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A systematic review of the impacts of extreme heat on health and wellbeing in the United Kingdom

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ABSTRACT

Climate change poses a concern globally, as it adversely affects planetary and population health. Extreme heat is one of the largest weather-related causes of mortality, projected to cause severe heatwaves and droughts globally. Current research has focused on the effects of outdoor heat exposure on population health risks, leaving a gap in knowledge regarding indoor exposure to extreme heat. This paper presents evidence for the effects of extreme heat, both indoors and outdoors, on non-communicable diseases (NCDs) in the United Kingdom. This study applies a systematic review methodology to identify, quality appraise, extract, and summarize findings from studies reporting on the associations between extreme heat and population health risk of NCDs. The literature search was conducted across six electronic databases. `There were 244 studies identified. Twenty-three studies met the inclusion criteria, of these 16 studies met the quality benchmark. Fourteen studies examined the links between heat exposure and mortality, while the remaining studies focused on emergency hospital admissions and years of life lost. The review highlights a consistent association between exposure to extreme heat and increased risk of mortality. Further research is needed to explore the effects of indoor extreme heat on the incidence of NCDs and related outcomes.

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Indoor exposure; extreme-heat; climate change; non-communicable disease; population health risk; all-cause mortality

Introduction

The dangers posed by climate change are of global concern, and the evidence of the adverse effects of climate change on the fundamental pillars of health, food, water and the air is well-established (McMichael *et al.* 2008).

Extreme heat has already been reported to be one of the largest weather-related causes of death in high-income countries (Centre for Disease Control and Prevention 2019), yet there are predictions of a rise in global temperature by 1.5°C above pre-industrial levels by 2052 (IPCC 2018). The UK climate projections under high emission scenarios forecast a rise in outdoor temperature of up to 5.4°C by 2070 (Met Office 2021). Estimates have shown that a 2°C rise in temperature would expose 37% of the global population to at least one form of severe heatwave every 5 years and expose nearly 200 million people to severe drought (Carbon Brief 2021). The intensity of the built environment amplifies indoor extreme heat conditions when there are extreme outdoor health conditions. Our previous systematic review of the impact of buildings on health and wellbeing also highlighted gaps in the evidence linking overheating in buildings and health (Ige *et al.* 2019, Ige-Elegbede *et al.* 2020)

A historical examination of the aftermath of heatwaves in the UK provides a stark reminder of the devastating impact of climate change. Over 2000 excess deaths were recorded during the 2003 heatwave in England and Wales (Vardoulakis and Heaviside 2012). Evidence linking the effect of urban heat islands (UHIs) on mortality consistently suggests an association between elevated temperatures in urban areas and increased mortality rates, particularly during heatwaves. Vulnerable populations, such as the elderly, children, and individuals with pre-existing health conditions, are at a heightened risk of mortality during extreme heat events in urban environments (Heaviside *et al.* 2016). Extreme heat has also been linked to inequalities in excess mortality and morbidity, particularly among older populations and clinically vulnerable groups (Ormandy and Ezratty 2016).

The projected increase in temperature along with further temperature impacts of the urban heat island (i.e. a rise in temperature of urban and metropolitan areas relative to rural areas that is predominantly due to human activities) should be important considerations for policy and action on the planning, development and management of our towns and cities. Unsurprisingly, there have been explicit calls by the Health Protection Agency for further research on the quantification of the impact of extreme heat and other extreme events such as flooding on health and wellbeing (Vardoulakis and Heaviside 2012). An analysis

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of the historic and potential impacts of extreme heat on health and wellbeing is a prerequisite for planning mitigative interventions (Maramba *et al.* 2004).

Beyond physical health, extreme heat also has implications for mental well-being. The study by Page *et al.* (2007) highlighted an association between heatwaves and an increase in hospital admissions for mental health disorders, while Hansen *et al.* (2018) reported a rise in the incidence of heat-related stress and exacerbations in pre-existing mental health disorders.

Research on the links between extreme heat and non-communicable diseases (NCDs) has been predominantly focused on outdoor ambient temperature and to our knowledge there is no systematic review evidence of the effects of extreme heat in homes on NCDs and related risk factors. This paper will therefore provide a comprehensive systematic review and synthesis of the evidence for the known and projected impacts of exposure to indoor and outdoor extreme heat on population health outcomes between 1990 and 2021 in the UK.

