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The social impacts of heat waves

Science Report – SC20061/SR6

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Steve Killeen

Head of Science

Executive Summary

The effects of the 2003 European heat wave have highlighted the need for society to prepare itself for and cope more effectively with heat waves. This is particularly important in the context of predicted climate change and the likelihood of more frequent extreme climate events; to date, heat as a natural hazard has been largely ignored.

In order to develop better coping strategies, this report explores the factors that shape the social impacts of heat waves, and sets out a programme of research to address the considerable knowledge gaps in this area.

Heat waves, or periods of anomalous warmth, do not affect everyone; it is the vulnerable individuals or sectors of society who will most experience their effects. The main factors of vulnerability are being elderly, living alone, having a pre-existing disease, being immobile or suffering from mental illness and being economically disadvantaged. The synergistic effects of such factors may prove fatal for some.

Heat waves have discernible impacts on society including a rise in mortality, an increased strain on infrastructure (power, water and transport) and a possible rise in social disturbance. Wider impacts may include effects on the retail industry, ecosystem services and tourism.

Adapting to more frequent heat waves should include soft engineering options and, where possible, avoid the widespread use of air conditioning which could prove unsustainable in energy terms. Strategies for coping with heat include changing the way in which urban areas are developed or re-developed, and setting up heat watch warning systems based around weather and seasonal climate forecasting and intervention strategies.

Although heat waves have discernible effects on society, much remains unknown about their wider social impacts, diffuse health issues and how to manage them.

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Background

The recent Stern Review called for evidence of the social and environmental consequences of climate change. The Environment Agency's response was drawn on our experience of managing the impacts of extreme events, particularly flooding. Whilst we were able to offer evidence of the social impacts of flooding and general impacts of climate change, little is known about the health and wider social impacts of extreme heat events.

This project builds on our work on environmental inequalities, by exploring current knowledge and understanding of the health and wider social impacts of extreme heat events associated with climate change. The study looks closely at the risks to and vulnerability of different social groups, particularly those who are socially and economically deprived. The report identifies gaps in our understanding and suggests ways in which these could be improved.

The study is part of the overall Science Project SC020061, *Tools for improving the worst quality environments for deprived areas and vulnerable social receptors*. This part of the project aims to scrutinise current policy responses and the evidence behind these policies, to understand how the Environment Agency can help address environmental inequalities from climate change.

1 Introduction

The effects of the 2003 European heat wave have highlighted the need for society to prepare itself for and cope more effectively with heat waves. This is particularly important in the context of predicted climate change and the likelihood of more frequent extreme climate events. To date, heat as a natural hazard has been largely ignored, but in recognition of the significant health effects of recent heat waves, the UK Department of Health has put in place a Heat Wave Plan for England (DoH, 2005).

There is no formal definition of a heat wave in terms of magnitude, duration and rapidity of onset. Accordingly, comparing heat wave studies is difficult as a variety of definitions are used for these events (Frich *et al.*, 2002; Souch and Grimmond, 2004; Robinson, 2001). In simple terms and for the purposes of this report, heat waves are considered as periods of “anomalous” heat that generate a societal response. Here, anomalous is interpreted qualitatively as an unusual event. A statistical definition of unusual or extreme would make reference to events that have a five percent chance or less of occurring based on historical records of, for example, temperature (McGregor *et al.*, 2005). Such events, because of their uniqueness, are often reported in the media because they have had some sort of societal impact.

In order to develop better coping strategies, this report explores the factors that shape the social impacts of heat waves, and sets out a programme of research to help address the considerable knowledge gaps in this area. Because heat waves have received less attention in the literature than other natural hazards, where many of the more pervasive effects remain unknown, this report emphasises the outcomes of mortality and morbidity, crime and infrastructure failure. Where examples are provided, these often have a London or South East focus, because these areas are located nearest to the air mass source regions associated with heat waves over the UK. Periods of anomalous warm weather are usually more intense and longer lasting in these areas than those experienced in the North.

This report focuses mainly on city to regional spatial scales and addresses impacts at the population level. Temporal scales relate to heat wave events covering less than 10 days typically. Some reference is made to climate change projections for the period 2070-2100.

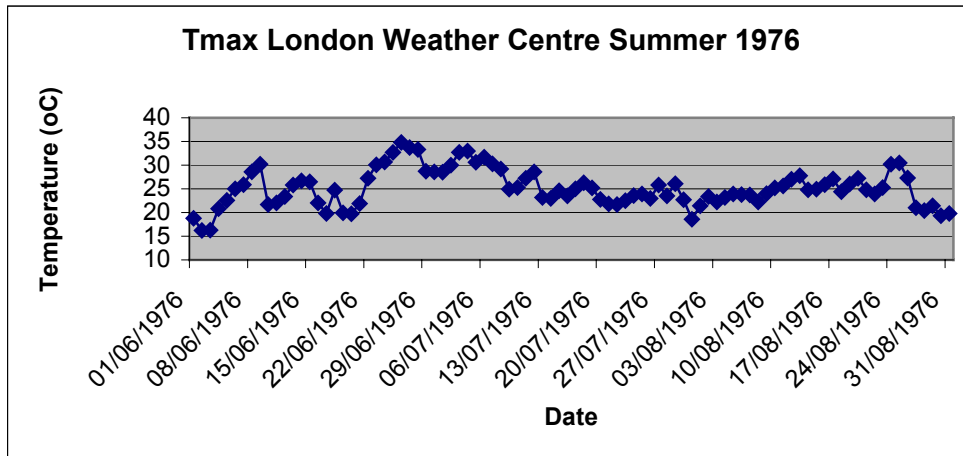
2 Heat waves: the climate context

Heat waves are a result of the interaction between atmospheric, oceanic and land surface processes that produce either prolonged periods of stable, often clear, weather with high inputs of solar radiation and thus high air temperatures leading to hot dry conditions or sequences of very warm and cloudy days that produce hot humid conditions.

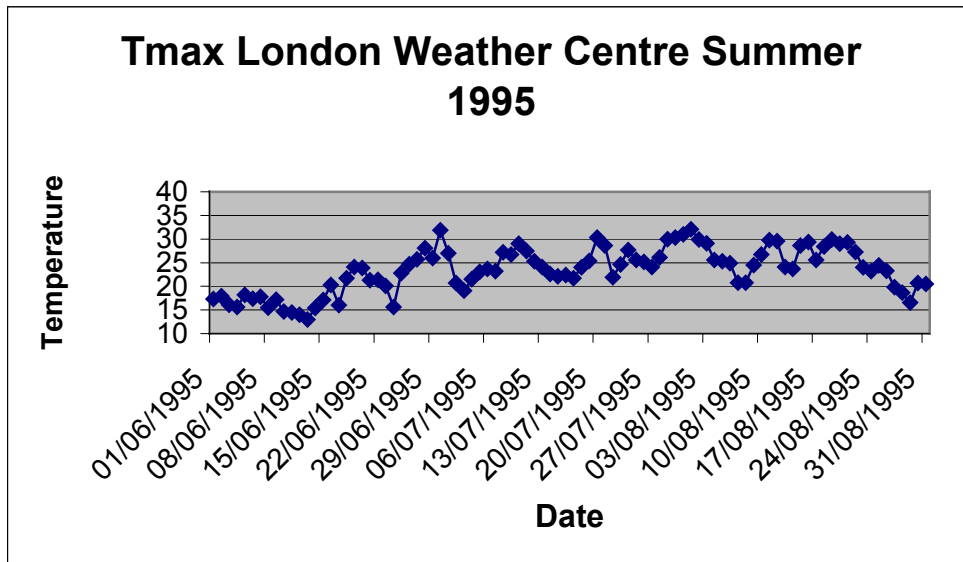
Evidence is emerging of a link between the anomalously hot, dry summer of 2003 and ocean and atmosphere interactions in the tropical Atlantic, related to wetter than average conditions in both the Caribbean and Sahel regions (Cassou *et al.*, 2005). Prolonged periods of blocking leading to reduced westerly flows, low precipitation and less soil moisture (Fink *et al.*, 2004) have also been identified as causative factors, with positive feedback between the dry European land surface and the overlying atmosphere resulting in reduced cloud cover, anomalously high amounts of sunshine and high surface and air temperatures (Zaitchik *et al.*, 2006). Further variations in North Atlantic and Mediterranean sea surface temperatures and connections further afield to the Intertropical Convergence Zone over West Africa, as well as atmospheric signals from South America and an intensification of the Azores high, are also likely to have played a role in the 2003 heat wave and associated drought (Black *et al.*, 2004). Understanding the nature of these interactions may lead to improvements in extended range forecasts of climate extremes (Grazzini *et al.*, 2003).

Over the last 30 years three major heat waves have occurred in England, namely 1976 (late June), 1995 (late July to early August) and 2003 (early to mid-August), all of which have had discernible social impacts. Although these events occurred at different times during the summer (Figure 2.1), all three coincided with widespread drought across the UK and all had distinct ozone episodes. These associations are quite common, but the synergistic effects are potentially lethal. July 2006 was also notable for record high temperatures for this time of the year, which exacerbated winter and spring drought conditions across much of Southern England. At the time of writing, the social impacts of this period of anomalous warmth are unrecorded.

(a)



(b)



(c)

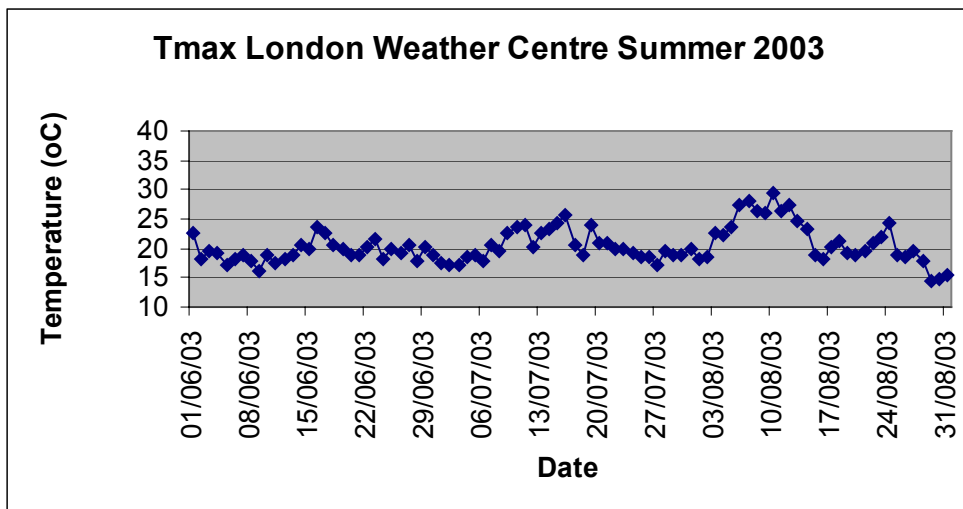


Figure 2.1: Daily maximum temperature (Tmax) during three heat wave events in London (a) 1976, (b) 1995 and (c) 2003

Although these three events received much attention in the literature, it is likely that some heat waves passed relatively unnoticed as their impacts were not as spectacular. A good example is the July 2003 heat wave which, although producing a noticeable impact on mortality across England and Wales, went relatively unreported in the press and became overshadowed by the August 2003 event (Table 2.1)

Table 2.1: Some climatological features of the July and August 2003 heat waves

	July heat wave	August heat wave
Highest maximum temperature and date	30.2°C, 15/7/03	33.0°C, 9/8/03
Highest minimum temperature and date	16.5°C, 17/7/03	17.5°C, 5/8/03
No. of days with Tmax > July-August 95 th percentile	4 days, 13-16/7/03	8 days, 3-10/8/03
No. of days with Tmin > July-August 95 th percentile	2 days, 16-17/7/04	3 days, 4-6/8/04 and 3 days, 10-12/8/04
Two highest temperature anomalies relative to 1961-1990 climatological value	10°C, 15/7/03 9°C, 14/7/03	12.8°C, 9/8/03 9.8°C, 6/8/03
Maximum rates of change of Tmax over 24 hours	4.1°C, 11-12/7/03 3.3°C, 12-13/7/03	5.6°C, 8-9/8/03 3.7°C, 3-4/8/03
Peak estimated mortality and date	1533, 15/7/03	1691, 11/8/03
Lag between Tmax and estimated mortality peak	0 days	2 days
Duration of persistent excess mortality from 1 st day of excess mortality	4 days, 13-16/7/03	10 days, 4-13/8/03

3 Climate change and heat waves

As noted in the Fourth IPCC Assessment on Climate Change (IPCC, 2007), heat waves may become more frequent, intense and of longer duration with anthropogenic forced climate change (Table 3.1).

Table 3.1 Confidence in project changes of temperature-related phenomena. VL is very likely, L is likely. Modified from IPCC (2007), Working Group I, Chapter 11.

Temperature-Related Phenomena	Projected changes
Change in Phenomena	Projected changes
Higher monthly absolute maximum of daily maximum temperatures(maxTmax); more hot/warm summer days	VL (consistent across model projections) maxTmax increases at same rate as the mean or median over Northern Europe. L (fairly consistent across models, but sensitivity to how the land surface is represented) MaxTmax increases more than the median over Souther and Central Europe. L (consistent with large projected increase in mean temperature Large increase in probability of extreme warm seasons.
Longer duration, more intense, more frequent heat wave/ hot spells in summer	VL (consistent across model projections) Over almost all continents, but particularly over Central Europe.
Higher monthly absolute maximum of daily minimum temperature (maxTmin); more warm and fewer cold nights	VL (consistent with higher mean temperatures) Over most continental areas
Higher monthly absolute minimum of daily minimum temperature (minTmin)	VL (consistent across model projections) MinTmin increases more than the mean in many mid- and high-latitude locations, particularly in winter over most of Europe, except the southwest.
Reduced diurnal temperature range	L ((consistent across model projections) Over most continental regions, night temperatures increase faster that the day temperatures.
Temperature variability on interannual and daily timescales	L (general consensus across model projections) Reduced in winter over most of Europe. Increase in Central Europe in summer.

