Health Climate Change impacts report card technical paper

1. Hotter Summers and Heat Waves

Katherine Arbuthnott[1] and Shakoor Hajat[1]

[1] London School of Hygiene & Tropical Medicine, Keppel Street, London WC1E 7HT -

Email: katherine.arbuthnott@lshtm.ac.uk

Contents

Abbreviations Used

CI	Confidence Interval
CET	Central England Temperature
DOH	Department of Health
GCM	Global Change Model
GDP	Gross Domestic Product
IPCC	Inter-governmental Panel on Climate Change
MI	Myocardial Infarction
MMT	Minimum Mortality Temperature
ONS	Office of National Statistics
PM	Particulate matter
RA	Risk Assessment
RCP	Representative Concentration Pathways. These represent four greenhouse gas trajectories used in the fifth IPCC report (AR5)
SRES	Special Report Emissions Scenarios. Produced by the IPCC, these are baseline scenarios and include the A1 family (an integrated world)A1F1 (emphasis on fossil fuels) A1B1 (balanced emphasis on all energy sources) A1T (emphasis on non -fossil energy sources). A2 (more divided world, self-reliant nations, increasing populations, regionally orientated economic development). B1 (rapid economic growth but towards a service and IT economy, population rises then declines past 2050introduction of clean and efficient technologies) B2 (world more divided but more ecologically aware)
UHI	Urban Heat Island
UK	United Kingdom
UKCP09	UK Climate Projections – UKCP09 represent the 5th generation of climate projections for the UK and are presented for three different future scenarios, representing low, medium and high emissions.
YLL	Years of Life Lost

Key messages

- There is a known association between increased temperature (heat) and heat waves and increased mortality in the UK. (High Confidence)
- The association between increased temperatures and other health and wellbeing outcomes is not as consistent as for mortality, and only known to be present for selected outcomes (for example, emergency respiratory admissions). (High confidence)
- Older persons (>75 years) are most vulnerable to the mortality effects of increased temperatures. This is important given future population projections predict increased elderly populations. (High confidence)
- Mean temperatures in the UK are projected to increase between 2°C and 5°C by the end of the century using UKCP09 projections under a medium emissions scenario and heat waves are likely to become more frequent in the future. (High confidence)
- Under recent projections, using UKCP09 projections and allowing for demographic changes, the number of heat related deaths is likely to increase (high confidence). It is estimated that this increase could be up to 540% by 2080 from the baseline figure of 1974 in the 2000s. (medium confidence)
- Effects are currently and are likely to be greatest in London (high confidence) and increased in the Southern, Central and Eastern regions of England (medium confidence).
- Current evidence on adaptation, with a particular focus on the UK and adaptation to heat is scarce. It is therefore difficult to identify effective adaptive measures. (High confidence)

Introduction and scope

The effects of hot weather are likely to become increasingly more important in terms of health impacts and planning effective public health measures and adaptation. It is unequivocal that our climate is warming and the consensus reported by the Intergovernmental Panel on climate Change (IPCC) is that this is largely due to anthropogenic climate change (1). In the UK, temperatures are projected to increase between 2°C and 5°C by the end of the century (2) and the frequency of extreme heat events or heat waves is also projected to increase.

This review summarises the key evidence from studies which have used historical or modelled data within the UK to examine the current associations between general increased temperatures or other meteorological variables and distinct heat waves on health and wellbeing impacts. The impacts which are reviewed are those which are directly related to increased ambient heat exposure and those which have been assessed using epidemiological methods within a given population (i.e. this review does not contain evidence from laboratory or individual level physiological studies or indirect impacts of temperature changes such as changing patterns of infectious diseases). Populations who are vulnerable to these impacts are highlighted and future risk assessments using a variety of climate projections with different emissions assumptions are reported. The review summarises the approaches used to undertake these studies, the key results and gaps in knowledge. Where it has not been possible to find evidence from studies within the UK, it has been the exception to include studies from other countries or reviews. Where this is done, care should be taken in extrapolating results to the UK given that geographic location is likely to affect basic associations of heat and health outcomes (for example, the prevailing climate itself and behaviour may affect local vulnerability to weather related outcomes) and context may affect how successful interventions or adaptations are and their distribution in society in terms of equity.

This has not been designed as a full systematic review. It is therefore outside the scope of this review to fully appraise all included studies and explore differences in methods or heterogeneity of results. An overall narrative summary of the evidence is given.

Evidence of Current Health and wellbeing outcomes in relation to heat

In this section the evidence for the association between increased ambient air temperature and heat waves and health and wellbeing outcomes is summarised. Results are given separately for studies which look at the association between a general increase in temperature – i.e. those deaths or health outcomes that occur throughout the summer and those which analyse a defined period of unusually high temperatures, i.e. a heat wave.

Mortality & Morbidity

It has been widely demonstrated both within the UK and many other countries that there is an association between all-cause mortality and both increasing temperatures and more extreme heat wave episodes(3). Deaths during the summer months and heat waves, however, are very rarely due to heat stroke or hyperthermia. Instead, deaths and morbidity from many causes are likely to be affected or increased by heat. Therefore, epidemiological studies usually analyse all-cause mortality or broad categories of disease.

In this section, the main methods used to understand the relationship between heat and health outcomes are briefly described followed by results from UK studies (separated into those which look at deaths occurring throughout summer months and those which examine heat wave effects). Vulnerability is described last.

Epidemiological methods used

The relationship between mortality (and morbidity) and temperature is usually assessed using time series regression models or case crossover designs. These studies allow the short term relationship between ambient temperature and health outcomes to be assessed, whilst adjusting for trends in the outcome which vary by season or longer time periods. Studies presented in this section have mostly controlled for a combination of potential time varying confounders such as humidity, air pollution (e.g. PM_{10} and ozone – though the precise role of pollutants in analysis is currently under debate (4)). The effect of heat on death occurs within a short time frame and results of most studies presented here have used a lag of between 0-2 days to analyse the relationship between exposure and outcome. In general, outcomes measured throughout are usually assumed to have a log-linear relationship with temperature above a certain threshold value. Results are generally presented as the increased risk of the outcome for every 1°C increase above that threshold[1]. Case-crossover studies have also been used, in which cases are temperature values on the days of each individual health event (e.g. death) and controls are temperatures values on proximate days. This design can be viewed as equivalent to a matched case control design. The control period or days are selected from a time-period usually both before and after the event, and possibly matched by day-of-week. As the study population is made up only of cases, they effectively act as their own controls for individual level confounders such as co-morbidities and age. Both time series and case crossover designs need to allow for auto-correlation of data, and in case crossover studies the choice of control days may lead to bias[2]. Studies have shown that case-crossover and time series studies yield similar results when investigating the effect of heat on health outcomes within a population (5, 6)

The effect of heat waves or defined periods of high temperatures on health has been mostly examined using episode analyses, where the outcome counts over the given heat wave period of analysis are compared to an expected baseline from either the same time period in adjacent years or from modelled relationships. There is no consensus around the definition of a heat wave, though most studies include a duration and severity component.

