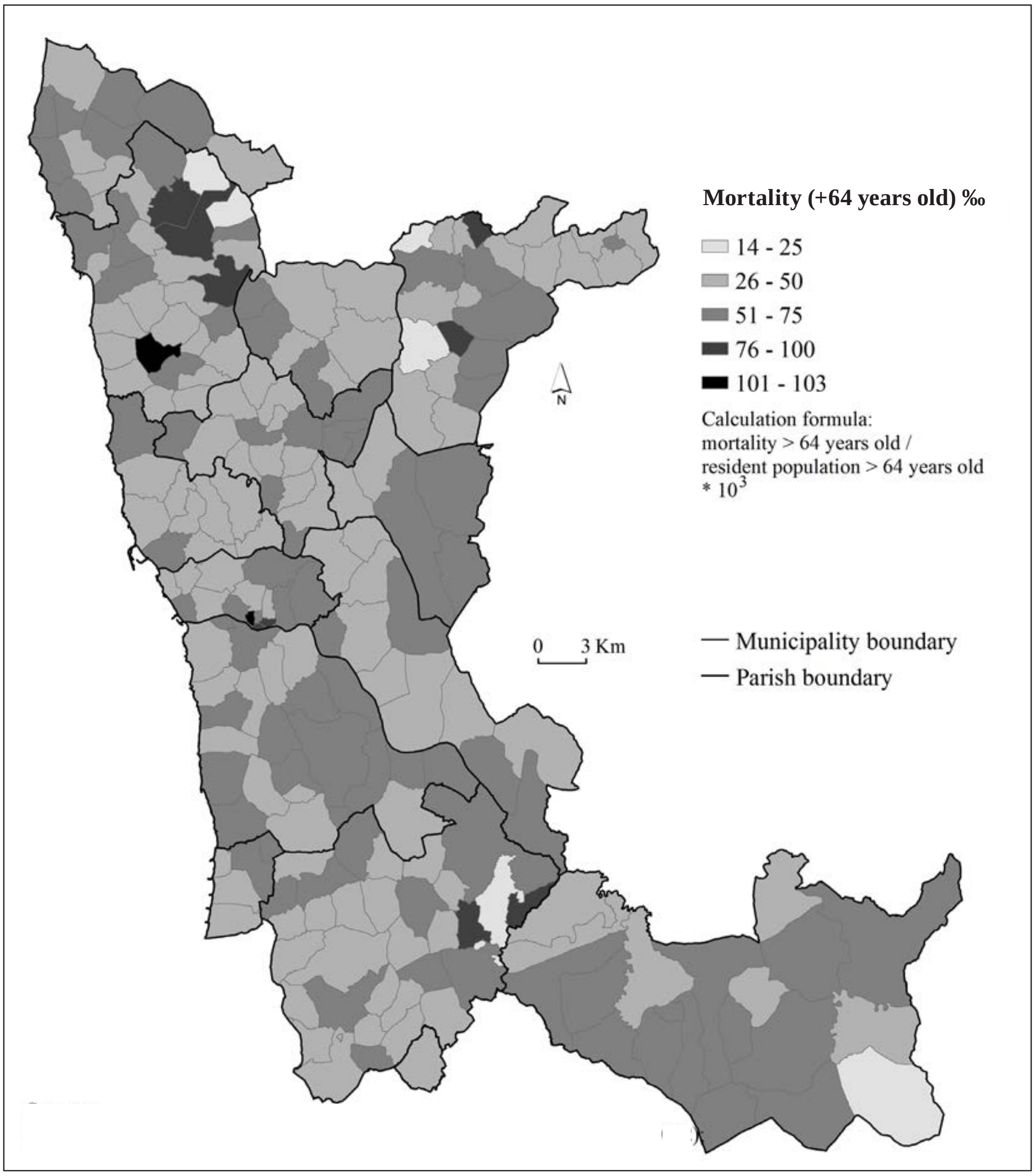

Fig. 6 Mortality of aged people in the Porto Metropolitan Area, 2011. Sources: IGEO-CAOP 2011; ACSS (2000-2007); PTDC/SAU-ESA/73016/2006 (2012); INE (2001 and 2011)

a city and inevitably the heat stress over human beings which corroborates much research on American cities (*Stone* et al. 2012) and on Porto (*Monteiro* et al. 2012a, 2012d, 2013a, 2013b, 2013c). It strengthens the need of downscaling and readjusts the local and regional extreme heat thresholds, considering the specificity of the regional climate context, as well as the local impacts on climate driven by intense urbanisation and socio-economic vulnerability.