Recent climate change experiments for Europe have used global climate models (GCMs) and regional climate models (RCMs) ‘forced’ with the IPCC A2 and B2 GHG emission scenarios to establish the possible effects of climate change. While the B2 scenario represents a future typified by low emissions, the A2 scenario assumes high emissions throughout the twenty-first century, resulting from low priorities for greenhouse-gas abatement and high population growth in the developing world (Nakićenović *et al.*, 2000). Under this scenario, atmospheric CO₂ levels will reach about 800 ppm per year by 2100

(three times their pre-industrial values). Projections based on this scenario therefore provide an estimate of the upper boundary of climate futures discussed by the IPCC (Beniston, 2004).

Climate projections for the period 2071-2100 under A2 and B2 scenarios reveal considerable warming in all seasons ranging from 1°C to 5.5°C, with temperatures generally 1-2°C lower in the case of low emissions (Beniston *et al.*, 2005; Ferro *et al.*, 2005; Giorgi *et al.*, 2004; Jones *et al.*, 2001; Jones *et al.*, 2004; Kjellstrom, 2004; Raisanen, 2004). Projections show maximum warming over Northern and Eastern Europe in winter. In summer, this occurs over Western and Southern Europe, with moderate changes over Southern England of 1-2°C. Changes in summer temperature extremes and periods of hot weather also occur under the A2 scenario. This can be seen in one projection of the impact of climate change on extreme events over Europe using the HIRHAM4 RCM developed at the Danish Meteorological Institute, one of the RCMs being used to investigate climatic change over Europe as part of the European Union project PRUDENCE (McGregor *et al.*, 2005).

Figure 3.1 shows an analysis of the projected changes (A2 scenario minus control) in the 90th percentile for summer maximum temperatures. The current situation is represented by the control run (Figure 3.1a). This shows higher temperatures for the 90 percent quantile over regions possessing a Mediterranean climate and also central South Eastern Europe where continental climates predominate. The projected change in the 90th percentile (Figure 3.1b) is greatest in two distinct regions: over Southern France and central and northern regions of the Iberian Peninsula where the greatest temperature anomalies occurred during the 2003 heat wave; and regions bordering the Black Sea. Except in regions that experience an increase in skewness (not shown), the change in 90th percentile is mostly attributable to a change in both the mean and the skewness indicating that a change in the variance, as well as the mean, will make a sizeable impact on future daily extreme temperatures.

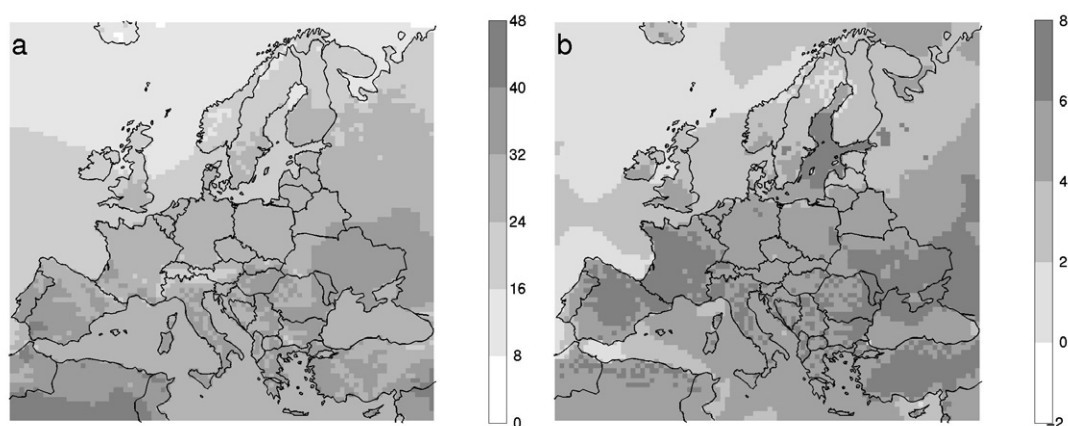


Figure 3.1: Current distribution (a) and projected changes in the distribution (b) of the 90th percentile for maximum temperature across Europe (source McGregor *et al.*, 2005)

Changes in temperature extremes can also be considered by evaluating the change in the number of days above 30°C, which provides a crude approximation of the way heat wave incidence and duration might change across Europe. According to the HIRHAM RCM control simulation, the majority of Western Europe currently experiences about five to ten days per summer with maximum temperatures in excess of 30°C (McGregor *et al.*, 2005). However, for the period 2071-2100 the situation could be quite different, with the model predicting increases of up to 60 days per summer in Mediterranean countries and 5 to 10

days over Southern England (Figure 3.2). By 2100, countries such as France may experience temperatures above 30°C as often as Spain and Sicily currently do. Consequently, this climate model predicts increases in heat wave frequency and duration across most of Europe, along with prolonged dry periods and increased probability of summer drought. Using a simple definition of a heat wave, based on three successive days above 30°C, a three- and ten-fold increase in the duration and frequency of heat waves might be expected for many places across Europe by the end of this century (Beniston *et al.*, 2005). This is in line with other assessments of changes in heat wave climatology for the Western Europe and the Mediterranean (Meehl and Tebaldi, 2004; Clark *et al.*, 2006).

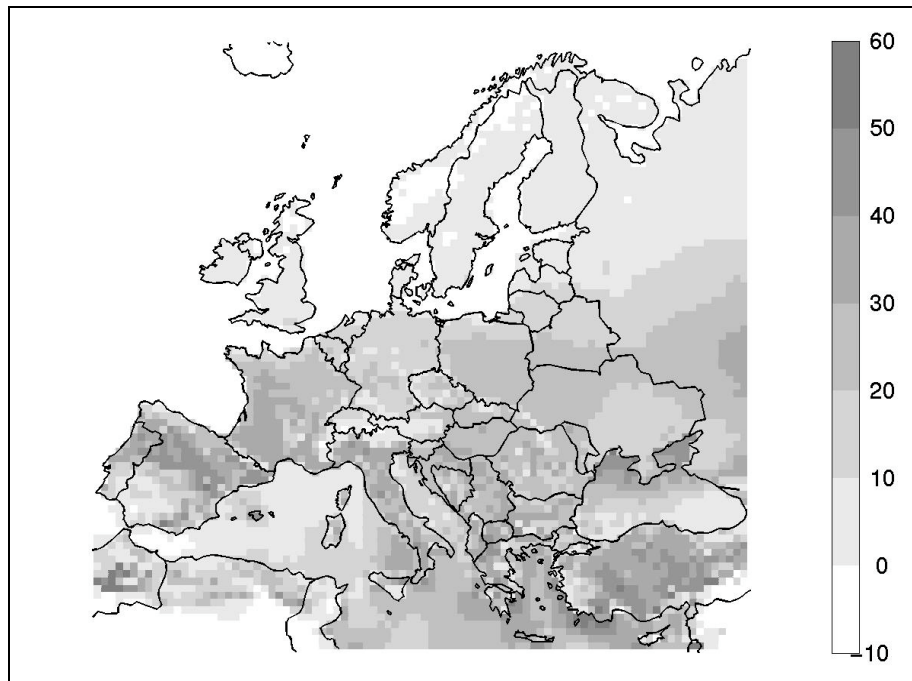


Figure 3.2: Changes in the occurrence of summer days (JJA) with maximum temperatures greater than 30°C (1961-90 compared to 2071-2100) (source McGregor *et al.*, 2005)

That such projections bear some semblance to reality is borne out by trends in the observed climate record. Hot days, hot nights, and heat waves have become more frequent (IPCC, 2007). Throughout most of Europe, the increase in the mean daily maximum temperature during the summer months was greater than 0.3°C per decade in the period 1976-1999. An increase in minimum or night-time temperature across Europe was noted for most locations over the period 1946-2004, with geographical contrasts apparent between the winter and summer and comparatively greater increases for summer compared to winter. Moreover, night-time increases were greater than that recorded for maximum or day-time temperatures (Klein-Tank *et al.*, 2002). Trends in warm spell duration (number of consecutive days above a given temperature threshold) were also observed, but unlike the situation for night-time temperatures, increases in this climate index were greater for winter compared to summer. A feature of the period 1946-2004 is symmetric warming (Klein-Tank and Konnen, 2003) meaning an approximately equal increase in the occurrence of both cold and hot extremes and thus no change in temperature variability. However, within this period, two asymmetric sub-periods of 1946-1975 and 1976-1999 may be identified due to contrasting relationships between the mean and extremes. During 1946-1975, slight cooling occurred across Europe with an associated decrease in the number of warm extremes. However, the annual number of cold extremes did not increase, implying a reduction in temperature variability. In

contrast, pronounced warming and an increase in the annual number of warm extremes at a rate two times faster than the expected change in cold extremes, implying increased variability, characterised the period 1976-1999 (Klein-Tank *et al.*, 2005).

The frequency of very hot days in central England has increased since the 1960s, with extremely hot summers in 1976, 1983, 1990, 1995 and 2003. Sustained hot periods have become more frequent, particularly in May and July. From a biometeorological point of view, such changes have had an impact on levels of human thermal comfort and the length of the discomfort season (McGregor *et al.*, 2002), the phenology of a range of plant and animal species (Ahas *et al.*, 2002; van Veilt and Schwartz, 2002) and the possible re-emergence of some tick-borne diseases (Randolph, 2004).

While there is general consensus that observed global warming is associated with a human-induced enhanced greenhouse effect, emerging evidence of an anthropogenic influence on the 2003 heat wave suggests that human influence doubles the risk of a heat wave exceeding 2003 temperatures (Stott *et al.*, 2004). If projections of climate change are considered in relation to the anomalous summer temperature in 2003, it is clear that the summer of 2003 may well be a harbinger of what we might expect as fairly normal by 2050 (Figure 3.3).

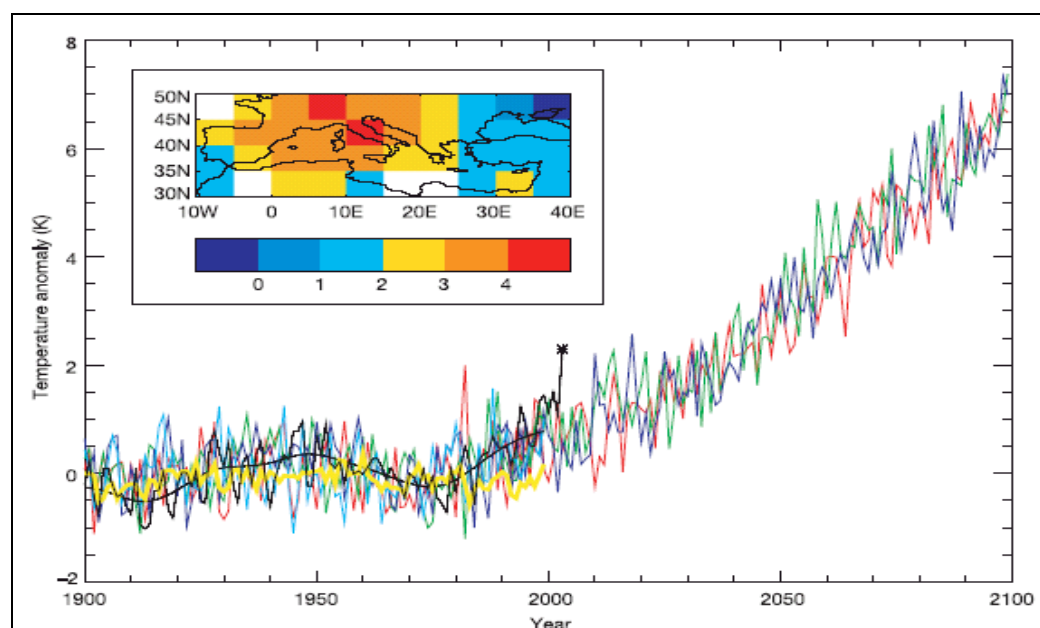


Figure 3.3: Projected changes in European temperatures up to 2100. Black line is observed and smoothed observed. Note that 2003 equates with what might be expected as an average summer for around 2050 (source Stott *et al.*, 2004).

Because a large percentage of the planet's population will be concentrated in cities by the middle of the twenty-first century, of special concern is the future climate of cities. Living in cities may be a health risk factor for those most at risk to heat, as cities during heat waves, because of an enhanced urban heat island effect, are usually much warmer than their rural environs (see Section 4.1). Furthermore, climate change is likely to have implications for urban drainage and flood risk (Hawkes *et al.*, 2003), city water resources (Diaz-Neito and Wilby, 2005), air quality and biodiversity (Wilby and Perry, 2006).

4 Vulnerability to heat

Vulnerability to heat is defined as a function of: the degree of exposure to the heat hazard, sensitivity to changes in weather/climate (the degree to which a person or system will respond to a given change in climate, including beneficial and harmful effects), and adaptive capacity (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate) (IPCC, 2001a). In general, vulnerability can be defined as follows:

Vulnerability = f (hazard, sensitivity, adaptation)

This concept may be applied to individuals and populations and is used as defined above in this report.

4.1 Heat hazard

The heat hazard is a function of the magnitude and duration of a period of anomalous heat. Exposure to heat may occur either outdoors or indoors. Nocturnal indoor temperatures are especially important, as it is at night that people usually gain some respite from the heat of the day. Unfortunately, little data exists for the UK on indoor temperatures in summer, so it is difficult to establish the degree to which indoor thermal climates pose a threat to human health. However, during the August 2003 heat wave nocturnal temperatures in London remained high for several nights and persisted beyond the peak in daytime temperatures, remaining high despite a decrease in daytime maximum temperatures (Figure 4.1). Such “nocturnal heat waves” may well be an important aspect of exposure for heat-related vulnerability.