Relationship Between Ambient Temperatures (occurring throughout summer months) and Health Outcomes

Mortality

Studies have analysed effects of temperature for England and Wales, or for certain cities (mostly London – see results by region below) within England (7-14). Studies reporting associations within Scotland and Ireland are scarce, although one study has estimated the effect of heat on mortality in the Republic of Ireland (see later) (7). All studies found an increasing risk of all-cause mortality with increasing temperature above a threshold value. The size of the effect varied in analyses between regions (see below) and also between studies, which may be partly driven by choice of the

[1] Note a threshold may not be used or may not be necessary of only summer months are being assessed

[2] . More commonly now, the time-stratified approach is used for selecting control days in case-crossover studies, which minimises this bias(5). The time-stratified approach allows selection of a control day from before or after the event but within the same time stratum as the event occurs. This is important as it controls for both longer term and seasonal time-varying factors

threshold (larger risk seen with higher thresholds). Where the risk was modelled above the 93rd percentile of average yearly temperatures, the increase of all-cause mortality was around 2.1% for each 1°C increase in temperature (95% CI 1.6% to 2.6%) for England and Wales (9).

Some of the studies (7-9) examined cause specific mortality. This is most commonly broken down into cardiovascular, respiratory and other events. In these analyses, the risk was greatest for respiratory mortality (although still increased for cardiovascular mortality). Gasparrini et al (9) examined a more detailed breakdown of deaths and also found the increase in relative risk was also higher for genito-urinary, neurological causes.

Years of Life Lost (YLL) has been estimated in a multi-city European study (15), which included London and Dublin. It explicitly took into account harvesting (mortality displacement) which describes the process by which some deaths which occur in an already frail population are brought forward by a few days or weeks. This has not been consistently analysed in studies, but where it has not been taken into account it may lead to some over-estimation of the health burden of increased temperature. For example, Baccini et al (12), estimated that in London there were an average of 1914 YLL per year (credibility interval 1033,2841) not adjusted for harvesting, reduced to 356 per year adjusted for short-term harvesting – an 81% reduction. For Dublin, there were an average of seven YLL per year unadjusted and one per year adjusted for harvesting (84% reduction). It should be noted that the harvesting evaluation could be sensitive to modelling choices[3]. The effect of harvesting has also been examined for London and it was concluded that the data supported a proportion of deaths occurring in those who were already vulnerable (16).

Morbidity and Other Health and wellbeing Outcomes

There have been a variety of different health and well-being outcomes used in UK studies examining their association with increased temperatures, including hospital admissions, incidence of myocardial infarction and ambulance call out times. The results from these studies have varied. The association between morbidity outcomes and increasing temperatures appears greater for some specific outcomes (such as emergency respiratory admissions) but for all cause hospital admissions, the demonstrated effect is in general less strong than for mortality.

Where the relationship between increasing temperature and emergency hospital admissions has been characterised for Greater London, no clear evidence of an association was found when total admissions were used as the outcome(17) – the % increase per °C increase above the threshold temperature was -0.04% (95% CI: -0.22%,0.13%). However the same study did find that there was a significant increase for respiratory admissions (5.44% increase per °C above threshold, 95%CI 1.92%, 9.09%) and for renal disease (1.3 % increase per °C increase in temperature (95% CI: 0.27%, 2.35%)). A study examining effects of temperature (above the 90th Centile) in 12 European cities, including London (18) agreed largely with these findings. No significant increased risk was found with emergency admissions for cardiovascular or cerebrovascular causes in London for this study, but an increase was found in respiratory admissions (1.7% increase per °C for all ages, 95% CI 0.7%, 2.8%). It has been hypothesised that the contrast between mortality and hospital admissions may in part be due to heat causing a rapid deterioration in those who are vulnerable meaning they do not present to medical attention before death.

[3] For example, the threshold and model choice for the exposure-response relationship (in the Baccini study described, the threshold used was fitted from data from the general population, whereas the threshold (minimum mortality temperature) may be lower for those at risk of harvesting. The YLL are also based on standard life expectancy, which may not be applicable to those who are vulnerable to harvesting. That is to say, the study may have under-estimated the effect that harvesting had on results.

One study (19) specifically examined the effect of temperature on stroke incidence within west Scotland, comparing days which were hotter than previous days. For each 1°C rise in temperature above the average temperature of the past 24 hours, there was an estimated 2.1% increase in ischaemic stroke admissions for (P=0.004).

In two studies examining the effects of temperature throughout the summer months on myocardial infarction (MI) in England and Wales, one study (20) found no increased risk of MI admissions with increasing temperatures at a daily resolution. The second study using data from England and Wales to examine the hourly association between MI hospital admissions and temperature (21) found a 1.9% (95% CI: 0.5%,3.3%) increased risk of MI 1-6 hours after exposure (above a threshold of 20°C) but that the excess risk at shortest lags was followed by reduced risk at 24 hours. It is hypothesised that the reduction in MIs at longer time intervals are due to short term displacement. A systematic review (which did not include any studies from the UK) found mixed results from studies characterising the risk of MI with increasing temperature(22).

The association between ambient temperature and cardio-respiratory hospital admissions and ambient temperature has recently been systematically reviewed (23). In this review, four of the 21 included papers included results from the UK. The pooled estimate across the studies, for respiratory admissions per 1°C rise in temperature across all regions was 3.2% (95% posterior interval-3.0% to 2.1%) and for cardiovascular admissions was -0.5% (-3%, 2.1%).

A recent study in Birmingham (24) showed that both increased temperatures and the heat wave of 2003 were correlated with poorer ambulance category A response times, though further work is planned in this area to include better confounder control and to analyse the types of calls in more detail.

There have been studies on birth outcomes and ambient temperature. For example, in one London based study, Lee et al (25) demonstrated that although the odds of preterm birth were affected by seasonality (increased odds within the winter months), but showed no association between premature birth and increased or decreased temperatures up to six days before birth. This study had good control for time varying and confounding factors. Whilst no other UK based studies investigating the effect of ambient temperature on neonatal or maternal outcomes are known of, there are studies from different settings. These have been reviewed elsewhere (26). This review found papers used range of methods and study designs, exposure timings (e.g. whether the exposure temperature of interest was immediately before birth or during certain trimesters of pregnancy), outcomes of interest (e.g. pre-term birth, still birth, birth weight etc.) and that findings from studies were also varied.

Other health outcomes, such as infectious or food borne diseases (e.g. salmonella) may be associated with increased temperatures but, as indirect impacts of heat, are not specifically reviewed here.

Heat Waves

Mortality and heat wave episodes – national level
UK studies which have examined the effects of the HW on health outcomes have all found an excess mortality compared to baseline period. Where excess mortality has been analysed by cause of death in heat waves, respiratory deaths have been those with largest proportional increase (27).