The existing climate, socio-economic and health data available at the local scale (*Almeida* 2012) suggest that there is a health-temperature relationship in the Porto Metropolitan Area, and it appears reasonable to propose a new risk temperature threshold guideline and a list of recommendations (*Tabs. 9* and *10*).

These thresholds and recommendations were obtained after considering the day-to-day behaviour

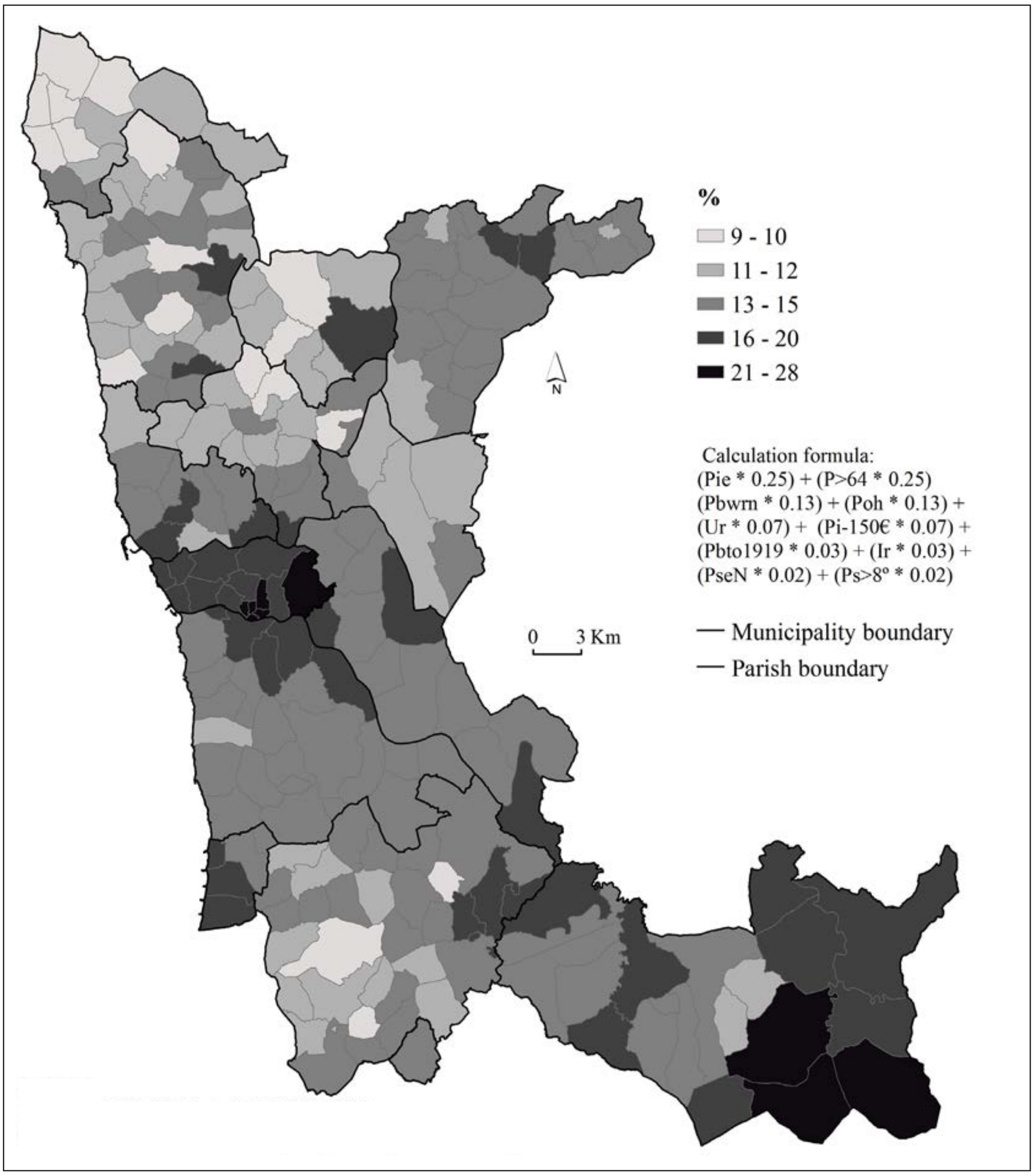

Fig. 7 Deprivation index for the Porto Metropolitan Area. Variables of the deprivation index: Pie – % isolated elderly; P > 64 – % population over 64 years; Pbwrn – % buildings with repair need; Poh – % overcrowded housing; Ur – Unemployment rate; Pi-150€ – % incomes up to 150 €; Pbto 1919 – % buildings contructed before 1919; Ir – illiteracy rate; PseN – % exposure to N; Ps – % slopes > 8°. Sources: IGEO-CAOP 2011; ACSS (2000-2007); PTDC/SAU-ESA/73016/2006 (2012); INE (2001 and 2011)

Tab. 9 Risk temperature thresholds proposal for Mediterranean cities like Porto (Almeida 2012; Monteiro et al. 2012c).

Warning – Severity	Tmax	Tmin
Yellow	25 °C – 29 °C	15 °C – 17 °C
Orange	29 °C – 33 °C	17ºC – 19 °C
Red	33 °C – 37°C	19 °C – 21°C
Brown	≥ 37 °C	≥ 21°C
≈ P70	25 °C	15 °C
≈ P90	29 °C	17 °C
≈ P97	33 °C	19 °C

of mortality and morbidity both during and after the extreme heat event. They also reflect the validated existing Deprivation Index Map that considers the demographic, socio-economic and built bioclimatic outdoor and indoor discomfort features of the urbanised area (*Monteiro* et al. 2012b, *Wilhelmi* and *Hayden* 2010).

From the research in Porto, it would be more appropriate and efficient to issue the warnings of possible negative public health outcomes during extreme heat events, when the maximum and minimum temperatures reach both 70th percentiles (25 °C – 29 °C; 15 ° – 17 °C). The risk is highest when the 97th percentile (37 °C; 21 °C) is reached. These values differ considerably from those of other authors and especially from those used to issue official warnings (*Dessai* 2002, 2003, *D'Ippoliti* et al. 2010). However, they are closer to those used in some case studies made in similar Mediterranean contexts (*Díaz* et al. 2006).