Assuming a general linear relationship between indoor and outdoor temperatures, it is likely that the August 2003 heat wave saw indoor temperatures in some unventilated buildings venture beyond what is considered to be a comfortable range of 18-24°C (ASHRAE, 1992; WHO, 1987). High indoor and outdoor night-time temperatures reduce the exchange of heat between buildings and the atmosphere due to a decreased temperature gradient. Consequently, discomfort may persist with little respite from daytime heat.

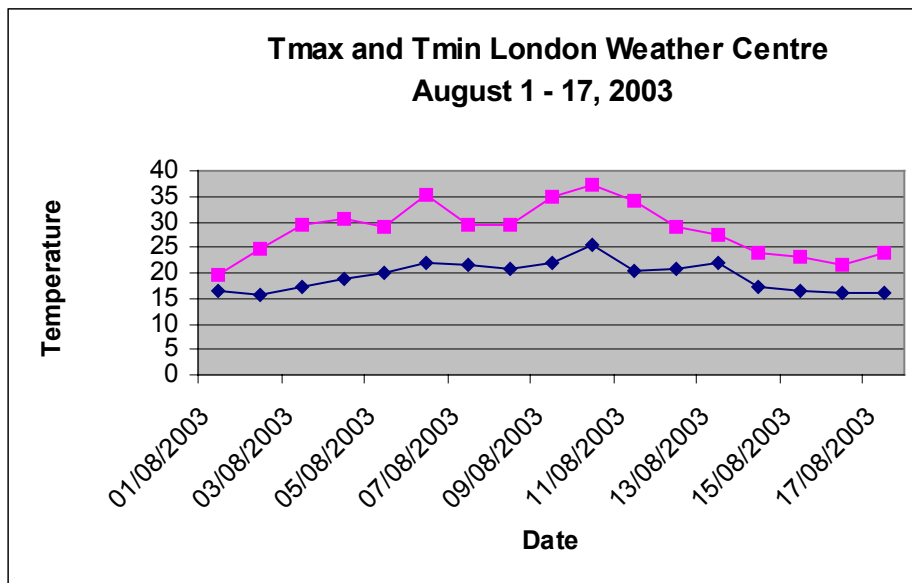


Figure 4.1: Daily maximum (Tmax, upper line) and minimum (Tmin, lower line) temperature over the course of the August 2003 heat wave

The “natural” heat hazard during heat waves may be exacerbated by the built form and land cover characteristics in some parts of cities, as well as emissions of anthropogenic heat from air conditioning units and vehicles. This has led some to suggest that the urban heat island (UHI), as represented by air temperature measurements, poses an additional risk to urban inhabitants during heat waves. Certainly the elevated nocturnal temperatures recorded within London during the August 2003 heat wave lend some support to this argument (Figure 4.1). For the UK, most work on the UHI has focused on London. Further, there is mounting concern about how climate change may affect the intensity of London’s UHI (Wilby, 2003a).

Luke Howard pioneered work on London’s UHI at the turn of the nineteenth century. Based on nine years of measurements, he noted an UHI effect of around 2°C during the night and an urban cool island of approximately 0.2°C during the day (Howard, 1820). By the mid-1960s, London’s UHI intensity (the nocturnal temperature difference between central London and its surroundings) had increased to 4-6°C (Chandler, 1965). More recently, Graves *et al.* (2001) and Threlfall (2001) have observed maximum UHI intensities of around 7°C for London. Although these studies cannot be compared directly, because of methodological differences, it is likely that as London has become more urbanised and the area of continuous built cover has increased, so has the UHI intensity.

Climatologically, the UHI reaches its maximum intensity between June and September. Based on a comparison of temperatures at Heathrow airport (urban site) and Beaufort Park (rural site), Threlfall (2001) found UHI intensities in excess of 3°C (7°C) occurring with a frequency of 15 (2) days a month, while Wilby (2003b) showed that the UHI has a clear weekly cycle. As with elsewhere, London’s UHI is primarily a night-time phenomenon, with the UHI intensity peaking at around 02:00-04:00. This is seen clearly during the August 2003 heat wave when the afternoon (15:00) temperature difference between central London (as represented by the London Weather Centre) and Heathrow airport was negligible. In fact, on some occasions central London was slightly cooler than Heathrow, indicating that

the UHI effect has a minimal impact on maximum daily temperatures in the city. In contrast, sizeable differences in temperature occur at night (03:00) of up to 3-4°C (Figure 4.2).

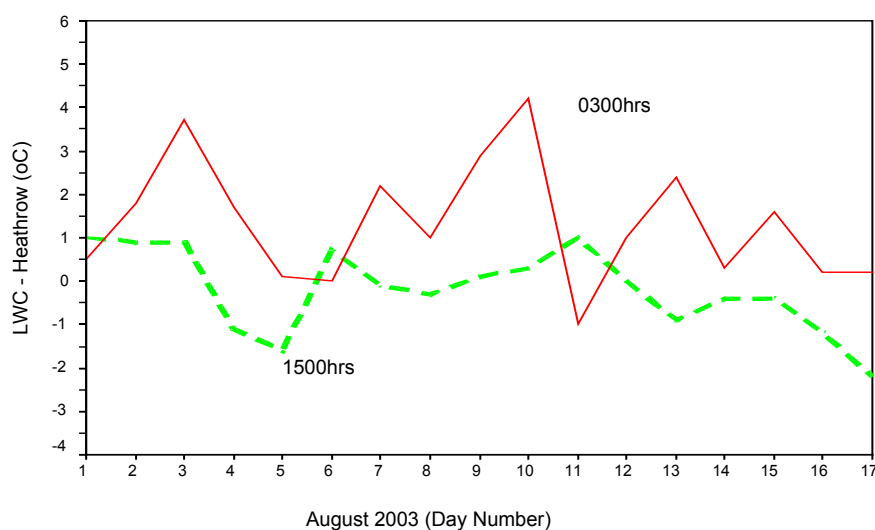


Figure 4.2: UHI intensity at 15:00 and 03:00 during the London 2003 heat wave

As noted by Graves *et al.* (2001), the intensity of London’s nocturnal UHI decreases with distance from the city centre, while at night there is a marked plume of warmth, which on average is oriented southwest-northeast centred on the British Museum (as the reference point). Crack (2002) also notes that the proportion of continuous urban cover has an impact on the UHI. Parks have a marked impact on the thermal field, with a mid-afternoon cooling of around 1-3°C demonstrated for a radial distance of around 200-400 metres from the park when compared to nearby streets (Graves *et al.*, 2001).

An alternative to the UHI view offered by conventional air temperature measurements is that provided by satellites of the surface heat island. Figure 4.3 shows one realisation of the surface heat island during the August 2003 heat wave. Assuming a general relationship between air and surface temperature under calm conditions, as occurred on this occasion, Figure 4.3 clearly shows the spatial variation of the heat hazard. Central London has much higher surface temperatures than surrounding areas. Areas with the highest temperatures coincide with densely built-up parts of the city characterised by little open green space.

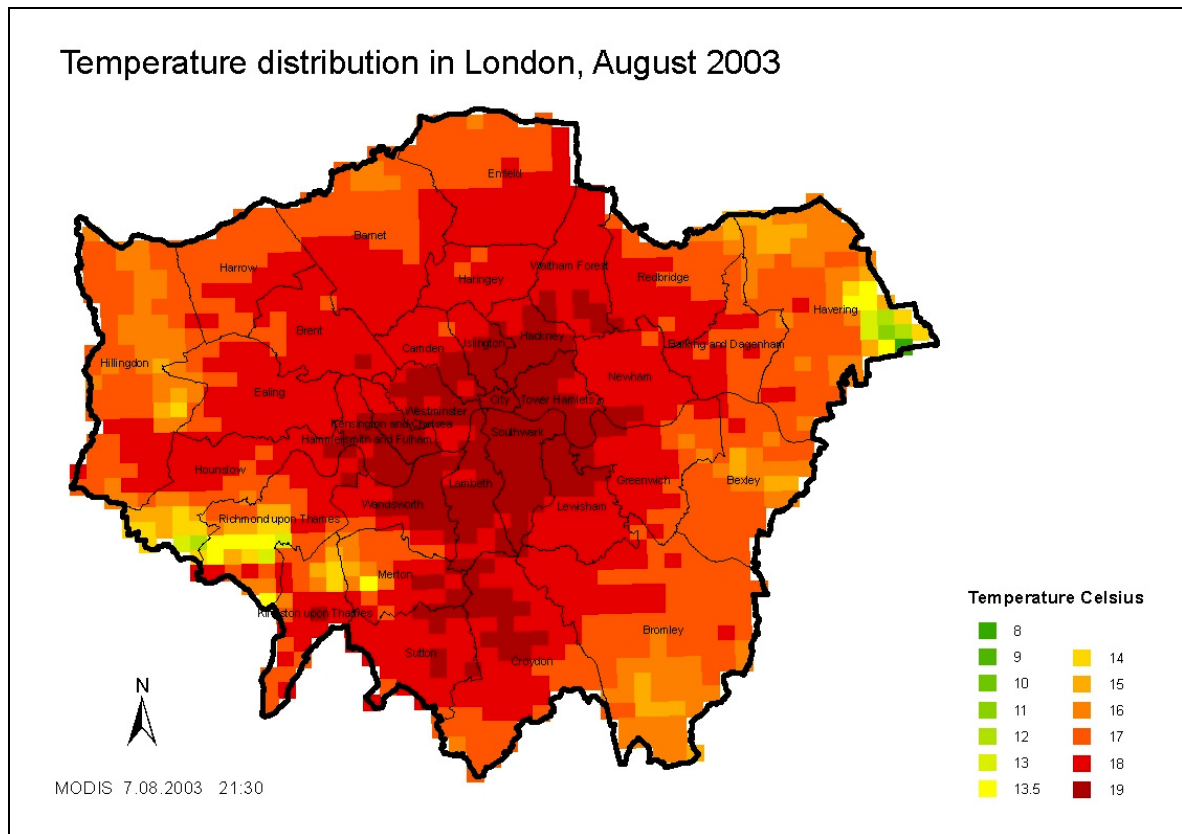


Figure 4.3: Surface temperature distribution across London at 21:00, 7 August 2003

A number of studies, mainly on urban areas, have attempted to identify threshold temperatures beyond which there are health effects. Some of these studies are summarised in Table 4.1. Different thresholds have been identified for different causes of death (Páldy *et al.*, 2005; Huynen *et al.*, 2001), though threshold values may be confounded by other meteorological variables. For example, Saez *et al.* (2000) found a 2°C higher threshold (23°C) on very humid days (relative humidity above 85 per cent) in Barcelona, Spain. Thresholds have also been found to vary according to age, with elderly populations being most susceptible to changes in temperature (Conti *et al.*, 2005; Empereur-Bissonnet, 2004; Donaldson *et al.*, 2003; Huynen *et al.*, 2001; Danet *et al.*, 1999; Whitman *et al.*, 1997), and temporally for a single location (Davis *et al.*, 2003a; Ballester *et al.*, 1997).

Comparative studies have found thresholds for heat-related (cold-related) mortality occur at higher(lower) temperatures in locations with a relatively warmer(colder) climate. For example the temperature of minimum mortality for South East England is 15 - 18°C whereas it is 22.7 - 25.7°C for Athens (Table 4.1). Also the gradient (or steepness) of the temperature-mortality relationship for increasing(decreasing) temperature is often found to be lower in warmer (colder) locations than colder (warmer) ones (Donaldson *et al.*, 2003; Pattenden *et al.*, 2003; Keatinge *et al.*, 2000; Eurowinter 1997). Hence, U- or V-shaped temperature-mortality relationships are common (Páldy *et al.*, 2005; Pattenden *et al.*, 2003; Huynen *et al.*, 2001; Ballester *et al.*, 1997), and in some cases a J- or hockey-stick shaped relationship is observed due to excess mortality in colder or warmer conditions from acclimatisation or adaptation (Donaldson *et al.*, 2003; Braga *et al.*, 2001; Saez *et al.*, 2000; Pan *et al.*, 1995). For example, Curriero *et al.* (2002) observed J-relationships for southern US cities with a warm climate and U-relationships for cooler northern cities. For London, Hajit *et al.* (2002) identified a threshold daily maximum temperature of around 27°C beyond which the ratio of observed to expected mortality increases dramatically (Figure 4.4)

Table 4.1: Summary of health-related threshold temperatures and mortality rates above threshold