Methods

This study applies a systematic review methodology to apply objective, reproducible and comprehensive search concepts and strategies to identify, critically appraise and summarise empirical studies between 1990 and 2021 reporting the association between heatwaves, extreme heat and the risk of NCDs. The review start date, 1990, was chosen because pollution controls on aerosols produced by dust, pollution, combustion of biofuels and fossil fuels were implemented globally in that year.

Arbuthnott and Hajat (2017), Arbuthnott *et al.* (2020) and Petrou *et al.* (2015) provided strong, narrative literature reviews of this area. Narrative literature review is not as comprehensive or reproducible as systematic review, reviewers select studies, apply individual critical evaluation and discussion. Systematic reviews play an important role in informing research evidence base (Moher *et al.* 2009). They provide a formal assessment of using a systematic approach to identify, select and appraise the quality of existing research that meets the inclusion criteria between the dates and to extract and analyse data from these selected studies, limiting the opportunity for studies to be missed or discarded in error.

Search strategy

A list of potentially relevant databases was compiled from existing narrative reviews across similar topics (Arbuthnott and Hajat 2017, Tham *et al.* 2020). A search was conducted by JI across six electronic databases (MEDLINE, GreenFILE, Psych INFO, Applied Social Sciences Index and Abstracts, SocINDEX, Allied and Complementary Medicine). The databases were initially searched by title and abstract to identify relevant publications from 1990 to 2021. The search terms were adapted from a recent systematic review (Tham *et al.* 2020). These terms were categorised into three-word groups relating to indicators of indoor and outdoor exposure to extreme heat, health outcomes and population location. Following an initial draft of search terms, subject area experts were contacted to verify and refine the terms. A pilot search was performed by JI in one database (MEDLINE) to test the search strategy and refine the search terms prior to conducting the full search.

The reference lists of the included papers were also manually searched. Additional searches were conducted on Google and Google Scholar to locate potentially eligible studies and grey literature. Table 1 presents an example of the search strategy developed for the MEDLINE database.

Study selection inclusion/exclusion criteria

The eligibility criteria for inclusion in the final review were studies that i) report on measurable associations between extreme heat and at least one of the health outcomes in Table 1 ii) published in English language between January 1990 to 2021 with full text in a peer-reviewed journal or nationally recognised stakeholder website iii) contain secondary data from the United

Table 1. Search strategy for extreme heat.

Population Location	United Kingdom OR UK, OR Great Britain OR Wales OR England OR Scotland OR Northern Ireland OR Britain
	AND
Indicators for exposure to extreme heat	Extreme heat OR Temperature OR Hot temperature OR Indoor adj3 heat* OR Indoor adj3 threshold OR Indoor adj3 thermal OR Indoor adj3 climate OR Ambient adj3 temperature* OR Residential adj3 temperature OR Heat OR urban heat OR UHIE
	AND
Health outcomes	Accident OR asthma OR 'blood pressure' OR cardiovascular OR COPD OR CVD OR death OR disability OR disorder OR 'emotional health' OR 'health outcome' OR health OR illness* OR 'injury prevent*' OR 'life satisfaction' OR 'medical condition*' OR 'mental health' OR Anxiety OR posttraumatic OR 'Moderate-vigorous physical activity' OR MVPA OR obes* OR physical activity OR physical health OR sedent* OR suicide OR violence OR independence OR mobility OR safety OR fall OR depression OR isolation OR fire OR 'electrical hazards' OR wellbeing OR excess summer death OR heatstroke OR heat exhaustion OR dehydration OR Stress OR respiratory OR autoimmune triggers OR inequalities
	AND
Studies	Any that contain the desired outcomes

Kingdom or its individual countries. Qualitative studies were automatically excluded from this review as the focus of this study is to identify and quantify the impact of extreme heat on the risk of NCDs and to use findings as a basis for economic evaluation (to be reported elsewhere).

Data extraction

Data extraction tables were designed in Microsoft Excel to collate descriptive data from included studies rated strong or moderate. Data on study location, the population of interest, exposure to extreme heat, health outcome(s), quality of available evidence and key findings were all extracted to a data extraction sheet.