The most severe HW was in 2003, for which the health effects were most greatly seen in continental Europe (28). In England between 4-13th August 2003 the Central English Temperature (CET) exceeded average values (from 1871-2000) by 8 °C and in South East England, the maximum temperature exceeded 32 °C for 3 and then 5 consecutive days. It has been estimated that the 2003 heat wave led to 2091 excess deaths in England - a 17% increase (95% CI: 15%,19%) above the expected baseline of deaths in the same 10 day period between 1998-2002 (29).

During the 1995 heat wave (between 30th July-3rd August) there was an excess of between 691 - 768.2 excess deaths in England and Wales (between an 9.9% (95% CI: 6.4, 11.3%) to 11.2% excess)[4] (30)). The 1976 heat wave was estimated to have caused a 10% excess mortality in England and an 8.9% excess for results from England and Wales combined.

In 2011, a 'nowcasting' method to evaluate excess mortality in near time as part of a Heat-Health Watch system estimated 367 excess deaths in England and Wales in the over 65 years age group (31).

Whilst none of the studies described here undertook a formal analysis of harvesting, estimates attributed less than 10% of the excess deaths in the 2003 heat wave in Paris to mortality displacement (32) and less than around 25% of excess deaths were attributed to harvesting for the 1995 heat wave in Chicago (33).

The estimated increased effect of hot days that are part of a heat wave, compared to days of equivalent temperatures which occur in isolation has also been examined. One model (Hajat et al., 2006) examining the additional heat wave effect in European cities across the years 1976-2003 found an increase in mortality of 5.5% on heat wave days compared to the model's expected value for a given temperature.

Other Health Outcomes

Morbidity during heat waves has been characterised in UK studies by hospital admissions, ambulance call outs and in one study GP visits.

For the 2003 heat wave, excess hospital admissions were calculated per governmental region and overall(29). In regions where there where excess admissions, the proportion was small compared to proportional increase in mortality during that period (e.g. in London there was a 42% increase in mortality compared to the baseline period, but 6% increase in admissions) and two regions had a proportional decrease in admissions. The overall increase in hospital admissions was 1% (95% CI 1%, 2%).

The contrast between mortality and hospital admissions during the 1995 heat wave was examined for greater London (17). It was estimated that mortality increased by 10.8% during the episode and hospital admissions increased by 2.6% but this was not statistically significant (95% CI -2.2%, 7.6%).

During the 1976 heat wave, a study in Birmingham (34)looked at outcomes of medical and surgical admissions, sick claims and GP consultations. There was no significant increase in sickness benefit claims but a modest increase was seen in GP consultations.

[4] The estimates varied (9.9% (95% CI: 6.4,11.3%) to 11.2% excess) depending on baseline period used - moving average for 1995 or baseline of the 31 day moving average in the preceding 2 years respectively

Work Productivity and Heat

To our knowledge, the impact of hot days or recent heat waves in the UK has not been assessed in terms of productivity or occupational health outcomes. However, there is evidence that occupational health outcomes and productivity are affected by heat elsewhere. Many studies are from low and middle income countries, where the type of occupational exposure and working conditions are likely to differ from the UK. There are, however, some studies and reports from countries with similar socio-economic context. For example, for the two years 2012-2013, a formal review by the Occupational Safety and Health Administration (OSHA) in the United States found that there were 20 occupational cases of heat illness or death attributed to heat exposure (35). All cases occurred on days where the measured heat index was between 29°C to 41°C. Of these 20, 13 were heat-related deaths. The occupations involved were mostly outdoors (e.g. roofing, landscaping, ship building) and involved heavy to moderate work, although seven cases arose from indoor settings with sources of heat exposure (e.g. as combustion engines or laundry machinery). Of the 13 deaths, nine occurred on the first three days of work or within three days returning after leave. Potential lessons for the UK include the importance of health and safety measures – none of the employers involved had complete heat illness plans- and potential the importance of acclimatisation to heat in at risk occupations

Discussion

Geographical/Regional differences In Mortality and Morbidity Estimates for increased temperature and heat waves

Many studies with results from the UK have focused their analysis either on (Greater) London or have also presented results by regions of England and Wales. The increase in risk of mortality per °C change in temperature is greatest for London (9-11).

The regions which appear to have the largest increase in risk (in addition to London) are the South East and the East of England and, in some studies, the West Midlands. The North East, North West and Yorkshire & Humberside generally have the lowest increased risk. There is also some evidence for a difference in minimum mortality temperatures (MMT) between regions, with those where average temperatures are colder, displaying a lower MMT (but shallower RR slope). The study conducted in the Republic of Ireland ((7) demonstrated a lower RR of 0.4% per °C increase in temperature (95% CI: 0.3%, 0.6%).

In studies which have analysed results for (Greater) London only (i.e. with no UK baseline) the estimated % increase per °C is also generally higher compared to overall relative risk presented in other studies using similar methods.

The geographical regions at greatest risk from general temperature rises are also those with the highest proportion of excess mortality calculated during heat waves. During the 2003 heat wave, where the overall proportion increase in mortality was 17%, the largest increase in proportion of deaths was seen in London (42%), followed by Eastern England (27%) and the South East (23%). The areas with the lowest proportional increase were the North West (4%) and the North East (2%)(29). Evidence from the 1976, 1995 and 2011 heat waves also showed greater excess deaths occurring in London (and for 2011 where effects were analysed by region, they were greatest in the East of England and London).

The increased risk of both temperature related and heat wave mortality within the South and Eastern areas of England and within London is likely to be explained by a number of factors, including baseline average annual temperatures (the steepness of linear relationship slopes tends to increase with higher MMTs) and the Urban Heat Island (UHI) effect. The UHI effect refers to the increased temperature within cities compared to surrounding rural areas (36), due to alterations in the energy balance as a result of surface properties (e.g. albedo etc.), land use and city design. The UHI is likely to become increasingly important as we see an increasing proportion of the population living in cities (Office of National Statistics projections).

Whilst the UHI can explain some increased vulnerability within cities, explaining further differences in vulnerability to heat (other than relation to background climate) is difficult due to the scarcity of standardised data between locations.

Distribution of impacts by age, gender, socio-economic status

Age

A consistent finding across studies, of both increased ambient temperature and mortality and the effect of heat waves, is that older age groups are more at risk. This may be due to diminished ability to thermo- regulate, increasing medical co-morbidities or use of medications, and social factors which may limit behavioural adjustments to the increased temperatures. In studies that have found an increased risk in respiratory hospital admissions, this was also greater in older age groups (18).

One study also showed an increased risk per °C for hospital admissions in the 0-4 year age group but not for any other ages (17). In studies outside the UK, there have been cases of mortality in children and infants in heat waves(37).

Vulnerability in older age groups is increasingly important, as future projections show increasing proportions of our population in older age bands.

Gender

Where it has been examined, studies have mostly but not consistently shown that females are at higher risk of dying in a heat wave (34, 37, 38), especially within European studies. However, it is likely that many of these results for females are confounded by age: older age groups also contain more females. By contrast, some studies of the Chicago heat waves, elderly men were found to be at higher risk (39, 40).