Location	Temperature of minimum mortality (°C)	Reference	Notes
Netherlands	14.5	Huynen <i>et al.</i> (2001)	Total mortality, age 0-64, 1979-1997
South Finland	12.2 - 15.2	Donaldson <i>et al.</i> (2003)	Total mortality, age over 55, 1971-1997
Netherlands	15.5	Huynen <i>et al.</i> (2001)	For 1°C increase/decrease above/below 15.5°C, malignant neoplasms mortality increased by 0.47%/0.22% for 65yr+
Netherlands	16.5	Huynen <i>et al.</i> (2001)	For 1°C increase/decrease above/below 16.5°C, total mortality increased by 1.86% for period 1979-1997.
North Finland	14.3 - 17.3	Keatinge <i>et al.</i> (2000)	For 1°C increase/decrease above/below minimum mortality band, total mortality increased by 6.2/0.58
Various European countries	18	Eurowinter (1997)	Mean increase in total mortality/1°C fall below 18°C was 0.29%, 0.59%, 1.37% 2.15% for N. Finland, Netherlands, London, Athens respectively
South East England	15.0 - 18.0	Donaldson <i>et al.</i> (2003)	Total mortality, age over 55, 1971-1997
London (UK), Sofia (Bulgaria)	18	Pattenden <i>et al.</i> (2003)	Total mortality, all ages, 1993-1996. For London (and Sofia), increasing/decreasing temperature associated with a mortality change of +1.30%(+2.21%)/+1.43%(+0.70%) per 1°C temperature rise/fall above/below 18°C
Budapest (Hungary)	18	Páldy <i>et al.</i> (2005)	All ages, 1970-2000. For 5°C increase in temperature above threshold, risk of total mortality increased by 10.6% (total mortality), 18% (CD), 8.8% (RD)
United Kingdom	15.6 - 18.6	Donaldson <i>et al.</i> (2001)	Total mortality, all ages, 1976-1996
London (UK)	19	Hajat <i>et al.</i> (2002)	Above 21.5°C (97 th percentile value), 3.34% increase in deaths/1°C rise in temperature in total mortality (1976-96).
Barcelona (Spain)	21.1	Saez <i>et al.</i> (2000)	Age over 45, 1986-1991 (threshold higher (23°C) on very humid days (relative humidity over 85%)). Risk of IHD death increased ~2.4%/1°C drop of temperature below 4.7°C and ~4% with every rise above 25°C.
London (UK)	19.3 - 22.3	Keatinge <i>et al.</i> (2000)	Age 65-74, 1988-1992. For 1°C increase/decrease above/below minimum mortality band, total mortality increased by 3.6/1.25 percent
Valencia (Spain)	22.0 - 22.5	Ballester <i>et al.</i> (1997)	V-relationship evident annually, and in winter (NDJFMA) and summer (MJJASO) months respectively (min mortality at 22-22.5°C (annually), 15°C (winter) and 24°C (summer)).
North Carolina (US)	22.3 - 25.3	Donaldson <i>et al.</i> (2003)	Total mortality, age over 55, 1971-1997
Athens (Greece)	22.7 - 25.7	Keatinge <i>et al.</i> (2000)	Age 65-74, 1988-1992. For 1°C increase/decrease above/below minimum mortality band, total mortality increased by 2.7/1.6
Taiwan	26 - 29	Pan <i>et al.</i> 1995	Coronary heart disease and cerebral infraction in elderly
Lisbon (Portugal)	15.6 - 31.4	Dessai (2002)	Total mortality, all ages, 1980-1998
11 cities in eastern US	Various	Curriero <i>et al.</i> (2002)	J- or U-relationship depending on latitude of city – greater effect of cold on mortality risk in southern cities and of warmth in northern cities.

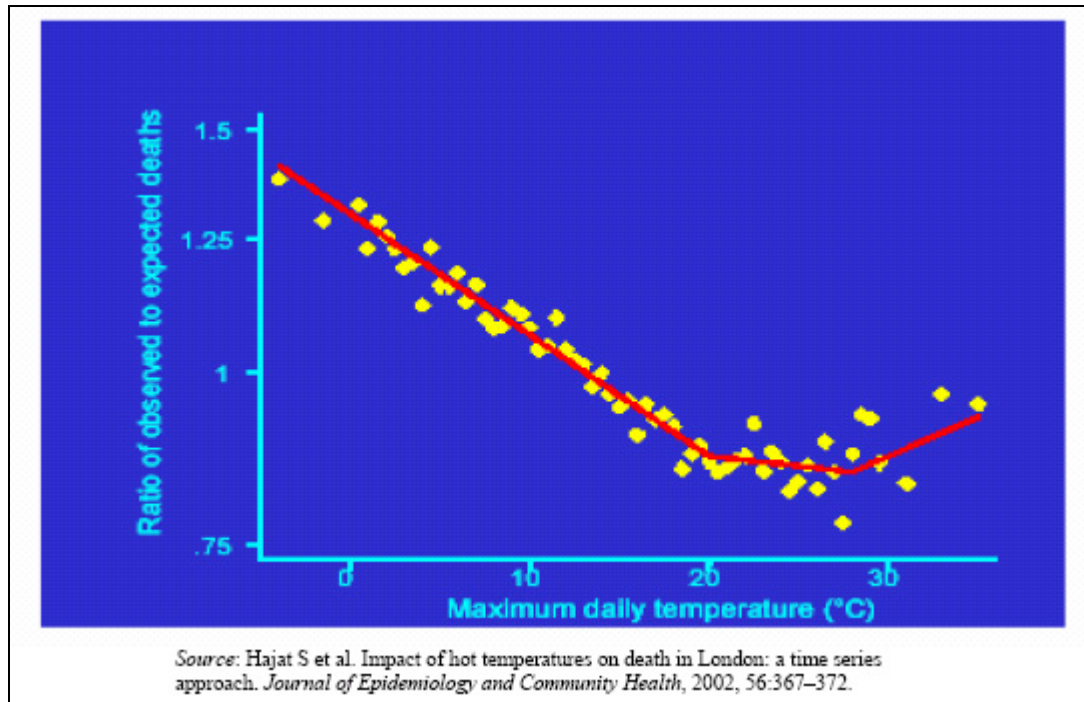


Figure 4.4: Relationship between temperature and mortality for London. Note the threshold around 27°C beyond which expected deaths rise steeply.

4.2 Sensitivity

Sensitivity refers to both the physiological and behavioural response to anomalous heat. The former will not be addressed here, but there is emerging literature offering insights into how people may respond to changes in levels of human comfort in response to heat and cold (BSIRA, 2002; Chappells, 2003; Nicol *et al.*, 1999; Neimeyer *et al.*, 2005).

A variety of studies have found that some sectors of the population are more vulnerable to heat than others. The elderly (usually defined as 65 years and over) are more vulnerable to heat illness than younger people because of dysfunctional thermoregulatory mechanisms, chronic dehydration, medication, and diseases involving systems that regulate body temperature (Worfolk, 2000). Epidemiological studies on heat and health indicate that people at highest risk of death following heat waves are over 60, or work in jobs requiring heavy labour, or live in the inner city and/or low-income districts and thus are exposed either to low economic status or higher temperatures or both (Keatinge *et al.*, 2000; Basu and Samet, 2002). Although children are another potential risk group, evidence from the August 2003 heat wave in England indicates only a small effect of hot weather on children. Moreover, it is uncertain whether this is directly attributable to the hot weather as a range of causes, including injuries/accidents, generally increase in good weather as children spend more time outdoors (Johnson *et al.*, 2005).

Prominent causes of heat wave fatalities are cardiovascular, respiratory and cerebrovascular diseases (Basu and Samet, 2002). People with a pre-existing illness, especially heart and lung disease, are at higher risk of dying in heat waves. In fact, cardiovascular and respiratory causes of deaths are most strongly linked with changes in temperature. This makes elderly people with pre-existing health problems and those suffering from poor social conditions most susceptible to the impact of rapid weather

changes (Ballester *et al.*, 2003; O'Neill *et al.*, 2003b). Also, mental illness shows a positive association with heat-related death (Kaiser *et al.*, 2001). Evidence from the US and Italy indicates that people with diabetes, fluid/electrolyte disorders and some neurological disorders are at much higher risk of heat-related death (Schwartz, 2005; Stafoggia *et al.*, 2006)

Underlying the demographic risk factors are some behavioural risk factors such as living alone, being confined to bed, not being able to care for oneself, having no access to transportation, not leaving home daily and social isolation (Semenza *et al.*, 1996). Such factors characterise the social status of many elderly people. It is primarily an individual's reduced physical capacity to cope with the heat (high sensitivity), and a limited capacity to adapt in conjunction with social dependency that produces high sensitivity.

Much has been learnt about risk factors from the August 2003 heat wave in France, where a significant correlation was found between mortality and socio-professional categories (workers at risk), the degree of autonomy (people confined to bed or not autonomous in getting washed and dressed), health status (patients with cardiovascular, psychiatric or neurological diseases) and the quality of thermo-insulation of the home (INVS, 2004).

Air conditioning has been shown to protect people from the adverse health effects of heat (Davis *et al.*, 2003; Semenza *et al.*, 1996). Its increasing use may have reduced heat-related mortality in US (Donaldson *et al.*, 2003; Davis *et al.*, 2003). As an adaptive strategy air conditioning is hotly debated, given its high energy consumption and its contribution to anthropogenic heat flux and thus enhancement of the urban heat island. Further, those least capable of adopting this type of adaptation strategy, namely the urban poor, are also the sector of the population most vulnerable to heat stress.

Socio-economic status is another important determinant of sensitivity. Life expectancy at birth varies with socio-economic deprivation and is highest in the most affluent groups. Regional life expectancies display a north-south gradient in UK. Further linear regression analysis shows that deprivation explains most of the geographical variation in life expectancy in the UK (Woods *et al.*, 2005). Based on this, it might be expected that spatial variation in the social response to heat waves at the intra to inter-city scales may in some way reflect variations in deprivation, as this is also a key sensitivity factor. A recent study of 11 European countries showed that high excess mortality among the elderly population of lower socio-economic status constitutes an important health problem in Europe. Absolute differences in mortality were found to be substantial and relative socio-economic inequalities in mortality to be large. Inequalities in mortality related to education and to housing tenure showed varying patterns (Huisman *et al.*, 2004).

Wealth is a fundamental variable of exposure and sensitivity. Access to economic assets plays a large role in determining an individual's district of residence, housing tenure and quality. Economic assets are also associated with lifestyle, employment, age, gender, ethnicity, health status and ability to buy goods that might alleviate heat stress – all shaping an individual's sensitivity to heat. This makes wealth a key indicator of sensitivity but also limits its utility as an explanatory variable, as many underlying factors are compounded in measures of economic wealth.

Wealth also impacts indirectly on individual sensitivity through the capacity of local authorities to provide co-ordinated and timely assistance to enable people to cope with heat. Thus, poor individuals at risk can have their vulnerability exacerbated by living in areas controlled by local government or health practice administrations with limited resources. It is, of course, also possible for well managed and financed local agencies to ameliorate vulnerability above the norm, particularly when shared resources are made available through comprehensive disaster planning involving multiple agencies such as city managers, public health and social services workers and emergency medical officers.

The evidence for modest neighbourhood effects on health is consistent despite heterogeneity of study designs, substitution of local area measures for neighbourhood measures and probable measurement error. By drawing attention to the health risks associated with the social structure and ecology of neighbourhoods, innovative approaches to community-level interventions may ensue. Attributing health disparities to neighbourhood social context requires the isolation of individual-level socio-economic influence. Findings of significant interactions suggest that neighbourhood context may differentially affect the health of people. (Pickett and Pearl, 2001) and therefore may be an important determinant of sensitivity to the heat hazard. There is good evidence from the US that low income groups are more at risk of heat-related mortality where it is likely that air conditioning plays a major role in prevention – and it is only the very poorest groups that do not have the capacity to maintain air conditioning during heat waves (Kilbourne *et al.*, 1982; Rogot *et al.*, 1992; Smoyer, 1998).

Many factors may explain why such inequalities occur. The increased risk in groups with lower socio-economic status may be due to differences in housing, neighbourhood or the underlying prevalence of chronic disease. Material and behavioural factors also contribute to socio-economic differences in health and therefore potentially to heat-related vulnerability. The effect of material factors on health may be mediated by behavioural factors, and unhealthy behaviours may partly result from living in poorer material circumstances (Laaksonen *et al.*, 2005).

Middelkoop *et al.* (2001) found that mortality risk generally increases with an increase in the deprivation score of a residential area. They found that the main contributors to mortality differences between the highest and lowest socio-economic quartiles amongst males were ischaemic heart disease and other diseases of the circulatory system. For females, the differences were even greater. In the context of heat vulnerability, these findings are significant as such illnesses lead to increased sensitivity to heat and the possibility that sensitivity to heat is partly conditioned by the degree of deprivation. Educational inequalities in cause-specific mortality in middle-aged and older men and women have been found in eight Western European populations (Huisman *et al.*, 2005) and may also contribute to the degree of sensitivity from the individual to societal scale.

Education and training are key to building social resilience to heat stress. This is true for individuals at risk and also for those caring for the vulnerable, as family members or professionals. Sensitivity is reduced when people are empowered to take risk-reducing actions. Knowledge is the first step in this process. However, this does not mean that educational standard is an unproblematic indicator of sensitivity. Those with limited formal education may be very well informed about how to cope with heat waves. A more useful indicator might be the extent to which public information campaigns have been targeted at high risk groups, for example recent migrants, tourists, the elderly, care workers, those working in conditions that might raise exposure. Where such campaigns are organised by local authorities or health agencies, this could translate into spatially differentiated sensitivity.

Housing standards shape exposure through the tendencies for particular ages and styles of housing to occupy high and low heat stress districts of the city and through the characteristics of particular architectural styles (those where windows cannot be opened, for example) (Hacker *et al.*, 2006). Design standards for work places, transport infrastructure and public places such as sports arenas or schools are equally important in shaping exposure. The association of housing standards with sensitivity is less clear. Housing standards will influence coping to some degree, for example the availability of design features to allow heat to escape - or that force heat build-up, for example in loft conversions. Housing standards also provide an indirect indicator of economic resources and of infrastructure quality, such as reliability of access to water – low water pressure during droughts might limit water availability in some ill-maintained dwellings. Housing affects

health in direct and indirect, physical-material and social ways (Shaw, 2004) and as shown for cold spells in the UK, can play an important role in health outcomes (Rudge and Gilchrist, 2005). Although housing characteristics appear to play a role in determining sensitivity in the US (Smoyer, 1998), as yet no evidence has emerged of its role during heat waves in the UK (Kovats *et al.*, 2006).

Being elderly and institutionalised may increase vulnerability to heat-related illness and death (Faunt *et al.*, 1995). For example, the mortality rate increased almost two-fold in geriatric hospital inpatients (but not other inpatients) during the 1976 heat wave in the UK (Lye and Kamal, 1977). This may be associated with high indoor temperatures in institutions such as hospitals and care homes; high indoor temperatures were measured in one hospital in London during the 2003 heat wave (Newton, 2005).