Quality assessment

Effective Public Health Practice Project (EPHPP) Tool was used to rate the quality of rigour of studies deemed eligible for full-text inclusion (EPHPP 2023). EPHPP is highly recommended for quality rating empirical studies based on construct validity and acceptable content (Jadad *et al.* 1996, Mulrow *et al.* 1997). The tool features six domains for evaluating quality: (i) the likelihood that populations in the study reflect the intended group (selection bias); (ii) the study's design; (iii) managing confounding elements; (iv) masking of populations and researchers (blinding); (v) the consistency and accuracy of data gathering techniques; and (vi) the presentation of participant withdrawals and dropout rates. Each of these elements received a rating of high, moderate, or low. An overall rating of 'Strong (S) = 1', 'Moderate = 2' or 'low = 3' quality was defined for each study according to the EPHPP data dictionary guidelines.

Results

The initial database search returned 244 studies which were screened for duplicates. Following the removal of 79 duplicates, the remaining 165 studies were screened by titles. 100 of these were excluded for failing to meet the eligibility criteria. The remaining 65 studies were screened by abstract, and 42 studies were excluded at this stage for a lack of focus of the impact of extreme heat on relevant health outcomes. A total of 23 studies were included in the review; further details of the search are summarised in Figure 1.

All included studies reported using secondary data sources as exposure and outcome variables. Of the 23 studies selected for inclusion, five were rated Strong (S) high quality, while 16 studies were deemed to be of Moderate (M) quality and the remaining seven studies were rated weak quality. Data from studies deemed to be of moderate and high quality were included in the final synthesis.

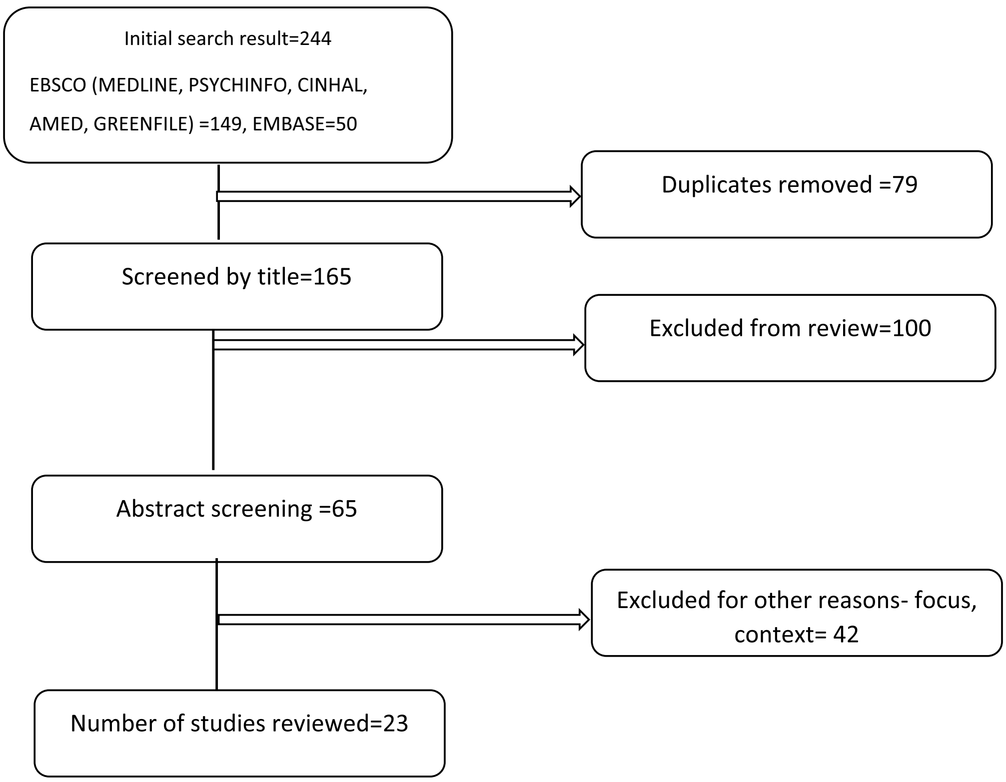

Figure 1. PRISMA flow chart.

Population

In terms of study location, the majority of the studies were described as nationwide studies or included data from multiple cities in the UK ($n = 10$), although there were a few multi-country studies which included data from the UK ($n = 6$). However, four of the studies were conducted using data from London only, while one study used data collected in the West Midlands region only.

Exposure

There were significant variations in the definition of heat thresholds used across studies, e.g. 93rd percentile of daily mean temperature, average of lags 0–1 (Vardoulakis *et al.* 2014), 91st percentiles of the mean temperature (Arbuthnott *et al.* 2020). Temperature measurements were retrieved from different sources including the air quality monitoring stations and meteorological stations. Only one of the studies included in the review examined the health impacts of extreme heat indoors (Murage *et al.* 2020).