Underlying co-morbidities and medications

Certain co-morbidities have been associated with increased mortality and morbidity from heat exposure. Studies outside the UK have also shown increased risks in those with cardiovascular, respiratory, renal disease and diabetes(41) (42). One UK study demonstrated that the risk of mortality was associated with increased temperature in patients with neurological and psychiatric diagnoses, such as dementia and substance misuse (43) and in people prescribed antipsychotics, antidepressants and hypnotics. Although no baseline risk for the general population was available within the study for comparison, the overall RR per 1°C increase in temperature for this group of patients (4.9% (95% CI 2.0%,7.8%) is higher than given for the overall population in other studies using similar methodologies. Of the patients with neurological and psychiatric diagnoses, younger patients and those with diagnoses of substance misuse were most vulnerable. An increased risk of hospitalisation and mortality from use of prescribed medication and recreational substance use has been found elsewhere (44, 45). Plausible hypotheses for mechanisms underlying this increased risk have been given (46) , such as decreased thirst and decreased sweating.

Socio-Economic Status

UK studies have not found a consistent relationship between socio-economic status (SES) (quintiles of deprivation analysed) and an increased vulnerability to heat or heat waves (38). However, for the analysis aggregated data (statistic ward level) was used, and thus potentially masking differences in outcome by deprivation at the level of the individual.

Studies in other countries, most notably North America have found some linkage with SES (41) (47). Though this relationship may be partially explained or related to access to air conditioning, which is much more prevalent in the US compared to the UK.

Other Factors Affecting Vulnerability

Studies from heat wave episodes have shown a number of other factors may also contribute to vulnerability to the effect of heat. A systematic review and meta-analysis examined factors affecting vulnerability to mortality in heat waves or increased temperatures (48). The review analysed 4 case control studies from the US and 2 from Europe (but none from the UK) and found that living alone, being unable to care for oneself, not leaving the house and pre-existing illnesses (cardiovascular, pulmonary and mental illnesses) were associated with increased odds of death. Factors which were protective included increased social contact, air conditioning (working air con in own residence or visiting places with air conditioning). Whilst this review did not contain results from the UK, place of residence (if a nursing home or residential home) has been associated with an increased risk of mortality in England (38, 49), though this may reflect that those living in sheltered accommodation are likely to be more frail.

Identifying those at risk can allow improved targeted prevention policies. A few UK studies have sought to incorporate known vulnerabilities into spatial heat health risk assessments combining geographical information on the heat hazard, exposure and vulnerability of small area populations within cities. Examples include the development of a vulnerability index for London (50) and a spatial heat health risk assessment for Birmingham (51)which included the UHI as a contributor to the hazard presented by heat waves, and vulnerability indicators such as age, co-morbidities, housing density and high rise dwellings.

However, identification of vulnerable populations can be difficult to translate into the social and medical support required: whilst front line responders feel they know those individuals who are at increased risk at a given time, vulnerabilities such as co-morbidities and social isolation fluctuate rapidly and keeping a systematic record of these is difficult(52). Further, barriers to implementation of protective policies may result from the low priority given to heat risk by practitioners(52)and also by the vulnerable populations themselves, who may not feel health protection advice is relevant to them or that they are not at risk (53). It has been suggested whilst some case control studies have identified living alone as a risk factor for heat related morbidity/mortality, the picture may be more complex, for example increased contact in social networks may perpetuate views amongst the elderly that they are not at risk(54).

Size of Current Effects Attributable to climate/weather and anthropogenic Climate Change

Some UK based studies have examined the attributable deaths due to heat exposure. For example, Gasparrini et al (9)found that 1.03% of all summer deaths in England and Wales were attributable to temperature. Armstrong et al(11) found a similar figure of 1% of summer deaths being attributable to heat exposure. Baccini et al (12) also examined deaths attributable to heat exposure and found that for London, during the 1990s, 143 deaths per year (80% credibility interval 99,185) were attributable to heat over summer periods.

UK studies which have estimated the burden of health effects of heat which are considered attributable to (anthropogenic or other) climate change that has already occurred, have not been located.

The lack of studies in this area highlights a key gap in knowledge and area for further research.

Future Health Impacts: a review of studies that have estimated future impacts of heat on health outcomes in the UK

Studies which have examined future impacts have all presented an increasing proportion of deaths as a result of increasing temperatures throughout the 21st century. Impact studies for a wide range of countries have been review elsewhere (55) and this section only contains evidence from UK projections.

Impact studies have been conducted by taking a quantified baseline relationship between temperature and health outcomes and applying future temperature projections to this relationship. Temperature projections are obtained using regional climate change projections. This requires a combination of climate change scenarios (or RCPs), Global Change Models (GCMs) and downscaling (dynamically or statistically) models to a local level. Whilst this will give projections of the baseline relationship, demographic and other non-climate changes should also be considered, for example increase in population size and distribution between ages, urbanisation, change in baseline mortality rates and whether populations are likely to adapt to climatic changes over time (current evidence suggests this – see earlier). Given the complexities in the models, uncertainty is introduced at many levels including uncertainty in future emissions, the parameters and processes included in climate change models, downscaling, the baseline exposure response scenarios, and uncertainties in demographic projections (56) . Sensitivity analysis is usually carried out to address some of these, although cannot tell us which are the best projections to use. Some studies (57) have suggested that future health impact projections are most sensitive to the choice of climate projections rather than uncertainties in the baseline exposure-response relationship or demographic projections.

The most recent projections from future impacts of climate change on health estimate an increase in heat related mortality from a baseline of 1974 deaths per year in the 2000s, to 3,281 deaths per year(66% increase) in the 2020s, 7,040 deaths per year (increase 257%)in the 2050s and 12,538 deaths (535% increase) in the 2080s. These projected deaths are attributable both to increased temperature but also the increased projected population size (note, table 1 below gives estimates per 100,000 instead).This study (10) was based on the recent Health Protection Agency (HPA) report of the health effects of climate change (58) and is described in more detail.

The study used results from a time series analysis of historic weather and mortality data in England and Wales from 1993-2006 for the baseline estimates of the relationship between mortality and heat. The 93rd centile was used for the heat threshold and a linear-threshold model was assumed. Additional mortality due to extreme temperatures occurring during a heat-wave was also modelled. The risk assessment used projected daily mean temperatures for the periods 2000-2009 (to model baseline), 2020-29, 2050-59 and 2080-89. Ten available variants of the Met Office Hadley Centre Regional Climate Model (HadRM3-PPE-UK) were used to dynamically downscale GCM results for historical emissions and SRES A1B as the medium emissions scenario as part of the UKCP09 climate projections (giving projections to a horizontal resolution of 25Km). For the risk assessment, nine regional climate model variants were used (range of climate sensitivity of 2.6-4.9°C).

Key non-climate determinants considered were demographic changes – population data based on the ONS projections for the UK were used for population projections and future mortality trends were used. No assumptions about adaptation were included.