Overcrowding is often associated with low income, inner city locations and rental tenure. These variables indicate high vulnerability. However, overcrowding can also reduce vulnerability. If household members are supportive of one another, then the capacity to watch for and respond to symptoms of heat stress in more vulnerable household members is increased. In other words, overcrowding can lead to greater care. This potential is determined by cultural and socio-economic characteristics. The latter in particular is amenable to public policy that enables household members to care for others during heat waves. Measures might include time off work (a siesta model) and public education programmes.

As well as physical health, mental health can be an important determinant of sensitivity. Physical and mental health problems have been shown to cluster within households (Chandola *et al.*, 2005) such that people living within the same area or from the same household share similar mental and physical health functioning. The apparent clustering of health functioning at the ward level may be partly explained by a combination of compositional risk factors and the clustering of health problems at the household level. This suggests that certain families or neighbourhoods may be more susceptible to the health effects of heat waves.

4.3 Adaptation capacity

As defined by Adjer *et al.* (2004), adaptation capacity is recognition of the need to adapt, belief that adaptation is possible and desirable, willingness to adapt, availability of resources to implement a strategy, ability to use resources in an appropriate manner and external constraints on, or obstacles to, the implementation of adaptation strategies.

In the context of heat-related adaptation capacity, cognisance is important. Probably more people have been killed by a lack of recognition of the need to adapt, belief that it was possible/desirable or willingness to adapt than from the lack of air conditioning and cheap energy. In terms of economic conditions, Alberini (2005) has concluded, based on a survey of 100 experts, that the adaptation capacity (and thus vulnerability) may not only depend on income, but also on the inequality of income distribution within an area which may in turn influence social interaction/isolation. This builds on the ideas of Shevky and Bell (1955) who refer to the importance of difference in socio-ecological status in neighbourhoods for social action/activity spaces and thus group adaptation capacity: the shorter the spatial distance between two individuals/groups, the greater the number of contacts made and the shorter the social distance, the greater the number of contacts. This seems to be borne out by evidence from the 1995 Chicago heat wave; during this time, a relatively low number of heat-related deaths occurred amongst the Latino population because of tight social networks and strong family bonds across several generations, which contributed to this community's ability to cope with the heat (Klinsberg, 2002).

Air conditioning is often recommended as a way of adapting to heat. Although air conditioning is not used widely in the UK, it is increasingly used in domestic buildings. With an average installation cost of £4,500 for a whole house, this is an expensive alternative affordable for only a few, thus increasing inequity between the economically advantaged and disadvantaged. Alternative technologies such as heat pumps are even more expensive than conventional air conditioners (Triggle, 2004). Environmental groups are fundamentally opposed to the use of mechanical air conditioning, as its widespread use could intensify the urban heat island (Ichinose *et al.*, 1999). Despite the arguments against its use, there is a common belief amongst building and environmental engineering services that it would only take two or three hot summers for the UK market to reach a critical mass and like air conditioning in cars, it would be here to stay (Giles, 2003).

This scenario has obvious implications for energy demand. Excessive use of air conditioning may account partly for the power cuts in London reported by the electricity company EDF during the period of hot weather in July 2006 (Jowit and Espinoza, 2006). Associated with air conditioning is the concept of the artificial preservation of a prescribed thermal optimum, but as noted by Chappells and Shove (2004), maintaining engineered indoor climate conditions may commit society to unsustainable patterns of energy use. Accordingly, there must be some adjustment of lifestyles and building design to meet the challenges of higher indoor temperatures associated with climate change and extreme heat events.

5 Social impacts

5.1 Mortality and morbidity

A clear outcome of heat waves is a rapid rise in mortality, as seen in England during the 1976 (MacFarlane, 1977a, 1977b, 1978; Lye and Kamal, 1977; Ellis *et al.*, 1980; McMichael and Kovats, 1998), 1995 (Rooney *et al.*, 1998; Kovats *et al.*, 2004) and 2003 heat waves (Johnson *et al.*, 2005). Table 5.1 summarises the percentage increase in excess deaths for these three heat wave events. Of note is the high percentage increase amongst the elderly.

Table 5.1: Excess deaths (%) by age group for three heat wave events

Age group	England & Wales 1976	England & Wales 1995	England & Wales 2003	Greater London 1976	Greater London 1995	Greater London 2003
0–14	5.9	4.5	-9.9	13.5	13.1	0.8
15–64	7.2	8.2	9.4	12.0	15.6	14.7
65–74	7.2	8.4	2.0	10.2	13.2	14.1
75–84	11.5	8.5	17.7	19.5	14.9	44.7
85 and over	14.8	10.3		21.6	20.1	
All ages	9.7	8.9 (8.6) [§]	13.2	15.4	16.1 (15.4) [§]	33.3

[§] Values are age-adjusted to the age-at-death distribution of 1976. 2003 estimates for 75-plus.

Baseline mortality estimated as average deaths for same heat wave calendar period in previous five years. Source: Rooney *et al.* (1998), McMichael and Kovats (1998) and data from ONS.

Table 5.2 shows the variation in mortality by Government Office Region during the August 2003 heat wave. Despite higher temperatures recorded outside of London in the South East, the greatest increases in population-adjusted mortality occurred in the city, lending weight to the contention that the urban heat island contributes to the mortality rate. If so, it would appear that for the elderly, living in London is a risk factor. Further, the impacts of the 2003 heat wave in London appear to be greater than previous heat waves, as increases in all-age mortality were 15 and 16 percent for the 1976 and 1995 heat waves respectively, compared with 42 per cent for 2003 (see Table 5.2).

Such differences may be related to the prolonged nature of the 2003 heat wave compared to the shorter previous events, although confounding social factors cannot be discounted. An analysis of the location of deaths in London during the 2003 heat wave reveals a high percentage of excess mortality in nursing and especially residential care homes for the under-75 age group. Increases in excess mortality in hospitals and own homes were greater in the over-75 compared to the under-75 age group (Kovats *et al.*, 2006).

Table 5.2: Geographical variation in mortality by Government Office Region for the August 2003 heat wave (source Johnson *et al.*, 2005).

Government Office Region	Age Group			All ages
	0-64	65-74	75+	
London	13	18	59	42
South East	13	17	26	22
South West	17	11	25	22
Eastern	28	-10	27	20
East Midlands	23	-2	21	17
West Midlands	2	4	14	10
Yorkshire and Humber	-3	-6	15	8
North West	-4	-2	8	4
North East	6	-6	3	1
Wales	5	-10	10	5
England and Wales	11	3	22	16

Although increases in hospital admissions would be expected to complement trends in mortality, this appears not to be the case; there is little evidence of increases in such admissions during the August 2003 heat wave. The reasons for this are not clear, but heat-related deaths may occur before people come to medical attention (Kovats *et al.*, 2004). The role of health services in reducing hospital admissions is shown by the pattern of calls to NHS Direct during the 2003 heat wave. For example, Leonardi *et al.* (2006) found that calls to NHS Direct during the July 2003 heat wave reached greater levels compared to those for the August heat wave. This suggests that the first heat wave may have prepared some sectors of the population for the second, thus preventing high hospital admissions.

As noted earlier, little attention has been given to the health effects of other periods of anomalous heat over the past 30 years in the UK. This offers an area for future work. Further, the extent to which serious mental conditions such as schizophrenia and manic depression worsen with changes in the weather, with associated changes in suicide rates, warrants investigation.

5.2 Crime

There is much debate about the association between hot weather and crime (Anderson, 1989; Anderson *et al.*, 1997; Cohn, 1990, 1993; Field, 1992). Hot weather is also linked with higher levels of street violence and attacks, as well as rioting and unrest (Rotton and Cohn, 2000a, 2000b). However, many reports of the association between crime and hot weather are more speculative than definitive. For example, it has been suggested that the riots that erupted on the streets of Oldham in 2001 were partly fuelled by very warm night-time temperatures. Although the factors that conspire to bring about riots are complex, it has been noted recently that major riots in England have often occurred during periods of anomalous warmth for the time of year. For example, the Notting Hill riots in August 1976 (19°C); the Toxteth riots in July 1981 (21°C); the Brixton riots in September 1985 (21°C); the Handsworth riots, the same month (21°C) and the second chapter of the Toxteth riots in October 1985, which took place in a 27°C heat wave. (<http://www.guardian.co.uk/weather/Story/0,2763,498326,00.html>) (last accessed August 8, 2007)

For the US, most major riots appear to have occurred when the temperature was between 27°C and 34°C. New York City sees regular summer crime waves, believed to be a result of the hot weather (http://www.bbc.co.uk/weather/features/health_culture/behaviour.shtml) (last accessed August 8, 2007). In Canada, acute gun crime may be associated with hot weather. There is also the likelihood that road rage increases during periods of anomalous

warmth (Kenrick and MacFarlane, 1984), as does domestic violence (Auliciems and DiBartolo, 1995) and the number of police call outs (LeBeau and Corcoran, 1990). In contrast, warm weather may reduce crime as people chose to go elsewhere during hot weather, thus diverting incidences (Bailey K, Exeter News, August 3, 2004).

5.3 Role of infrastructure

This section explores the ways in which the infrastructures of urban societies can magnify as well as mitigate the human health and wider social effects of extreme heat. Evidence from past urban heat shock events is framed by a general discussion of the interactions of critical infrastructures and urban disasters.

5.3.1 What magnifies the impact of extreme heat?

Cities include many different but interdependent types of critical infrastructures and services: systems for life support (energy, drinking water and sanitation, food distribution), social development (health, education, community development and social support), innovation (cultural and intellectual services including the media), communication (transport, telephone and IT networks), social control (policing and regulatory functions) and the economy (private markets and financial services). Each system is dependent on the others. Events disrupting one system can have domino effects on others, so that disaster can spread and multiply if not checked.

For rapid onset disasters (storms, earthquakes and so on) and human disasters (technological and political events), the magnifying effect of critical infrastructure during disasters is well documented. Much effort in disaster management is expended on containing initial shocks, to prevent the escalation of hazard impacts through the knock-on consequences of infrastructure failure. This is not the case for extreme heat events, where limited work has been carried out on potential and actual knock-on effects of weaknesses or failures in infrastructure. Despite a lack of studies, knock-on effects have been identified in:

- critical physical infrastructures which may fail under high demand, such as drinking water and electricity systems, thus greatly magnifying the number of people at risk;
- emergency services staff and vehicles which may be overwhelmed by the scale of an unfolding crisis – emergency staff may themselves become prone to heat stress as a result of overwork;
- the capacity of hospitals and mortuaries, which may soon be exhausted – this has consequences for the care of patients and relatives.

Disaster managers often divide their work into the components of a disaster cycle. Preparedness and prevention precede a disaster event, emergency response and rehabilitation follow an event and feed into subsequent rounds of preparedness and preparation, which should be undertaken as everyday elements of development practice. The complexity of urban neighbourhoods and city regions means it is not uncommon for multiple elements of the disaster cycle to be unfolding in the same place at any given time. Extreme heat can interrupt the management of other hazards by undermining preparedness, prevention, response or reconstruction tasks. Similarly, other hazards (including social, economic and political as well as environmental pressures) could undermine the management of vulnerability to extreme heat. For example, an episode of extreme heat would magnify, and be magnified by, the impacts of a prolonged drought or civil unrest in the city.

Very little work has been carried out on the interaction of extreme heat with other hazards and pressures on the city, although the US Federal Emergency Management Agency (FEMA) notes that extreme heat combined with drought can have a serious impact on a community: “*increased demand for water and electricity may result in shortages of resources. Moreover, food shortages may occur if agricultural production is damaged or destroyed by a loss of crops or livestock.*”¹

The geographically distributed character of urban life support systems means that extreme heat in the city also affects social systems at a distance from the metropolis. For example, strategies to manage heat stress that rely on air conditioners would contribute negatively to government targets for greenhouse gas emissions and serve to shift the burden of environmental risk from British cities to those parts of the world most at risk from climate change and a sea-level rise.

5.3.2 What determines the resilience of critical infrastructure?

Understanding what shapes the contribution of urban infrastructure systems to social vulnerability is helped by framing this question in terms of resilient systems. Pelling (2005), drawing from Wildavsky (1988), identifies six principles of resilient systems.

Communication and learning. Systems are maintained by feedback between component parts, which signals changes and can enable learning.

Diversity of inputs. External shocks are mitigated by diversifying resource requirements and their means of delivery. Failure to source or distribute a resource can then be compensated for by alternatives.

Fast throughput. The faster the movement of resources through a system, the more resources will be available at any given time to help cope with perturbation.

Horizontal governance. Overly hierarchical systems are less flexible and hence less able to cope with surprise and adjust behaviour. Top heavy systems will be less resilient.

Spare capacity. A system which has a capacity in excess of its needs can draw on this capacity in times of need, and so is more resilient.

Dual functions. A degree of overlapping function in a system permits the system to change, by allowing vital functions to continue while formerly redundant elements take on new functions.

These principles of resilience are exemplified in Box 1, which describes the unexpected testing of a system for supporting the elderly and vulnerable during heat crises.

Box 1: Resilience to extreme heat contributes to city risk management

Following the 1995 Chicago heat wave, the Office of Emergency Management (OEM) for New York City created a network to address the special needs of the elderly and the particularly vulnerable. At risk individuals were identified through their being registered to receive home-based care or nursing services, having contact with the New York State Department for the Aging, or participating in activities at senior citizen centres.

¹ <http://www.fema.gov/hazards/extremeheat/heat.shtm>

While this network was designed to respond to potential heat waves, it was fully tested following the World Trade Centre attacks on 11 September 2001. When implemented, the OEM needed to contact the 3,500 vulnerable individuals within the affected area to ensure that they were receiving care. Within two hours of the disaster, a call centre was initiated, and within 24 hours, all but 30 individuals were contacted.