Outcomes

All-cause mortality was by far the most prevalent outcome reported. Other outcomes identified were heat-related/cause specific, suicide, emergency hospital admissions and years of life lost (YLL), Figure 2.

Mortality

Fourteen studies examined the links between heat exposure and mortality (Pattenden *et al.* 2010, Gasparrini *et al.* 2012, Hajat *et al.* 2014, Vardoulakis *et al.* 2014, Gasparrini *et al.* 2015a, 2015b, Petrou *et al.* 2015, Heaviside *et al.* 2016, Zhang *et al.* 2018, Kim *et al.* 2019, Arbuthnott *et al.* 2020, Murage *et al.* 2020, de Schrijver *et al.* 2021, Evangelopoulos *et al.* 2021). The evidence of increased risk of mortality with higher temperatures above threshold levels was consistent across the studies examined except for Gasparrini *et al.* (2015a) which assessed temporal variations in heat mortality across multiple countries and reported no significant findings (Table 2).

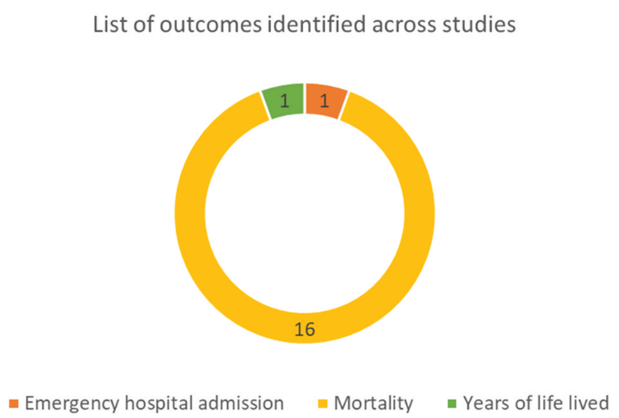

Figure 2. Breakdown of outcome measures across 16 included studies.

The study by Vardoulakis *et al.* (2014) investigated the relationship between current and future heat exposure and mortality in England and Wales using three Special Report on Emissions Scenarios Low (B1) Medium (A1B) and High (A1FI). Findings showed a 2.5% [95% CI: 1.9, 3.1] increase in mortality per 1°C rise in temperature above the heat threshold [93rd percentile of daily mean temperature]. The authors also predicted a 90% increase in heat-related mortality between the 2020s ($n = 1503$) and 2050s ($n = 2866$) under the medium emissions scenario and by approximately 72% between the 2050s ($n = 2866$) and 2080s ($n = 4922$). Likewise, the study by Hajat *et al.* (2014) was conducted to model the projected impacts of temperature exposure and weather variability on mortality in the UK during the 2020s, 2050s and 2080s. The authors reported a 2.1% [95% CI: 1.5 to 2.7] increase in mortality for every 1°C rise in temperature above the heat threshold at the national level. London RR = 1.04 (1.03–1.04) and East Midlands RR = 1.03 (1.02 = 1.03) were the UK regions most vulnerable to heat. Further analysis suggests that the mean estimate of heat-related mortality could increase by approximately 66% ($n = 3281$), 257% ($n = 7{,}040$) and 535% ($n = 12{,}538$) in the 2020s, 2050s and 2080s, respectively, from a current baseline of 1974 deaths.

Pattenden *et al.* (2010) assessed the effects of ozone, heat, and their interaction, on all-cause mortality, cardiovascular and respiratory mortality across 15 conurbations in England and Wales. Findings from the study showed that extreme heat remained independently associated with deaths in all three causal subgroups, with the mean rate ratio for respiratory mortality reaching 1.139 (1.079–1.202), cardiovascular diseases 1.055 (1.025 to 1.087), and all-cause mortality 1.071 (1.050 to 1.093). Arbuthnott *et al.* (2020) ecological time-series study reported that in London, for each 1°C above the heat threshold the risk of mortality increased by 3.9% [95% CI: 3.5%, 4.3%]. The study by Gasparrini (2012), reported a significant increase in all-cause mortality for a 1°C rise above the England and Wales regional heat threshold RR = 2.1% [95% CI 1.6% to 2.6%]. Among the main causes, the steepest increase in risk was for respiratory mortality 4.1% (3.5% to 4.8%).