The baseline co-efficient from the time series was used to project annual mortality under different climate change models and population projections was used[5]. The estimates using the mean, minimum and maximum from nine model realisations were extracted for each region. The results for the mean estimates of heat related deaths are given below for each region per 100 000 population. The regions most at risk are the East and South of England, the West Midlands and London. The additional heat-wave effect was significant only for London where it was estimated to add an extra 58%, 64%, 70% and 78% to heat-related mortality in the 2000s, 2020s, 2050s and 2080s.

Table 1. Projected Heat Related All-age Annual Mortality by region of the UK (Hajat et al2014(10))

Region of UK	2000s mean heat related deaths per 100 000 population per year	2020s mean heat related deaths per 100 000 population per year	2050s mean heat related deaths per 100 000 population per year	2080s mean heat related deaths per 100 000 population per year
NE	1.2	2.1	3.9	6.7
NW	1.3	2.0	3.7	6.2
Yorks & Humber	1.4	2.3	4.4	7.6
East Midlands	4.4	6.5	11.5	18.4
West Midlands	4.2	6.1	11.1	17.2
East England	3.9	5.6	9.9	15.5
London[6]	4.4	6.1	11.3	17.5
SE	6.3	8.6	15.3	22.9
SW	3.5	5.1	9.6	15.3
Wales	2.4	3.5	6.5	10.6
Scotland	0.7	1.3	2.4	4.4
N. Ireland	0.9	1.6	2.9	4.9
Total UK	3.3	4.8	8.8	14.0

Whilst this study and the related HPA report represent the most recent projections for the UK and by region, there have been other studies covering the UK (or part of it). A previous Department of Health report (59) used baseline mortality from 1976-1996 and in-patient hospital days (as a measure of morbidity) from 1995 and 1996 for England and Wales respectively for a risk assessment using low, medium low, medium high and high emissions scenarios (other specifics of Climate Change model not stated). Assumptions about future demographics and adaptation were not included. Heat related mortality was projected to increase by 253% under a medium-high emissions scenario for the 2050s. The projections for heat related mortality per 100 000 were 1.4 for the baseline and for the medium-high emissions scenario 3.2, 4.9 and 6.3 for the 2020s, 2050s and 2080s respectively. In absolute figures, this was an increase in 798 heat related deaths per year for the UK in the 1990s, to 2793 heat-related deaths in the 2050s and 3519 heat related deaths

[5] Where data for a region were not available for the baseline assessment (Scotland and Ireland) data from the NE and NW of England were used.

[6] This table does not include the increase in estimates that are projected if the additional heat-wave effect for London is taken into account

in the 2080s under a medium-high emissions scenario. For total UK in-patient hospital days, the baseline of 81 000 per year was expected in to increase to 285 000 per year by 2050 under a medium emissions scenario.

There have also been some studies that have projected heat-related mortality for European or Global cities and included London in these estimates (12, 56, 60).

Baccinni et al (12) projected results for 15 different cities for the 2030s. The baseline used data modelled in a previous project from 1990-2001 which estimated the number of heat-attributable deaths in this period. Temperature rises under three different emissions scenarios (B1, A1B and A2) were then taken from the IPCC SRES report for best estimate of temperature change for 2090-99 and values for the 2030s under scenarios calculated assuming a constant rate of temperature change. Attributable deaths (to heat exposure) per year for London in the observed series was 142 per year, and projections for the 2030s under different scenarios were 183 per year for B1 (low emission, 206 per year for A1B (middle emission scenario) and 220 per year for A2 (high emissions). No assumptions or projections regarding demographic changes or adaptation were included.

Gosling et al used a baseline from 1976-2003 for their risk assessment for 6 European cities projecting heat related mortality per 100 000 between 2070-2099 (56) . The GCM used was the UK HadGM3 and emissions scenarios were A2 and B2. There was no downscaling of the models and no assumptions about demographic changes. Assumptions were included regarding adaptation – an assumption that the population would not adapt, adapt to 2°C or to 4°C. Cases were constructed taking into account increases in mean temperature alone, or increases in mean temperature and variability. Projected mortality was greater when both the increase in variability and mean temperature were included, compared with mean temperature increase alone. With the assumptions about acclimatisation, the projected mortality for London roughly halved for each 2°C adaptation assumed.

The study by Martens et al examined 'net' effects of changes in thermal stress under climate change scenarios, and therefore is not included given the effects of increased temperature specifically were not modelled (60). One UK based study (61) described how a health risk assessment would be carried out for the 2030s, but no results were given in the study for this time period.

To our knowledge, there have not been any recent UK focused studies which have predicted the effect of heat on outcomes other than mortality. There have been recent studies which have projected future respiratory admissions under different climate change scenarios in the US(62) and for four regions of Europe (Northern, Southern, Western and Eastern Europe) using estimates for 27 countries (63). The study projecting admissions within Europe included estimates for London and projected the proportion of future respiratory hospital admissions attributable to heat. Four climate and two emissions scenarios were used to project future climate changes. The respiratory admissions used as the baseline were those from the PHEWE project (64) [7]. The baseline of the proportion of respiratory hospital admissions attributable to heat for Northern Europe (which included contributions from London) was projected to increase from 0.13% (0.10%, 0.15%) to 0.27% (0.19%, 0.32%) in the period 2021-2050.

[7] In the PHEWE project, apparent temperature as the exposure of interest for 12 European cities (including London) and mortality and hospital admissions (respiratory, cardiovascular and cerebrovascular) in the 1990s were used as outcomes.

Potential for impacts to be avoided by adaptation measures

Adaptation has often been used to refer to planned and unplanned structural and policy level actions which may reduce a population's vulnerability to heat. The extent to which adaptation can be achieved will depend upon the local context, vulnerabilities and adaptive capacity (65). Acclimatisation more commonly refers to increased short term physiological tolerance to heat.

Whilst there is evidence that populations residing in areas with a warmer climate have increased thresholds for heat sensitivity (66-68) and also some evidence that sensitivity to increased temperatures has decreased over time (69) (12), the specific adaptive measures which have been taken to achieve this are difficult to distinguish from demographic or socio-economic background factors which may decrease sensitivity to heat. Further, the evidence of efficacy for given planned and implemented policies or interventions, in terms of systematic reviews or evaluations using robust methods, is scarce(70) . This is true at a global level across all high and middle income countries - the UK is no exception. Therefore, the strategies presented in this section are based on evidence at systematic review level where possible, but otherwise a combination of studies and case reports (69), and expert opinion is used.