A joint team of Red Cross volunteers and construction workers began to locate the remaining individuals, because the OEM and the police were occupied with events at the World Trade Centre site. The use of the call centre was successful and demonstrated the scope for flexibility that spare capacity, dual functions, horizontal governance, diversity of inputs, fast throughput, communication and learning can deliver.

Source: The National Academies (2005)

5.3.3 What is the role of critical infrastructure in extreme heat events?

Infrastructure and public health are not necessarily thought of as interconnected, although their relationship can be profound, especially in disasters. Below are examples of infrastructure failures during extreme heat events. .

Failures in communication infrastructure

Reflecting on the heat wave that hit Europe in 2003, Dr Bettina Menne of WHO Europe's Global Change and Health Programme argues for the need for early warning, as past events have taken health services by surprise "*We didn't expect Europe to have been so affected by extreme weather. The crisis came much earlier than we thought*"². A variety of early warning systems are now being developed, typically by combining meteorological and mortality data (Pascal *et al.*, 2006). The contribution of early warning to reduced mortality has been demonstrated in studies of extreme heat events in Philadelphia and Chicago (Ebi *et al.*, 2004).

In France, a report by Health Minister Jean-Francois Mattei noted a number of failures in communication and data management. Information on the scale of the 2003 crisis was not pooled because the health ministry, other government departments and workers on the ground were so compartmentalised. The August leave system meant that the cabinet was absent and many doctors were on holiday, compromising the workings of the emergency system. Mattei's report called for improved organisation of the healthcare system, liaison between weather services, hospitals and those caring for the elderly, and better provision of beds for elderly patients. It demanded an adequate alert, monitoring and warning system to allow those involved to act more quickly and flexibly to adapt the health care system before and during a crisis.

At a more strategic level, planning for extreme heat with the public and with emergency management agencies is difficult because of a positive association with heat. Images of heat waves do not have the same destructive properties as a tsunami, flood or terrorist event. This makes it difficult to garner popular and political will for prevention and planning for response.

Failures in physical infrastructure

² <http://news.bbc.co.uk/1/hi/sci/tech/3839833.stm>

Thornburgh (2001) notes that in US cities, where private air conditioning is the first line of defence against extreme heat, heavy stress is put on energy systems. He notes that peak demand during heat waves forces companies to engage in rolling blackouts to prevent a total blackout of the affected region. While rolling blackouts increase risk, this is preferable to a total blackout, which would increase the vulnerability of an entire population. During the summer 2005 heat wave, power usage in New York City reached a record of 12,551 megawatts³. Impacts of power supply may also be a result of the shutdown of nuclear power plants because cooling water temperatures become too high, as witnessed in the August 2003 heat wave and more recently during the hot July weather across Western Europe (Jowit and Espinoza, 2006).

In London, the underground system is a source of particular concern, with a number of studies highlighting the cost and technical difficulty of cooling. Ampofo *et al.* (2004) argue that under normal conditions, the high costs of cooling legitimise the view that established standards of thermal comfort for an office are not achievable for the underground. Less studied is the combined impact of heat, crowding and standing on health under conditions of extreme heat. The possibility of power outages associated with a heat event and the potential for underground passengers to be stranded for prolonged periods during hot weather should also be considered.

Failures in social infrastructure

Individual vulnerability can be managed by changing personal habits. Reflecting on vulnerability to extreme heat in the UK, Keatinge (2005) argues that the elderly could reduce their own risk by avoiding physical exercise, eating and drinking more and staying out of the heat. But changing habits is hard and more work needs to be done to develop support for those at risk to recognise when and how to change habits. In continental Europe, most mortalities were reported from retirement homes. Here, there is great scope for training carers to enable residents to adapt to high temperatures, especially as the elderly can fail to feel the need to drink enough in the heat (Menne, 2004).

US experience places great emphasis on private air conditioning as a first line of defence against extreme heat. However, Klinenberg (2002) points out that the cost of electricity may be too high for some vulnerable groups to use air conditioning, even if they have access to units. Indications from the 1978 Texas heat wave suggest that some elderly people on fixed incomes, many of them in buildings that could not be ventilated without air conditioning, found the cost too high, turned off their units, and ultimately succumbed to the stresses of heat⁴.

Alternatives to increased private use of air conditioning are suggested below.

For the work place, flexible working practices that incorporate a siesta break during periods of extreme heat offer a simple way of staying cool without installing air conditioning.

In US cities, where air conditioning is commonplace in public buildings, city officials have kept public buildings open 24 hours a day as cooling centres for residents without air conditioning⁵.

Building design can also take heat into account. But given the long-term investment for making change and the uncertainties of climate change and variability over this time span – including the possibility of climatic cooling in North West Europe – building design criteria might be difficult to rely on as an adaptive strategy.

³ <http://news.bbc.co.uk/1/hi/world/americas/4723233.stm>

⁴ Source: US Red Cross <http://www.nws.noaa.gov/om/brochures/heatwave.pdf>

⁵ Source: <http://news.bbc.co.uk/1/hi/world/americas/409080.stm>

A study by Solecki *et al* (2006) showed that greater vegetation cover and higher-albedo surface colours can reduce heat build-up (with vegetation cover also absorbing air pollution). Vegetation cover, including the greening of roof space, is an alternative to air conditioning, although densely populated inner-city neighbourhoods may have less open space and potential for thermal control through greening.

Klinenberg (2002) argued that neighbourhood factors also influence individual risk to extreme heat. Those who live in high-crime areas may be wary of opening windows, constraining indoor air circulation and increasing temperatures. Additionally, the mentally ill, who are more likely to be alone because of difficulty in gaining and maintaining social support, may also have difficulty cooling down or avoiding severe sunburn due to their medication. The social processes leading to isolation and lack of information amongst vulnerable groups requires further attention if patterns of risk are to be understood and fed into public health policy.

The Chicago extreme heat disaster of 1995 has been the most rigorously studied event to date. Box 2 offers a case study of the role of infrastructure in shaping patterns of risk during this event.

Box 2: Complicating factors in the Chicago heat wave of 1995

The health impact of the Chicago heat wave was magnified by a combination of failures in communication, physical and social infrastructures. The chief failures were:

Communication failures

Some paramedics who first arrived on the scene reported that their own departments refused to release additional ambulances and staff to cope with the workload.

City officials did not release an emergency heat warning until the last day of the heat wave. Because of the delay in issuing an excessive heat advisory, emergency measures such as Chicago's five cooling centres were not fully utilised, severely taxing the medical system as thousands were taken to local hospitals with heat-related problems.

Failure in physical infrastructure

Around 49,000 households were affected when the energy supplier ConEd failed, turning off fans and air conditioners.

Social infrastructure

The collapse of community life in some districts characterised by high crime rates and limited public spaces such as shops, libraries or health centres contributed to the isolation of the vulnerable elderly and their invisibility to health and community services as well as neighbours.

Source: Klinenberg (2002)

5.4 Wider social impacts

Three main types of impacts have so far been emphasised: mortality/morbidity, crime and infrastructure. However, this list is not exhaustive, as wider social impacts may occur during or immediately following heat waves. As little literature is available on the subject, this section only flags up potential impacts. Amongst these are impacts on the following:

- the natural environment, leading to loss of utility for ecosystem services and eco-tourism;
- forestry and agriculture, which has implications for employment in the rural sector;
- the occurrence of fire either through natural causes or arson;
- the supply of energy, with extra demands on electricity for cooling but savings on gas for heating;
- retail and manufacturing, especially in the clothing and food sectors as warm weather increases demand for certain food, drink and clothing items;
- construction and buildings through the effect of hot weather on building materials, although this might be offset by fewer days lost to wet weather;
- transport, through speed reductions on rail networks and the deterioration of surfaces on roads that have not been resealed following new standards for asphaltting;

- tourism, by encouraging people to take short domestic trips during hot weather;
- insurance, as heat waves may aggravate ongoing subsidence by exacerbating dry soil conditions as a result of moderate to severe drought.

In addition to the above, the water industry may be severely affected by the imposition of drought orders and hosepipe bans. Domestic water supplies may also become compromised in areas which rely heavily on surface water resources, requiring water to be imported to meet domestic demand.

6 Preparing for heat extremes

This section briefly considers adaptive measures to heat, their effectiveness and the implications of the heat hazard for UK policy.

6.1 Adaptive measures

Positive and preventative action can turn the magnifying effects of infrastructure failure into forces for mitigating disaster. Such actions also offer potential qualitative indicators for urban security from heat extremes. Preparedness programmes – a major component of any adaptation strategy for extreme heat –, can include heat warning systems and other measures such as telephone helplines or public cooling centres.

Heat warning systems are being developed which integrate weather forecast information with heat warnings and associated intervention strategies (Ebi *et al.*, 2004; Sheridan and Kalkstein, 2004). There may also be use for seasonal-scale climate predictions for long-lead warning of the likelihood of anomalously hot summers and possible heat waves (McGregor *et al.*, in press).

New and existing buildings can be designed or made heat-safe, for example by planting grass roofs on industrial buildings and expanding green space in the city. However, significant tree planting needs to take into account the effect of tree species and associated biogenic emissions on air quality, especially ozone in the summer. Greening of roofs will have impacts at the building scale, but are unlikely to affect wider areas. Urban development and re-development should take into account urban climate principles and the close association between climate processes and policy (Table 6.1)

Table 6.1: Association between urban planning/management policy and urban climate

Policy scale	Urban climate scale
Individual building/street (construction materials, design and orientation).	One to ten metres. Indoor climate and street canyon.
Urban design (arrangement of buildings, roads, green space).	Ten to 1,000 metres. Neighbourhood scale, suburban variations of climate.
City plan (arrangement of commercial, industrial, residential, recreational and natural space).	One to 50 km. City/metropolitan scale, UHI form and intensity.

Public air-conditioned buildings can be used as cooling centres, with free transport provided to these shelters 24 hours a day.

Lists should be compiled of elderly people who live alone and who might need assistance, so workers can call or visit those residents to alert them of imminent dangerous weather..

A telephone hotline can be set up to update the public on safety information.

A monitoring system for emergency room admissions and the activity of paramedics should be set up, as the danger posed by a weather system can immediately be understood by monitoring the health impacts reported by frontline responders.

Before a heat wave arrives, a city should examine its water system and communication infrastructure to determine how, when and where response systems will be needed. Heat

waves are often associated with periods of drought, with sustained dry conditions exacerbating heat wave intensity through positive feedback between the dry land surface and the overlying atmosphere. Heat waves associated with drought will exert considerable strain on water resources. This may limit measures such as street watering to reduce air temperatures.

Often a group of indicators, based on weather and social welfare information, can be used to help city managers decide when, in the slow onset of a heat wave, the hazard must be treated as an imminent threat. Indicators should be linked to a graded set of intervention strategies related to the severity of the event and projected impacts.

Managers should plan and maintain public education and communication, to acknowledge and publicise the imminent threat without creating undue public alarm. They should also plan, before a disaster, to put in place the administrative and data collection systems needed to perform a social autopsy after the disaster and learn from the event.

In a review of heat shock preparedness plans, the International Federation of the Red Cross and Red Crescent Societies (IFRC, 2004) recommended that preparedness plans should involve multiple partners, including city managers, public health and social services workers, and emergency medical officers. However, practical preparedness must be complemented by a fundamental change in attitudes towards highly vulnerable groups such as the elderly. Box 3 lists elements of Philadelphia's heat wave preparedness plan.

Box 3: Philadelphia's heat wave preparedness plan

The US city of Philadelphia saved 117 people during heat waves from 1995 to 1998 through a Hot Weather Health Watch Warning System, which comprises the following components:

- (i) Using mass media to encourage friends and neighbours to visit elderly people daily.
- (ii) Activating a telephone hotline to provide information and counselling.
- (iii) Organising visits by health authorities to people requiring attention.
- (iv) Informing care homes of a high-risk heat situation.
- (v) Increasing fire department and hospital emergency staffing.
- (vi) Implementing daytime outreach services to homeless people.

Source: IFRC (2004)

The components of planning for heat safety developed in US cities should not be used blindly in the very different context of the UK, where urban populations are less segregated, residential care may be differently regulated, building designs and urban planning have different forms, fewer vulnerable people have access to air conditioners and the generation and distribution systems for electricity, water and emergency health care are different. The influence of context can be seen by comparing the heat waves in France in 2003 and Chicago in 1995. In France, two-thirds of heat wave victims died in hospitals, private health care institutions and retirement homes, whilst in Chicago most died alone, locked in their apartments.

Context is also important in terms of health impacts. For example, mortality in Paris was high amongst the residents of social housing (Menne, 2004), while in Chicago, the most vulnerable group was the isolated elderly living at home (Klinenberg, 2002). The former points to the need for training of elderly care providers, whilst the latter indicates a need to understand the processes leading to isolation of the elderly, and for local community or health agencies to provide support during heat waves.

6.2 Effectiveness

A fundamental determinant of the effectiveness of any plan or early warning system is whether all social groups have equal access to, and the ability to use, the information provided.

Early warning is a core feature of any risk reduction strategy. Early warning has three stages: the generation of scientific information upon which a warning can be reliably based; dissemination of information to populations at risk; and the capacity of populations to act upon this information. For heat shocks, the second and third components present the greatest challenge.

Capacity to act upon environmental information is influenced greatly by factors based on economic assets, social integration, individual behaviour and lifestyle and physiological determinants such as age and mobility.

Trust in warning sources is also crucial. Individuals and social groups with the least stakes in society and those with past experience of inaccurate environmental information are less likely to take notice of or act on official warnings. As heat waves are set to increase in severity and frequency over the coming decades, past personal experience, and that of others transmitted through informal communication, will influence the extent to which warnings and advice are taken seriously. The next five years may be critical in providing advice on an emerging risk. Once personal experience of heat extremes has been gained, subsequent warnings and advice will be more closely followed.