5. Conclusions

This contribution clarifies the relevance of introducing major changes not only in the way heat warning systems are issued, but also in the way heat warning systems are established, if the goal is really to prevent negative health outcomes. The temperature thresholds should consider the historical data, as they are what people base their expectations upon and are biologically somewhat adjusted to. However, they should also incorporate the real present-day socio-economic and environmental conditions. So, the efficiency of a warning system is a matter of both (a) selecting the most appropriate and suitable temperature thresholds, and (b) considering the skills that people have that enable them to adapt to changing hot-spell heat levels and their frequency of occurrence under global and local environmental change.

Tab. 10 Risk lag time recommendations for the Porto Metropolitan Area

Extreme heat events	
Mortality	3 days
Morbidity	
Respiratory diseases (all causes)	3 days
Bronchitis and Asthma	3 days
COPD	4 days
Pneumonia and pleurisy	3 days
Circulatory diseases (all causes)	3 days
Stroke	2 days
Myocardial infarct	2 days
Heart failure	2 days

Acknowledgements

This work has been supported by FEDER grants through COMPETE (Programa Operacional Factores de Competitividade) and by the FCT (Fundação para a Ciência e Tecnologia), namely via the Project PTDC/SAU-ESA/73016/2006 and the Project URBAN/0001/2009.

References

Almeida, M. 2012: Fundamentação teórica para a criação de um sistema de alerta e resposta online durante episódios térmicos de calor extremo para uma unidade de saúde da GAMP (Theoretical fundamentation for a creation of an online early warning system and response during thermal extreme heat episodes for a health unit of GAMP – in Portuguese). – Master thesis in Hazards, Cities and Spatial Planning, Faculty of Arts, University of Porto, Portugal

Calado, R., P. Nogueira, J. Catarino, E. Paixão, J. Botelho, M. Carreira and *J. Falcão* 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). – Revista Portuguesa de Saúde Pública **22** (2): 7-20. – Online available at: http://www.cdi.ensp.unl.pt/docbweb/MULTIMEDIA/RPSP2004-2/2-01-2004.PDF, 23/05/2013