Potential adaptive strategies range from interventions and actions at an individual and housing level, health systems and infrastructure level through to national policy and plans. It is outside the scope of this review to present evidence on physiological acclimatisation. Whilst this section focuses on adaptive strategies, it is important to consider whether any of these could be 'maladaptive' (to avoid providing a short term benefit but increase energy demands which currently would be met using carbon energy sources e.g. air conditioning). Un-anticipated effects of adaptive strategies should also be considered, for example, strategies which decrease sensitivity to heat should not have the unintended consequence of increasing vulnerability to cold. Further, it would be most desirable if strategies both reduced health effects of heat and cold (for example through improved building design), had other health co-benefits (for example urban greening reducing the urban heat island effect but also giving the opportunity for increased exercise and potentially reducing non-communicable disease) or could contribute to climate change mitigation (for example increased building insulation against heat and cold reducing energy demands). However, evidence covering these points is scarce.

Attention should also focus on ensuring the adaptation needs of the most vulnerable populations are met. This requires knowledge of who the vulnerable populations are, recognition that these may change over time and interventions or planned strategies that are effective in these vulnerable groups. Evaluations of interventions and systematic reviews of adaptation options also need to assess effectiveness in vulnerable subgroups. Although there are increasing numbers of equity focused systematic reviews, and indeed criteria quality such as the equity extension of the PRISMA guidelines (71) to assess these, none have been identified in this area to date. This is unsurprising, given the generally low levels of evidence for adaptive measures. There are , however, organisations such as the Joseph Rowntree foundation that have highlighted the need for socially just adaptation (72).

Behavioural Measures

To our knowledge there are no studies which have fully quantitatively evaluated the impact of behavioural measures and adaptation to heat. Some case control studies have demonstrated that regular showers can offer some protection against heat related mortality (48). Other behavioural measures such as use of cool clothing, increasing intake of non-alcoholic fluids, and restricting strenuous activity to cooler parts of the day, are also advised.

Interventions at an individual or place of residence level

Air conditioning

There is evidence, mostly from Northern America where it is more prevalent, that air conditioning can offer protection against the impacts of heat on health (42, 73). There is also evidence that seeking a public space with air conditioning can be protective (48) and indeed this is a measure included in many heat wave plans. However, there are potential disadvantages to promoting this as an adaptive strategy. For example there may be equity issues in terms of both the prevalence and availability of air conditioning units and also in being able to afford to use the intervention, although access to shared air-conditioned space may remove some of these concerns. Extensive use of air conditioning could increase energy demands and itself contribute to climate change although air conditioning powered from renewable sources (e.g. solar powered) may not pose the same issues. There are also examples of power grid outages during extreme weather events such as heat waves, which would limit the protection that air conditioning could offer. Further evidence is required in order to be able to effectively weight the benefits of air conditioning against its environmental, energy and health costs. Passive cooling measures may reduce the need for air conditioning.

Electric Fans

A recent systematic review (74) sought to establish the role of electric fans in reducing health impacts of heat waves. Inclusion criteria by study design required studies to be randomised controlled trials (RCTs) or other experimental designs, such as interrupted time series or controlled before-after studies. No such studies were identified and therefore it was concluded that there were not enough high quality studies to assess the evidence. Where case control studies were found, results for the protective effect of fans were inconclusive with some studies showing a protective effect and others the opposite.

Community, Services and Design level Adaptations

Many interventions have been postulated that may improve adaptation at an urban design level, for example increased use of green spaces, improved insulation of housing against heat and cold, improved surface properties of buildings (e.g. increasing albedo) etc. Some of these, such as increased green spaces have improved benefits to health outside adapting to climate change. Unintended consequences of interventions should also be considered (e.g. indoor air quality concerns in more air tight houses etc.). Further, health services will also need to adapt to ensure comfortable and reliable care (e.g. indoor temperatures, power supply in heat waves, ability to cope with potential increased demands in hotter temperatures) in warmer temperatures. These measures will require multi-sectorial working and planning. Health and wellbeing boards that bring together Health, Local Authority and monitoring services may be well placed to undertake this inter-disciplinary strategic planning.

Policy Level Interventions

A recent systematic review has examined the effectiveness of heat warning systems (HWS) (75). These action plans, based on meteorological and demographic information usually include early alerts and public health measures for protection and are tailored to local contexts. The review found that there were no studies using robust enough designs to be able to quantitatively evaluate the effectiveness of HWS for health protection (in terms of morbidity and mortality outcomes). Many countries, including England, have heat wave plans. Further evidence to evaluate both the individual recommendations within the plans and the effectiveness of the plans overall would be useful for improvements to these.

Conclusions and Knowledge Gaps

This review has illustrated the key findings of UK studies illustrating the association between increased temperatures and heat waves and mortality. The results for other health outcomes are less clear. Vulnerable populations to heat effects include the elderly, those with certain co-morbidities, those living in London and the South East or East of England. Future projections all predict an increase in heat related deaths throughout this century, the magnitude of which depends on assumptions used within models.

However, key gaps in our knowledge remain and would merit further investigation. For example, with regards to what is known about the underlying epidemiological relationship between heat and health outcomes, uncertainties remain. These include knowledge gaps around the relationship between more extreme temperatures and health outcomes (there is a non-linear relationship between exposure and outcome at higher temperatures, but scarcity of data at extremes makes this difficult to model), the best way to characterise a heat wave, the need for better understanding of certain vulnerabilities to heat (for example, the effect of UHIs, socio-economic status, which medications increase risk, further characteristics or local level factors which increase or decrease risk within the UK). Evidence on attributable deaths or health outcomes to past and projected future climate change would also be welcome.

Considering future impacts, the use of RCPs rather than the emissions scenarios could be examined for future health impact assessments. Further work on impact by certain groups such as by age, SES in addition to location would be useful. There are also many gaps in our knowledge about adaptation. For example, what works now and what may work in the future? How can past specific adaptive measures be identified and evaluated? And how might adaptive strategies translate from one setting to another? And how much will estimates in risk differ, depending on whether adaptation is factored into our calculations?

In terms of research for policies regarding adaptation and protection, further work to examine the use of current or improved early warning systems for heat and evaluations of current interventions to prevent mortality and morbidity from heat would be useful. There are also gaps in our knowledge around adaptive measures that might be of co-benefit to other health outcomes or to mitigation of climate change and how we can best work with other sectors to promote integrated research and policy development in this area. The design and use of suitable indicators for adaptation and ensuring equity components are reflected in these, is important in order to evaluate progress.

Addressing these knowledge gaps will be paramount to ensure that evidence can inform policy for appropriate actions and use of resources to minimise future health impacts of heat, and to improve health under a changing climate.