Particular attention should be paid to people who care for vulnerable individuals. These include elderly home care workers, pre-school carers, friends and family caring for people at home. It is important that information and advice be presented in a format that reminds carers not only of their own risk but also that of the people they care for. For example, when doing a weekly shop for an elderly relative, this might also be a good time to talk about heat and hydration.

Ability to access and absorb environmental information is similarly influenced by social factors. The most important are language, access to broadcast media and informal knowledge networks.

Minority language groups are often doubly vulnerable through living in conditions that entail high exposure (high-density dwellings or rough sleeping, for example), and being excluded from English language media. The relatively large non-English speaking population in London and the rapid increase in the number of languages spoken by residents are a real challenge for the dissemination of timely warnings. The use of symbols to accompany verbal or written warnings is a common strategy in multi-linguistic communities, but this may not help in providing advice on safe behaviour (for example, do not leave children, the elderly or pets locked in cars for long periods).

Clearly access to television, radio and newspapers is fundamental to any public warning system. Many of the most vulnerable, including those on low incomes and recent migrants to the city, are also among the minority who do not have regular access to the media. A multi-media approach is most effective in reaching the largest population possible.

Networks of friends and family can help to verify official warnings. For those without access to broadcast media, such networks become the main channel of information. If summer heat waves are to become a regular occurrence, then providing information on coping with heat and recognising the signs of dehydration and heat stress might usefully be distributed amongst social workers or charity groups in contact with illegal immigrants or rough sleepers, for example.

6.3 Policy on vulnerability

Assessing UK policy on vulnerability is a little like assessing policy on wellbeing – all aspects of state and local government work and legislation impact on vulnerability. In recent years, early warning and information dissemination has improved. However, in 2004 a World Health Organisation study on urban heat risk in Europe concluded that the UK had no specific warning system, although a system was in place for hospitals to provide daily information on the weather situation (WHO, 2004). In 2005, a UK National Heat Wave Plan was introduced by the Department of Health. This has since been enhanced by the Met Office, which now coordinates a Heat Health Watch warning service from 1 June to 15 September each year, operated in association with the Department of Health and the Welsh Assembly.

The Department of Health has also been active in disseminating information via a leaflet called *Heat wave - a guide to looking after yourself and others in hot weather*, sent to GP surgeries and pharmacies. Charities such as Age Concern also provide gateways to inform the elderly and carers on how to reduce risk

Local authorities are well placed to carry out assessments of vulnerability and follow this up with targeted early warning and information campaigns. The Local Government Association issues press releases on heat stress⁶ and provides links to the UK Climate Impacts Programme (UKCIP) guidance for local authorities on adapting to climate change. The London Climate Change Partnership (LCCP) offers a focal point for disseminating information and advice on coping with climate change, including heat waves. Commenting on the UK National Heat Wave Plan, the LCCP argues that some agencies that need to take the most action to support the vulnerable have the most limited budgets, for example care services for the elderly. The following recommendations are made by the LCCP to reduce vulnerability in London (LCCP, 2006):

- the homeless population should be specifically targeted for support;
- local authorities and other public bodies should work together to plan cooling centres;
- local authorities and primary care trusts should consider setting up a buddy system for carers and those at risk;
- guidelines are needed for those caring for vulnerable people;
- risk assessments for institutions such as elderly people's homes, hospitals, prisons and hostels should be undertaken;
- warning systems should use novel ways of reaching all communities at risk, making use of informal networks, faith groups and so on.

The work of the LCCP, UKCIP, the Met Office and the Department of Health, in conjunction with local authorities and charities such as Age Concern, shows that heat stress has now firmly become a policy issue. However, much remains to be done to institute the reforms and practices advocated by these agencies. UK policy on ameliorating vulnerability to heat waves needs to be backed by discussion of and support for the innovative recommendations being proposed.

⁶ <http://www.lga.gov.uk/PressRelease.asp?id=-A783BEC9>

7 Pathways for improving the evidence base

This review has identified the following areas for research and opportunities for learning from the experience of other countries:

- develop a chronology of heat waves across England, keeping in mind that such a chronology will be heat wave definition dependent;
- explore the relationship between periods of anomalous warmth and social behaviour, with the aim of identifying socially relevant weather/climate thresholds;
- develop a set of heat vulnerability indicators of adaptive capacity and heat hazard components to aid heat risk mapping;
- evaluate potential and actual knock-on effects of weaknesses or failures in infrastructure that could magnify the impact of extreme heat, in particular, the consequences of a heat wave and electricity shut-down leading to failure in transport and water systems;
- assess the interaction of extreme heat with other hazards such as air quality and in particular, water security for UK cities;
- explore the social processes leading to isolation and lack of information amongst vulnerable groups;
- assess the scope for individual adaptation, including changes in behaviour and how this is constrained by social attributes;
- examine possible strategies for social adaptation, in particular alternatives to private air conditioning such as greening of city space and the provision of public cooling centres;
- explore and assess the effectiveness of early warning systems, to include technological aspects and also mechanisms for reaching the elderly and isolated.

References

- Adger NW, Brooks N, Bentham G, Agnew Md, Eriksen S. 2004. *New indicators of vulnerability and adaptive capacity*. Tyndall Centre for Climate Change Research Report.
- Ahas R, Aasa A, Menzel A, Fedotova G, Scheifinger H. 2000. Changes in European spring phenology. *International Journal of Climatology*, 22, 1727-1738.
- Alberini A, Chiabai A, Muehlenbachs L. 2005. Using expert judgment to assess adaptive capacity to climate change: Evidence from a conjoint choice survey. IN FEEM. Milano.
- Ampofo F, Maidment G, Missenden J. 2004. Underground railway environment in the UK. Part 1: Review of thermal comfort, *Applied Thermal Engineering*, 24, 611-631.
- Anderson CA. 1989. Temperature and aggression: Ubiquitous effects of heat on occurrence of human violence. *Psychological Bulletin*, 106, 74-96.
- Anderson CA, Bushman BJ, Groom RW. 1997. Hot years and serious deadly assault: empirical tests of the heat hypothesis. *Journal of Personality and Social Psychology*, 73, 1213-1223.
- ASHRAE. 1992. *Standard 55 – Thermal environmental conditions for human occupancy* American Society of Heating Ventilating and Air-conditioning Engineers, Atlanta, USA.
- Auliciems A, DiBartolo L. 1995. Domestic violence in a subtropical environment: police calls and weather in Brisbane. *International Journal of Biometeorology*, 39, 34-39.
- Ballester F, Corella D, Perez-Hoyos S, Saez M, Hervas A. 1997. Mortality as a function of temperature. A study in Valencia, Spain, 1991-1993. *International Journal of Epidemiology*, 26, 551-561.
- Ballester F, Michelozzi P, Iniguez C. 2003. Weather, climate, and public health. *Journal of Epidemiology and Community Health*, 57, 759-60.
- Basu K, Samet, JM. 2002. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiological Review*, 24, 190-202.
- Beniston M. 2004. The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations. *Geophysical Research Letters*, 31:L02202, Doi:10.1029/2003gl018857.
- Beniston M *et al.* 2005. Future extreme events in European climate: An exploration of regional climate model projections. *Climatic Change* (in press)
- Black E, Blackburn M, Harrison G, Hoskins B, Methven J. 2004. Factors contributing to the summer 2003 European heat wave. *Weather*, 59, 217-223.
- Braga AL, Zanobetti A, Shwartz J 2001. The time course of weather-related deaths. *Epidemiology*, 12, 662-667.
- BSRIA. 2002. *The world market for air conditioning*. Bracknell, Building Services Research and Information Association.
- Cassou C, Terray T, Phillips AS. 2005. Tropical Atlantic influence on European heat waves. *Journal of Climate*, 18, 2805-2811.
- Chandler TJ. 1965. *The climate of London*. Hutchinson, UK, 292 pp.

- Chandola T, Clarke P, Wiggins RD, Bartley M. 2005. Who you live with and where you live: setting the context for health using multiple membership multi-level models. *Journal of Epidemiology and Community Health*, 59, 170-175.
- Chappells H, Shove E. 2004. Comfort: A review of philosophies and paradigms. Department of Sociology, University of Lancaster. Available at: http://www.lancs.ac.uk/fss/sociology/research/projects/futcom/fc_litfinal1.pdf (15 August, 2006)
- Chappells H. 2003. *Re-conceptualising electricity and water: Institutions, infrastructures and the construction of demand*. PhD Thesis, Lancaster University.
- Cheatwood D. 1995. The effects of weather on homicide. *Journal of Quantitative Criminology*, 11, 51-70.
- Clark, R., S. Brown, and J. Murphy, 2006. Modelling northern hemisphere summer heat extreme changes and their uncertainties using a physics ensemble of climate sensitivity experiments. *Journal of Climate*, 19, 4418–4435.
- Cohn G. 1990. Weather and crime. *British Journal of Criminology*, 30, 51-64.
- Cohn G. 1993. The prediction of police calls for service: The influence of weather and temporal variables on rape and domestic violence. *Journal of Environmental Psychology*, 13, 71-83.
- Conti S, Meli P, Minelli G, Solimini R, Toccaceli V, Vichi M, Beltrano C, Perini L. 2005. Epidemiologic study of mortality during the summer 2003 heat wave in Italy. *Environmental Research*, 98, 390-399.
- Crack R. 2002. *Parameters controlling the spatial distribution and temporal development of London's heat island*. MSc. Dissertation, Reading University.
- Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. 2002. Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology*, 155, 80-87.
- Danet S, Richard F, Montaye M, Beauchant F, Lemaire B, Graux C, Cottel D, Marecaux N, Amouyel P. 1999. Unhealthy effects of atmospheric temperature and pressure on the occurrence of myocardial infarction and coronary deaths. *Circulation*, 100, 1-7.
- Davis RE, Knappenberger PC, Michaels PJ, Novicoff WM. 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives*, 111, 1712-1718.
- Dessai S. 2002. Heat stress and mortality in Lisbon. Part I. Model construction and validation. *International Journal of Biometeorology*, 47, 6-12.
- Diaz-Nieto J, Wilby RL. 2005. A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. *Climatic Change*, 69, 245-268.
- DoH. 2005. *Heat wave plan for England - protecting health and reducing harm from extreme heat and heat waves*. London, UK Government, Department of Health.
- Donaldson G, Kovats RS, Keatinge WR, McMichael AJ. 2001. Heat- and cold-related mortality and morbidity and climate change. In: Maynard, RL (ed.), *Health effects of climate change in the UK*, Department of Health, London, 70-80.
- Donaldson GC, Keatinge WR, Näyhä S. 2003. Changes in summer temperature and heat-related mortality since 1971 in North Carolina, South Finland, and South East England. *Environmental Research*, 91, 1-7.

- Ebi K, Teisberg TJ, Kalkstein LS, Robinson L, Weiher RF. 2004. Heat watch/warning systems save lives: Estimated costs and benefits for Philadelphia 1995-98. *Bulletin of the American Meteorological Society*, 85, 1067-1073.
- Ellis FP, Prince HP, Lovatt G, Whittington RM. 1980. Mortality and morbidity in Birmingham during the 1976 heat wave. *Quarterly Journal of Medicine*, 49, 1-8.
- Empereur-Bissonnet P. 2004. Health impacts of the 2003 heat wave in France. In: Kirch W, Menne B, Bertollini R (eds.), *Extreme weather events and public health responses*, Springer, New York, 21-22.
- Eurowinter. 1997. Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. *Lancet*, 349, 1341-1346.
- Faunt JD, Wilkinson TJ, Aplin P, Henschke P, Webb M, Penhall RK. 1995. The effete in the heat: heat-related hospital presentations during a ten-day heat wave. *Australian and New Zealand Journal of Medicine*, 25, 117-120.
- Ferro CAT, Hannachi A, Stephenson DB. 2005. Simple nonparametric techniques for exploring changing probability distributions of weather. *Journal of Climate*, 18, 4344-4354.
- Field S. 1992. The effect of temperature on crime. *British Journal of Criminology*, 32, 340-351.
- Fink AH, Brucher T, Kruger A, Leckebusch GC, Pinto JG, Ulbrich U. 2004. The 2003 European summer heat waves and drought – synoptic diagnosis and impacts. *Weather*, 59, 209-216.
- Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Klein Tank AMG, Peterson T. 2002. Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research*, 19, 193-212.
- Giles A. 2003. *Air conditioning still waits for the big push*. Building Services and Environmental Engineer. <http://www.bsse.co.uk>
- Giorgi F, Bi XQ, Pal J. 2004. Mean interannual variability and trends in a regional climate change experiment over Europe. II: Climate change scenarios (2071-2100). *Climate Dynamics*, 23, 839-858.
- Graves H, Watkins R, Westbury P, Littlefair P. 2001. *Cooling buildings in London: Overcoming the heat island*. Building Research Establishment Report 431, London CRC Ltd.
- Grazzini F, Ferranti L, Lalaurette F, Vitart F. 2003. The exceptional warm anomalies of summer 2003. *ECMWF Newsletter*, 90, 2-8.
- Hacker JN, Belcher SE, Goodess CM, Holmes MJ, Roaf S. 2006. Building scale scenarios: climate change and their implications to the design of climatically-sensitive buildings. *Planning and Environment B* (submitted).
- Hajat S, Kovats RS, Atkinson RW, Haines A. 2002. Impact of hot temperatures on death in London: a time series approach. *Journal of Epidemiology and Community Health*, 56, 367-372.
- Hawkes P, Surendran S, Richardson D. 2003. Use of UKCIP02 climate change scenarios in flood and coastal defence. *Water and Environmental Management Journal*, 17, 214-219.
- Howard. 1833. *The climate of London*. Harvey and Darton, London.