Murage *et al.* (2020) assessed how urban vegetation, housing characteristics and socio-economic factors modify the association between heat exposure and mortality in a large urban area. The authors reported lower daily temperatures in areas with more trees and vegetation cover and where the proportion of properties owned outright was highest, whilst higher daily mean temperatures were recorded in areas with a high proportion of social housing, higher-income deprivation and in areas with a high proportion of non-native English speakers. Although the findings were not always significant, the authors reported the highest odds of death in ports and airport areas (1.149, 0.959–1.376) and the lowest in forested and agricultural land (0.986, 0.848–1.146). Evangelopoulos *et al.* (2021) looked at the effects of temperature increases on the risk of mortality by the climatic zone of the country of origin for people born outside the UK and reported that UK, tropical and boreal (sub-polar) climate-born people have an increased risk of death from extreme heat, and migrants show little adaptation to their new climate zone. The authors of the study, however, acknowledged potential methodological limitations limiting the power of the study to detect an actual difference if one exists.

The study by Petrou *et al.* (2015) examined the daily total mortality (DTMORT) from heat exposure in the summer months in Yorkshire and the Humber, West Midlands, North East, North West and South East regions of the UK. Findings showed an increase in DTMORT across all five regions. Another study was conducted by Zhang *et al.* (2018) to examine the impacts of diurnal temperature range (DTR), which is the difference between the daily maximum and minimum temperature on mortality in England and Wales between 1993 and 2006. Daily DTR varied greatly from 0.8°C to 20.2°C during the study period, but the annual average was 7.3°. DTR extremes (both high and low DTR) exhibited a significant impact on mortality. The authors concluded that there was clear evidence of increased mortality associated with extremely high DTR for all regions except North East, whereas extremely low DTR tended to show some protective effects.

Kim *et al.* (2019) study investigated the relationship between extreme heat and suicide across multiple countries. Findings from the UK demonstrate a significant relationship between suicide rate and extreme heat in the UK 1.34 (1.22, 1.46) (Kim *et al.* 2019).

The study by Gasparrini et al. (2015b) attempted to quantify the total mortality burden attributable to heat or cold across 13 countries including the UK; the authors reported that the total deaths due to heat in the UK during the study period were 0.3% (0.25%–0.36%).

De Schrijver *et al.* (2021) conducted a study to critically assess the differences in temperature-related mortality risks and impacts derived from Gridded Climate Datasets (GCDs) and weather stations across two heterogeneous regions (UK and Switzerland). Excess deaths from heat in England and Wales were 2,979 (2,419, 3,493), 2,943 (2,404, 3,465), and 2,906 (2,425, 3,401) for the weather station and local and global GCD, respectively. RR estimates for heat in Greater London were 1.25 (95% CI; 1.19–1.30), 1.24 (95% CI; 1.18–1.29), and 1.26 (95% CI; 1.20–1.33) for the weather station and local and global GCD, respectively.

Urban heat island effect and mortality

The study by Heaviside *et al.* (2016) investigated the attribution of the Urban Heat Island (UHI) to heat-related mortality in the West Midlands during the heatwave of August 2003 by comparing health impacts based on two modelled temperature simulations. The results suggest that the UHI contributed around 50% of the total heat-related mortality during the 2003 heatwave in the West Midlands. The authors also projected that mortality estimates for a heatwave event similar to that of 2003 could result in a rise in mortality of 53% in the 2020s, 122% in the 2050s and 209% by the 2080s from the baseline of 90 deaths in 2003.

Emergency hospital admission

A study by Kovats *et al.* (2004) investigated the effects of hot weather and heatwaves on emergency hospital admissions in Greater London, UK. Emergency hospital admissions were stratified by age group and diagnostic groups (cardiovascular disease, respiratory disease, cerebrovascular disease, renal disease, acute renal failure and calculus of the kidney and urethra). Findings were not statistically significant for most of the age groups, but respiratory admissions increased by 10.86% (95% CI = 4.44 to 17.67) for each degree rise in daily mean temperature above 23 degrees in those aged 75 years and above (Table 3). The authors also reported that an increase in daily mean temperature above 12°C was associated with increased emergency hospital admissions (0.24% 95%CI = 0.02%–0.46%) in infants and children under 5 years.

Years of life lost (YLL)

One study examined the relationship between YLL and temperature in Greater London, West Midlands and Greater Manchester (Arbuthnott *et al.* 2020). Findings (Table 4) showed that in London, for each 1°C above the heat threshold, the YLL increased by 3.0% (2.5%, 3.5%). A corresponding increase of 1.5% (1.07-2.4%) and 2.4% (1.6-3.3%) was reported for each 1°C temperature increase above the heat threshold for Greater Manchester and West Midlands, respectively.