References

1. IPCC. Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker. T.F,. qin, G-K., Plattner, M. Tigor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley eds.)). 2013.
2. Jenkins GJ, Murphy JM, Sexton DMH, Lowe JA, Jones P, Kilsby CG. UK Climate Projections: Briefing report. Met Office Hadley Centre, exeter, UK., 2009.
3. Basu R, Samet JM. Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiol Rev*. 2002;24(2):190-202.
4. Buckley JP, Samet JM, Richardson DB. Commentary: does air pollution confound studies of temperature? *Epidemiology*. 2014;25(2):242-5.
5. Basu R, Dominici F, Samet JM. Temperature and mortality among the elderly in the United States: a comparison of epidemiologic methods. *Epidemiology*. 2005;16(1):58-66.
6. Tong S, Wang XY, Guo Y. Assessing the short-term effects of heatwaves on mortality and morbidity in Brisbane, Australia: comparison of case-crossover and time series analyses. *PLoS One*. 2012;7(5):e37500.
7. Goodman PG, Dockery DW, Clancy L. Cause-specific mortality and the extended effects of particulate pollution and temperature exposure. *Environ Health Perspect*. 2004;112(2):179-85.
8. Pattenden S, Armstrong B, Milojevic A, Heal MR, Chalabi Z, Doherty R, et al. Ozone, heat and mortality: acute effects in 15 British conurbations. *Occup Environ Med*. 2010;67(10):699-707.
9. Gasparrini A, Armstrong B, Kovats S, Wilkinson P. The effect of high temperatures on cause-specific mortality in England and Wales. *Occup Environ Med.* 2012;69(1):56-61.
10. Hajat S, Vardoulakis S, Heaviside C, Eggen B. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. J *Epidemiol Community Health.* 2014.
11. Armstrong BG, Chalabi Z, Fenn B, Hajat S, Kovats S, Milojevic A, et al. Association of mortality with high temperatures in a temperate climate: England and Wales. *J Epidemiol Community Health.* 2011;65(4):340-5.
12. Baccini M, Kosatsky T, Analitis A, Anderson HR, D'Ovidio M, Menne B, et al. Impact of heat on mortality in 15 European cities: attributable deaths under different weather scenarios. J *Epidemiol Community Health.* 2011;65(1):64-70.
13. Pattenden S, Nikiforov B, Armstrong BG. Mortality and temperature in Sofia and London. J *Epidemiol Community Health*. 2003;57(8):628-33.
14. Hajat S, Kovats RS, Atkinson RW, Haines A. Impact of hot temperatures on death in London: a time series approach. *J Epidemiol Community Health*. 2002;56(5):367-72.
15. Baccini M, Kosatsky T, Biggeri A. Impact of summer heat on urban population mortality in Europe during the 1990s: an evaluation of years of life lost adjusted for harvesting. *PLoS One.* 2013;8(7):e69638.
16. Hajat S, Armstrong BG, Gouveia N, Wilkinson P. Mortality displacement of heat-related deaths: a comparison of Delhi, Sao Paulo, and London. *Epidemiology*. 2005;16(5):613-20.
17. Kovats RS, Hajat S, Wilkinson P. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. *Occup Environ Med.* 2004;61(11):893-8.
18. Michelozzi P, Accetta G, De Sario M, D'Ippoliti D, Marino C, Baccini M, et al. High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. *Am J Respir Crit Care Med.* 2009;179(5):383-9.
19. Dawson J, Weir C, Wright F, Bryden C, Aslanyan S, Lees K, et al. Associations between meteorological variables and acute stroke hospital admissions in the west of Scotland. *Acta Neurol Scand*. 2008;117(2):85-9.
20. Bhaskaran K, Hajat S, Haines A, Herrett E, Wilkinson P, Smeeth L. Short term effects of temperature on risk of myocardial infarction in England and Wales: time series regression analysis of the Myocardial Ischaemia National Audit Project (MINAP) registry. *BMJ*. 2010;341:c3823.
21. Bhaskaran K, Armstrong B, Hajat S, Haines A, Wilkinson P, Smeeth L. Heat and risk of myocardial infarction: hourly level case-crossover analysis of MINAP database. *BMJ*. 2012;345:e8050.

22. Bhaskaran K, Hajat S, Haines A, Herrett E, Wilkinson P, Smeeth L. Effects of ambient temperature on the incidence of myocardial infarction. *Heart*. 2009;95(21):1760-9.
23. Turner LR, Barnett AG, Connell D, Tong S. Ambient temperature and cardiorespiratory morbidity: a systematic review and meta-analysis. *Epidemiology.* 2012;23(4):594-606.
24. Thornes JE, Fisher PA, Rayment-Bishop T, Smith C. Ambulance call-outs and response times in Birmingham and the impact of extreme weather and climate change. *Emerg Med J*. 2014;31(3):220-8.
25. Lee SJ, Hajat S, Steer PJ, Filippi V. A time-series analysis of any short-term effects of meteorological and air pollution factors on preterm births in London, *UK. Environ Res.* 2008;106(2):185-94.
26. Strand LB, Barnett AG, Tong S. The influence of season and ambient temperature on birth outcomes: a review of the epidemiological literature. *Environ Res.* 2011;111(3):451-62.
27. D'Ippoliti D, Michelozzi P, Marino C, de'Donato F, Menne B, Katsouyanni K, et al. The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. *Environ Health.* 2010;9:37.
28. Kovats RS, Kristie LE. Heatwaves and public health in Europe. *Eur J Public Health*. 2006;16(6):592-9.
29. Johnson H, Kovats RS, McGregor G, Stedman J, Gibbs M, Walton H, et al. The impact of the 2003 heat wave on mortality and hospital admissions in England. *Health Stat Q*. 2005(25):6-11.
30. Rooney C, McMichael AJ, Kovats RS, Coleman MP. Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. *J Epidemiol Community Health*. 1998;52(8):482-6.
31. Green HK, Andrews NJ, Bickler G, Pebody RG. Rapid estimation of excess mortality: nowcasting during the heatwave alert in England and Wales in June 2011. *J Epidemiol Community Health*. 2012;66(10):866-8.
32. Le Tertre A, Lefranc A, Eilstein D, Declercq C, Medina S, Blanchard M, et al. Impact of the 2003 heatwave on all-cause mortality in 9 French cities. *Epidemiology*. 2006;17(1):75-9.
33. Kaiser R, Le Tertre A, Schantz JT, Gotway CA, Daley WR, Rubin CH. The Effect of the 1995 heat wave in Chicago on all-cause and cause-specific mortality. *Am J Public Health*. 2007;97(Suppl 1):S158-62.
34. Ellis FP, Prince HP, Lovatt G, Whittington RM. Mortality and morbidity in Birmingham during the 1976 heatwave. *Q J Med*. 1980;49(193):1-8.
35. Arbury S, Jacklitsch B, Farquah O, Hodgson M, Lamson G, Martin H, et al. Heat illness and death among workers - United States, 2012-2013. MMWR Morb Mortal Wkly Rep. 2014;63(31):661-5.
36. Arnfield A. Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. *International journal of Climatology*. 2003;23:1-26.
37. Kovats RS, Hajat S. Heat stress and public health: a critical review. *Annu Rev Public Health*. 2008;29:41-55.
38. Hajat S, Kovats RS, Lachowycz K. Heat-related and cold-related deaths in England and Wales: who is at risk? *Occup Environ Med*. 2007;64(2):93-100.
39. Semenza JC, McCullough JE, Flanders WD, McGeehin MA, Lumpkin JR. Excess hospital admissions during the July 1995 heat wave in Chicago. *Am J Prev Med*. 1999;16(4):269-77.
40. Whitman S, Good G, Donoghue ER, Benbow N, Shou W, Mou S. Mortality in Chicago attributed to the July 1995 heat wave. *Am J Public Health*. 1997;87(9):1515-8.
41. Schwartz J. Who is sensitive to extremes of temperature?: A case-only analysis. *Epidemiology*. 2005;16(1):67-72.
42. Naughton MP, Henderson A, Mirabelli MC, Kaiser R, Wilhelm JL, Kieszak SM, et al. Heat-related mortality during a 1999 heat wave in Chicago. *Am J Prev Med*. 2002;22(4):221-7.
43. Page LA, Hajat S, Kovats RS, Howard LM. Temperature-related deaths in people with psychosis, dementia and substance misuse. *Br J Psychiatry*. 2012;200(6):485-90.
44. Ellis F. Heat wave deaths and drugs affecting temperature regulation. *Br Med J.* 1976;2(6033):474.