D'Ippoliti, D., P. Michelozzi, C. Marino, F. de 'Donato, B. Menne, K. Katsouyanni, U. Kirchmayer, A. Analitis, M. Medina-Ramón, A. Paldy, R. Atkinson, S. Kovats, L. Bisanti, A. Schneider, A. Lefranc, C. Iñiguez and *C. Perucci* 2010: The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. – Environmental Health **9** (37): 1-9

Dessai, S. 2002: Heat stress mortality in Lisbon Part I. Model construction and validation. – International Journal of Biometeorology **47** (1): 6-12

Dessai, S. 2003: Heat stress mortality in Lisbon Part II. An assessment of the potential impacts of climate change. – International Journal of Biometeorology **48** (1): 37-44

Díaz, J., A. Jordan, R. García, C. López, J. Alberdi, E. Hernandez and *A. Otero* 2002a: Heat waves in Madrid 1986-1997: effects on the health of the elderly. – International Archives of Occupational and Environmental Health **75** (3): 163-170

Díaz, J., R. García, F. Velasquez de Castro, E. Hernández, C. López and *A. Otero* 2002b: Effects of extremely hot days on people older than 65 years in Seville (Spain) from 1986 to 1997. – International Journal of Biometeorology **46**: 145-149

Díaz, J., T.R. Garcia-Herrera and *C. Linares* 2006: The impact of summer 2003 heat wave in Iberia: how should we measure it? – International Journal of Biometeorology **50**: 159-166

Endlicher, W., G. Jendritzky, J. Fischer and *J. Redlich* 2006: Heat waves, urban climate and human health. HU Berlin Public Report SAR-PR-2006-06. – In: *Kraas, F., Th. Krafft* and *W. Wuyi* (eds.): Global change. Urbanisation and health. – Beijing: 103-114. – Online avaible at: http://sar.informatik.hu-berlin.de/research/publications/SAR-PR-2006-06/SAR-PR-2006-06_.pdf, 23/05/2013

Endlicher, W., G. Jendritzky, J. Fischer and *J. Redlich* 2008: Heat waves, urban climate and human health. – In: *J. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, C. ZumBrunnen* and *U. Simon* (eds.): Urban ecology. An international perspective on the interaction between humans and nature. – New York et al.: 269-278

Fouillet, A., G. Rey, F. Laurent, G. Pavillon, S. Bellec, C. Ghihenneuc-Jouyaux, J. Clavel, E. Jougla and *D. Hémon* 2006: Excess mortality related to the August 2003 heat wave in France. – International Archives of Occupational and Environmental Health **80** (1): 16-24

Gabriel, K. and *W. Endlicher* 2011: Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. – Environmental Pollution **159** (8-9): 2044-2050

Gaffin, S., C. Rosenzweig, R. Khanbilvardi, L. Parshall, S. Mahani, H. Glickman, R. Goldberg, R. Blake, R. Slosberg and *D. Hillel* 2008: Variations in New York City's urban heat island strength over time and space. – Theoretical and Applied Climatology **94** (1): 1-11

Grize, L., A. Huss, O. Thommen, C. Schindler and C. Braun-Fahrländer 2005: Heat wave 2003 and mortality in Switzerland. – Swiss Medical Weekly **135**: 200-205

Höppe, P. 1999: The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. – International Journal of Biometeorology **43** (2): 71-75

Lindberg, F. and *S. Thorsson* 2009: SOLWEIG – the new model for calculating the mean radiant temperature. – The Seventh International Conference on Urban Climate, 29 June – 3 July, Yokohama, Japan

Lindberg, F., B. Holmer and *S. Thorsson* 2008: SOLWEIG 1.0 – Modelling spatial variations of 3D radiant fluxes and mean radiant temperature in complex urban settings. – International Journal of Biometeorology **52** (7): 697-713

Matzarakis, A. and *B. Amelung* 2008: Physiological equivalent temperature as indicator for impacts of climate change on thermal comfort of humans. – In: *Thomson, M.C., R. Garcia-Herrera* and *M. Beniston* (eds.): Seasonal forecasts, climatic change, and human health: Health and climate. – Advances in Global Change Research **30.** – Dordrecht et al.: 161-172

Matzarakis, A. and *H. Mayer* 2000: Atmospheric conditions and human thermal comfort in urban areas. – 11th Seminar on Environmental Protection "Environment and Health", 20-23 November, Thessaloniki, Greece: 155-166