- Huisman M, Kunst AE, Bopp M, Borgan JK, Borrell C, Cost G, Deboosere P, Gadeyne S, Glickman M, Marinacci C, Minder C, Regidor E, Valkonen T, Mackenbach JP. 2005. Educational inequalities in cause-specific mortality in middle-aged and older men and women in eight Western European populations. *Lancet*, 365, 493-500.
- Huynen MMTE, Martens P, Schram D, Weijenberg MP, Kunst AE. 2001. The impact of heat waves and cold spells on mortality rates in the Dutch population. *Environmental Health Perspectives*, 109, 463-470.
- Ichinose T, Shimodozono K. 1999. Impact of anthropogenic heat on urban climate in Tokyo. *Atmospheric Environment*, 33, 3897-3909.
- IFRC. 2004. *World disasters report*. International Federation of the Red Cross and Red Crescent Societies, Geneva
- INVS. 2004. Etude des facteurs de deces des personnes agees resident a domicile durant la vague de chaleur d'aout 2003. IN Institut de Veille Sanitaire.
- IPCC. 2001a. *Climate change 2001. Impacts, adaptations and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, New York, Cambridge University Press.
- IPCC (2007) *Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, New York, Cambridge University Press.
- Johnson H, Kovats S, McGregor GR, Stedman JR, Gibbs M, Walton H, Cook L, Black E. 2005. The impact of the 2003 heat wave on mortality and hospital admissions in England. *Health Statistics Quarterly*, 25, 6-11.
- Jones CG, Willen U, Ullerstig A, Hansson U. 2004. The Rossby Centre Regional Atmospheric Climate Model. Part 1: Model climatology and performance for the present climate over Europe. *Ambio*, 33, 199-210.
- Jones R, Murphy J, Hassell D, Taylor R. 2001. Ensemble mean changes in a simulation of the European climate of 2071/2100 using the new Hadley Centre regional modeling system HadAM3H/HadRM3H. *Hadley Centre Report* 2001.
- Jowit J, Espinoza J. 2006. Heat wave shuts down nuclear power plants. *The Observer*, 30 July, 2006, <http://observer.guardian.co.uk/world/story/0,,1833620.html>
- Kaiser R, Rubin CH, Henderson AK, Wolfe MI, Kieszak S, Parrott CL, Adcock M. 2001. Heat-related death and mental illness during the 1999 Cincinnati heat wave. *American Forensic Medicine and Pathology*, 2, 303-7.
- Keatinge WR. 2005. Siestas needed to beat heat wave. *BBC News*, 12/08/2005, <http://news.bbc.co.uk/1/1/health/4145570.stm>
- Keatinge WR, Donaldson GC, Cordioli E, Martinelli M, Kunst AE, Mackenbach JP, Nayha S. 2000. Heat-related mortality in warm and cold regions of Europe: observational study. *British Medical Journal*, 321, 670-673.
- Kenrick DT, MacFarlane SW. 1984. Ambient temperature and horn-honking: A field study of the heat/aggression relationship. *Environment and Behaviour*, 18, 179-191.
- Kilbourne EMK, Choi T, Jones S, Thacker SB. 1982. Risk factors for heatstroke. A case-control study. *Journal of American Medical Association*, 247, 3332-3336.
- Kjellstrom E. 2004. Recent and future signatures of climate change in Europe. *Ambio*, 33, 193-198.

- Klein-Tank AMG, Können GP. 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946-99. *Journal of Climate*, 16, 3665-3680.
- Klein-Tank AMG, Können GP, Selten FM. 2005. Signals of anthropogenic influence on European warming as seen in the trend patterns of daily temperature variance. *International Journal of Climatology*, 25, 1-16.
- Klein-Tank AMG, plus 35 others. 2002. Daily dataset of twentieth-century surface air temperature and precipitation series for the European Climate Assessment. *International Journal of Climatology*, 22, 1441-1453.
- Klinenberg E. 2002. *A social autopsy of disaster in Chicago*. London, University of Chicago Press.
- Kovats RS, Hajat S, Wilkinson P. 2004. Contrasting patterns of mortality and hospital admissions during heat waves in London, UK. *Occupational Environmental Medicine*, 61, 893-898.
- Kovats RS, Johnson H, Griffiths C. 2006. Mortality in Southern England during the 2003 heat wave by place of death. *Health Statistics Quarterly*, 29, 6-8.
- Laaksonen M, Roos E, Rahkonen O, Martikainen P, Lahelma E. 2005. Influence of material and behavioural factors on occupational class differences in health. *Journal of Epidemiology and Community Health*, 59, 163-169.
- LeBeau JL, Corcoran WT. 1990. Changes in calls for police service with changes in routine activities and the arrival and passage of weather fronts. *Journal of Quantitative Criminology*, 6, 269-291.
- Leonardi G, Hajat S, Kovats RS, Smith GE, Cooper D, Gerard E. 2006. Syndromic surveillance use to detect the early effects of heat waves: An analysis of NHS Direct data in England. *Preventive Medicine* (in press).
- London Climate Change Partnership. 2006. *Adapting to climate change, lessons for London*, Greater London Authority, London
- Lye M, Kamal A. 1977. Effects of a heat wave on mortality rates in elderly inpatients. *Lancet*, 1, 529-531.
- MacFarlane A. 1977a. Daily deaths in Greater London, *Population Trends*, 1, 20-25.
- MacFarlane A. 1977b. Daily mortality and environment in English conurbations. I: Air pollution, low temperature, and influenza in Greater London. *British Journal of Preventative and Social Medicine*, 31, 54-61.
- MacFarlane A. 1978. Daily mortality and environment in English. II: Deaths during hot spells in Greater London. *Environmental Research*, 15, 332-341.
- McGregor GR, Cox M, Cui Z, Huang Y, Davey MK, Graham RF, Brookshaw A. 2006. Winter season climate prediction for the UK health sector. *Journal of Applied Meteorology and Climatology* (in press).
- McGregor GR, Ferro CAT, Stephenson DB. 2005. Projected changes in extreme weather and climate events in Europe. In: Kirch W, Menne B, Bertollina R (eds.), *Extreme weather events and public health responses*, Springer, 13-24.
- McGregor GR, Markou MT, Bartzokas A, Katsoulis BD. 2002. An evaluation of the nature and timing of summer human thermal discomfort in Athens, Greece. *Climate Research*, 2, 83-94.

McMichael AJ, Kovats RS. 1998. *Assessment of the impact on mortality in England and Wales of the heat wave and associated air pollution episode of 1976*. London, LSHTM. Report.

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

Menne B. 2004. In: Kirby, 2004, Europe tackles freak weather risk. *BBC News*, 25/06/2004.

Middelkoop BJ, Struben HW, Burger I, Vroom-Jongerden JM. 2001. Urban cause-specific socio-economic mortality differences. Which causes of death contribute most? *International Journal of Epidemiology*, 30, 240-247.

Nakicenovic N et al. 2000. *IPCC special report on emission scenarios*. Cambridge University Press, Cambridge, UK and New York, USA.

Newton S. 2005. *Design of environmental conditions in hospital wards. Case study: Four wards in Whittington Hospital, London*. Master of Science, University College London,

Nicol F, Raja I, Allaudin A, Jamy G. 1999. Climatic variations in comfortable temperatures: the Pakistan projects. *Energy and Buildings*, 30, 261-79.

Niemeyer S, Petts J, Hobson K. 2005. Rapid climate change and society: Assessing responses and thresholds. *Risk Analysis*, 25, 1443-1456.

O'Neill M, Zanobetti SA, Schwartz J. 2003. Modifiers of the temperature and mortality association in seven US cities. *American Journal of Epidemiology*, 157, 1074-82.

Páldy A, Bobvos J, Vámos A, Kovats,RS, Hajat S. 2005. The effect of temperature and heat waves on daily mortality in Budapest, Hungary, 1970-2000. In: Kirch W, Menne B, Bertollini R (eds.), *Extreme weather events and public health responses*, Springer, New York, 99-107.

Pan WH, Li LA, Tsai MJ. 1995. Temperature extremes and mortality from coronary heart disease and cerebral infarction in elderly Chinese. *Lancet*, 345, 353-355.

Pascal M, Laaidi K, Ledtans M, Baffert E, Caserio-Schonemann C, Le Tertre A, Manach J, Medina S, Rudant J, Empereur-Bissonnet P. 2006. France's heat health watch warning system, *International Journal of Biometeorology*, 50, 144-153.

Pattenden S, Nikiforo, B, Armstrong BJ. 2003. Mortality and temperature in Sofia and London. *Journal of Epidemiology and Community Health*, 57, 628-633.

Pelling M. 2005. *Current issues and trends in urban safety*. UN-HABITAT, Nairobi.

Pickett KE, Pearl M. 2001. Multi-level analyses of neighbourhood socio-economic context and health outcomes: a critical review. *Journal of Epidemiology and Community Health*, 55, 111-122.

Raisanen J, Hansson U, Doscher R, Graham LP, Jones C, Meier M, Samuelsson P, Willen U. 2004. European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios. *Climate Dynamics*, 22, 13-31.

Randolph SE. 2004. Evidence that climate change has caused 'emergence' of tickborne diseases in Europe? *International Journal of Medical Microbiology*, 293, (Suppl 37), 5-15.

Robinson PJ. 2001. On the definition of a heat wave. *Journal of Applied Meteorology*, 40, 762-775.

- Rogot E, Sorlie PD, Backlund E. 1992. Air-conditioning and mortality in hot weather: *American Journal of Epidemiology*, 136, 106-116.
- Rooney C, McMichael AJ, Kovats RS, Coleman C. 1998. Excess mortality in England and Wales, and in Greater London, during the 1995 heat wave. *Journal of Epidemiology and Community Health*, 52, 482-486.
- Rotton J, Cohn EG. 2000a. Weather, disorderly conduct and assaults: From social contact to social avoidance. *Environment and Behaviour*, 32, 651-673.
- Rotton J, Cohn EG. 2000b. Violence is a curvilinear function of temperature in Dallas: A replication. *Journal of Personality and Social Psychology*, 78, 1074-1081.
- Rudge J, Gilchrist R. 2005. Excess winter morbidity among older people at risk of cold homes: a population-based study in a London borough. *Journal of Public Health*
- Saez M, Sunyer J, Tobias A, Ballester F, Antó JM. 2000. Ischaemic heart disease and weather temperature in Barcelona, Spain. *European Journal of Public Health*, 10, 58-63.
- Schwartz J. 2005. Who is sensitive to extremes of temperature? A case-only analysis. *Epidemiology*, 16, 67-72.
- Semenza JC, Rubin CH, Falter K H, Selanikio JD, Flanders WD, Howe HL, Wilhelm JL. 1996. Heat-related deaths during the July 1995 heat wave in Chicago. *New England Journal of Medicine*, 335, 84-90.
- Shaw M. 2004. Housing and public health. *Annual Review Of Public Health*, 25, 397-418.
- Sheridan SC, Kalkstein LS. 2004. Progress in heat watch warning system technology. *Bulletin of the American Meteorological Society*, 85, 1931-1941.
- Shevky E, Bell W. 1955. *Social Area Analysis*.
<http://info.wlu.ca/~wwwgeog/courses/FW0405/Fall2004/GG265/Social%20Theory%20and%20Segregation-Part%201.doc>, 28-53.
- Smoyer KE. 1998. Putting risk in its place: Methodological considerations for investigating extreme event health risk. *Social Science and Medicine*, 47, 1809-1824.
- Solecki WD, Rosenzweig C, Parshall L, Pope G, Clark M, Cox J, Wiencke M. 2006. Mitigation of the heat island effect in urban New Jersey. *Environmental Hazards* (in press).
- Souch C, Grimmond CSB. 2004. Applied climatology: Heat waves. *Progress in Physical Geography*, 28, 599-606.
- Stafoggia M. 2006. Vulnerability to heat-related mortality: a multi-city population-based case-crossover analysis. *Epidemiology*, 17, 315-323.
- Stott PA, Stone DA, Allen MR. 2004. Human contribution to the European heat wave of 2003. *Nature*, 432, 610-613.
- Thornbrugh C. 2001. Are America's cities ready for the hot times ahead?
<http://www.isse.ucar.edu/heat/casestudy.pdf>.
- Threlfall A. 2004. *A study of urban-rural temperature and humidity differences between Beaufort Park, Bracknell and London Heathrow*. MSc. Dissertation, Reading University.
- Triggle N. 2004. It's getting hot in here. *BBC News Online*, Monday 2 August 2004.
www.bbcnews.co.uk.
- van Vliet AJH, Schwartz MD. 2002. Phenology and climate: the timing of life cycle events as indicators of climatic variability and change. *International Journal of Climatology*, 22, 1713-1714.

- Whitman S, Good G, Donoghue ER, Benbow N, Shou W, Mou S. 1997. Mortality in Chicago attributed to the July 1995 heat wave. *American Journal of Public Health*, 87, 1515-1518.
- Wilby RL. 2003a. Weekly warming. *Weather*, 58, 446-447.
- Wilby RL. 2003b. Past and projected trends in London's urban heat island. *Weather*, 58, 251-260.
- Wilby RL, Perry GLW. 2006. Climate change, biodiversity and the urban environment: a critical review based on London, UK. *Progress in Physical Geography*, 30, 73-98.
- WHO. 1987. *Health impact of low indoor temperatures*. Copenhagen, WHO Regional Office for Europe, 1987 (document ICP/RUD 003/m01).
- Woods LM, Rachet B, Riga M, Stone N, Shah A, Coleman MP. 2005. Geographical variation in life expectancy at birth in England and Wales is largely explained by deprivation. *Journal of Epidemiology and Community Health*, 59, 115-120.
- Worfolk JB. 2000. Heat waves: their impact on the health of elders. *Geriatric Nursing*, 21, 70-7.
- Zaitchik B, Macalady AK, Bonneau LR, Smith RB. 2006. Europe's 2003 heat wave: a satellite view of impacts and land-atmosphere feedbacks. *International Journal of Climatology*, 26, 743-769.

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