45. Sommet A, Durrieu G, Lapeyre-Mestre M, Montastruc JL, Association of French PharmacoVigilance C. A comparative study of adverse drug reactions during two heat waves that occurred in France in 2003 and 2006. *Pharmacoepidemiol Drug Saf*. 2012;21(3):285-8.
46. Stollberger C, Lutz W, Finsterer J. Heat-related side-effects of neurological and non-neurological medication may increase heatwave fatalities. *Eur J Neurol.* 2009;16(7):879-82.
47. O'Neill MS, Zanobetti A, Schwartz J. Modifiers of the temperature and mortality association in seven US cities. *Am J Epidemiol*. 2003;157(12):1074-82.
48. Bouchama A, Dehbi M, Mohamed G, Matthies F, Shoukri M, Menne B. Prognostic factors in heat wave related deaths: a meta-analysis. *Arch Intern Med*. 2007;167(20):2170-6.
49. Kovats RS, Johnson H, Griffith C. Mortality in southern England during the 2003 heat wave by place of death. *Health Stat Q*. 2006(29):6-8.
50. Wolf T, McGregor G. The development of a heat wave vulnerability index for London, United Kingdom. *Weather, Climate and Society.* 2013.
51. Tomlinson C, Chapman L, Thornes J, Baker C. Including the urban heat island in spatial heat health risk assessment strategies: a case study for Birmingham, UK. international *Journal of Health Geographics.* 2011;10(42).
52. Abrahamson V, Raine R. Health and social care responses to the Department fo Health Heatwave Plan. *Journal of Public Health*. 2009;31(4):478-89.
53. Abrahamson V, Wolf J, Lorenzoni I, Fenn B, Kovats S, Wilkinson P, et al. Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. *J Public Health* (Oxf). 2009;31(1):119-26.
54. Wolf J, Adger N, Lorenzoni I, Abrahamson V, Raine R. Social Capital, individual responses to heat waves and climate change adaptation: an empirical study of two UK cities. *Global Environmental Change.* 2010;20:44-52.
55. Huang C, Barnett AG, Wang X, Vaneckova P, FitzGerald G, Tong S. Projecting future heat-related mortality under climate change scenarios: a systematic review. *Environ Health Perspect*. 2011;119(12):1681-90.
56. Gosling SN, McGregor GR, Lowe JA. Climate change and heat-related mortality in six cities Part 2: climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change. *Int J Biometeorol.* 2009;53(1):31-51.
57. Dessai S. Heat stress and mortality in Lisbon Part II. An assessment of the potential impacts of climate change. *Int J Biometeorol*. 2003;48(1):37-44.
58. Vardoulakis S, Heaviside C. Health Effects of Climate Change in the UK 2012 - current evidence, recommentations and research gaps. *Health Protection Agency*, 2012.
59. Donaldson GC, Kovats RS, Keatinge WR, McMichael AJ. Heat- and cold-related mortality and morbidity and climate change. *Department of Health.*, 2002.
60. Martens WJ. Climate change, thermal stress and mortality changes. *Soc Sci Med*. 1998;46(3):331-44.
61. Doherty RM, Heal MR, Wilkinson P, Pattenden S, Vieno M, Armstrong B, et al. Current and future climate- and air pollution-mediated impacts on human health. *Environ Health*. 2009;8 Suppl 1:S8.
62. Lin S, Hsu WH, Van Zutphen AR, Saha S, Luber G, Hwang SA. Excessive heat and respiratory hospitalizations in New York State: estimating current and future public health burden related to climate change. *Environ Health Perspect*. 2012;120(11):1571-7.
63. Astrom C, Orru H, Rocklov J, Strandberg G, Ebi KL, Forsberg B. Heat-related respiratory hospital admissions in Europe in a changing climate: a health impact assessment. *BMJ Open.* 2013;3(1).
64. Michelozzi P, Kirchmayer U, Katsouyanni K, Biggeri A, McGregor G, Menne B, et al. Assessment and prevention of acute health effects of weather conditions in Europe, the PHEWE project: background, objectives, design. *Environ Health*. 2007;6:12.
65. IPCC. Fourth Assessment Report : Climate Change 2007. 2007.
66. Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni K, Analitis A, et al. Heat effects on mortality in 15 European cities. *Epidemiology*. 2008;19(5):711-9.

67. McMichael AJ, Wilkinson P, Kovats RS, Pattenden S, Hajat S, Armstrong B, et al. International study of temperature, heat and urban mortality: the 'ISOTHURM' project. *Int J Epidemiol.* 2008;37(5):1121-31.
68. Basu R, Feng WY, Ostro BD. Characterizing temperature and mortality in nine California counties. *Epidemiology*. 2008;19(1):138-45.
69. Donaldson GC, Keatinge WR, Nayha S. Changes in summer temperature and heat-related mortality since 1971 in North Carolina, South Finland, and Southeast England. *Environ Res*. 2003;91(1):1-7.
70. Kovats S, Bickler G. Health protection and heatwaves: The need for systematic reviews. Cochrane Database Syst Rev. 2012;8:ED000044.
71. Welch V, Petticrew M, Tugwell P, Moher D, O'Neill J, Waters E, et al. PRISMA-Equity 2012 extension: reporting guidelines for systematic reviews with a focus on health equity. *PLoS Med*. 2012;9(10):e1001333.
72. Brisley R, Welstead J, Hindle R, Paavola J. Socially Just Adaptation to Climate Change. 2012.
73. Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, Howe HL, et al. Heat-related deaths during the July 1995 heat wave in Chicago. *N Engl J Med*. 1996;335(2):84-90.
74. Gupta S, Carmichael C, Simpson C, Clarke MJ, Allen C, Gao Y, et al. Electric fans for reducing adverse health impacts in heatwaves. Cochrane Database Syst Rev. 2012;7:CD009888.
75. Toloo G, FitzGerald G, Aitken P, Verrall K, Tong S. Evaluating the effectiveness of heat warning systems: systematic review of epidemiological evidence. *Int J Public H*ealth. 2013;58(5):667-81.