Meehl, G. and *C. Tebaldi* 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. – Science **305** (5686): 994-997

Metzger, B., K. Ito and *T. Matte* 2010: Summer heat and mortality in New York City: How hot is too hot? – Environmental Health Perspectives **118** (1): 80-86

Monteiro, A. 1997: O clima urbano do Porto – Contribuição para a definição das estratégias de planeamento e ordenamento do território (The urban climate of Porto – Contribution towards the definition of territory planning). – Fundação Calouste Gulbenkian – Junta Nacional de Investigação Científica e Tecnológica, Portugal. – Lisbon

Monteiro, A., S. Velho and *J. Góis* 2012a: 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 the urban landscapes fragmentation in the Porto's Metropolitan Area for urban heat islands modeling - a methodological approach – in Portuguese). – Revista da Faculdade de Letras, Geografia, Universidade do Porto série III, **1**: 123-159. – Online avaible at: http://ler.letras.up.pt/uploads/ficheiros/10560.pdf, 23/05/2013

Monteiro, A., L. Fonseca, M. Almeida, M. Sousa, S. Velho and *V. Carvalho* 2012b: Atlas da saúde e da doença – Vulnerabilidades climáticas e socioeconómicas: Grande Área Metropolitana do Porto – Concelho do Porto (Atlas of health and sickness – climatic and socio-economic vulnerabilities in the Greater Metropolitan Area of Porto and Concelho of Porto – in Portuguese). – PROJECTO ONDAS (PTDC/SAU-ESA/73016/2006), FCT – COMPETE I and II

Monteiro, A., V. Carvalho, S. Velho and *C. Sousa* 2012c: Assessing and monitoring urban resilience using COPD in Porto. – Science of the Total Environment **414**: 113-119

Monteiro, A., V. Carvalho and *C. Sousa* 2012d: Excess mortality and morbidity during the July 2006 heat wave in Porto, Portugal. Tmrt efficiency to anticipate negative effects on health (Paper T4A/306). – ICUC8 – 8th International Conference on Urban Climates, 6-10 August, UCD, Dublin, Ireland

Monteiro, A., V. Carvalho, T. Oliveira and *C. Sousa* 2013a: Excess mortality and morbidity during the July 2006 heat wave in Porto, Portugal. – International Journal of Biometeorology **57** (1): 155-167

Monteiro, A., V. Carvalho, A. Velho and *C. Sousa* 2013b: The accuracy of the heat index to explain the excess of mortality and morbidity during heat waves – a case study in a mediterranean climate. – Bulletin of Geography. Socio-economic Series **20**: 71-84

Monteiro, A., V. Carvalho, J. Góis and *C. Sousa* 2013c: Use of "Cold Spell" indices to quantify excess chronic obstructive pulmonary disease (COPD) morbidity during winter (November to March 2000-2007): case study in Porto. – International Journal of Biometeorology **57** (6): 857-870

Nastos, P. and *A. Matzarakis* 2008: The effect of air temperature and the thermal index PET on mortality in Athens, Greece. – Proceedings 18th International Congress on Biometeorology, 22-26 September, Tokio, Japan

Oke, T. 1973: City size and the urban heat island. – Atmospheric Environment **7** (8): 769-779

Philips, A., C. Schuster and *T. Lakes* 2013: Spatial modeling of heat stress risk in Berlin. – AGILE, 14-17 May, Leuven, Belgium

Planton, S., M. Déqué, F. Chauvin and *L. Terray* 2008: Expected impacts of climate change on extreme climate events. – Comptes Rendus Geoscience **340** (9-10): 564-574

Rooney, C., A. McMichael, R. Kovats and *M. Coleman* 1998: Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. – Journal of Epidemiology and Community Health **52** (8): 482-486

Silva, V. 2012: Vulnerabilidades socioeconómicas e ambientais em episódios térmicos extremos (Socio-economic and environmental vulnerabilities in extreme heat episodes – in Portuguese). – Master thesis in Hazards, Cities and Spatial Planning, Faculty of Arts, University of Porto, Portugal

Stone B., J. Hess and *H. Frumkin* 2010: Urban form and extreme heat events: Are sprawling cities more vulnerable to climate change than compact cities? – Environmental Health Perspectives **118** (10): 1425-1428

Wilhelmi, O. and *M. Hayden* 2010: Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. – Environmental Research Letters **5** (1): 1-7