Table 2. Main findings from studies on extreme heat and mortality.

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Vardoulakis *et al.* (2014) England, Wales and Australia	Secondary data analysis- time series	Study to compare the mortality associated with heat and cold in UK regions and Australian cities for current and projected climates and populations	Ambient temperature and relative humidity were downloaded for the British Atmospheric data (England and Wales). Daily mean temperature and relative humidity was calculated. Projected monthly mean temperatures for 2020-2029, 2050-2059, and 2080-2089 were obtained from the UK Climate Impacts Programme.	Analysis of the data for England and Wales showed that the estimated national-level percentage change in mortality associated with exposure to heat was 2.5% (95% CI: 1.9, 3.1) per 1°C rise in temperature above the heat threshold (93rd percentile of daily mean temperature, average of lags 0-1) Findings show that the annual mean heat-related mortality was estimated to increase overall by approximately 90% between the 2020s and 2050s (125% with population projections), and by approximately 72% between the 2050s and 2080s (95% with population projections) under the medium emissions scenario	Moderate
Hajat *et al.* (2014). UK	Secondary data analysis- time series	Study to estimate temperature-related health burdens for the UK during the 2020s, 2050s and 2080s.	Outdoor measurements of temperature and relative humidity were obtained from the British Atmospheric Data Centre. Daily mean temperature and relative humidity series representative of each region	Findings show that at the national level, there was a 2.1% (95% CI 1.5 to 2.7) increase in mortality for every 1°C rise in temperature above the heat threshold. London RR= 1.04(1.03-1.04)and East Midlands RR=1.03 (1.02=1.03) were the region's most vulnerable to heat. The mean estimate of heat-related mortality increases by approximately 66%, 257% and 535% in the 2020s, 2050s and 2080s, respectively, from a current baseline of around 2000 deaths	Strong
Pattenden *et al.* (2010). England and Wales	Secondary data analysis over 10 years	Study to assess the effects of ozone, heat, and their interaction, on mortality (respiratory, cardiovascular and all-cause mortality) in Britain.	For each conurbation, data from corresponding urban background air quality monitoring stations (obtained from the UK Air Quality Archive) and meteorological stations (from the British Atmospheric Data Centre), were used to construct daily exposure variables	Findings showed that heat remained independently associated with deaths in all three causal subgroups, with the mean rate ratio for respiratory mortality reaching 1.139 (1.079-1.202), cardiovascular diseases (1.055 (1.025 to 1.087), and all-cause mortality 1.071 (1.050 to 1.093).	Moderate
Arbuthnott *et al.* (2020). Greater London, the West Midlands and Greater Manchester	Secondary data analysis- ecological time series regression analysis	Study to (a) to determine the nature of the relationship between YLL and temperature in the studied conurbations, (b) to estimate (and compare) the proportion of total yearly mortality and YLL attributable to heat and cold	Daily mean temperature obtained from the UK Met Office UKCP09 gridded observation datasets	Findings show that in London, each 1°C above the heat threshold the risk of mortality increased by 3.9% (CI 3.5%, 4.3%)	Strong

(*Continued*)

Table 2. (Continued).

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Gasparrini *et al*. (2012). England and Wales	Secondary data analysis- time series/England and Wales	Study to assess heat-related mortality with a wide range of causes using data for England and Wales in the period 1993-2006.	Data on minimum and maximum dry-bulb and dew point temperatures were obtained from the British Atmospheric Data Centre. Relative humidity was calculated using the average from dew point and dry-bulb temperatures at 9:00 h and 15:00 h	Findings show evidence of increased mortality with increasing temperature for almost all cause-of-death groups examined. The overall increase in all-cause mortality was 2.1% (95% CI 1.6% to 2.6%) for a 1°C rise above the regional heat threshold. Among the main causes, the steepest increase in risk was for respiratory mortality (+4.1% (3.5% to 4.8%) per 1°C). Findings for mortality from cardiovascular causes (+1.8% (1.2% to 2.5%)) and myocardial infarction (+1.1% (0.7% to 1.5%)), arrhythmias (+5.0% (3.2% to 6.9%)) and pulmonary heart disease (+8.3% (2.7% to 14.3%). Among non- cardiorespiratory causes, the strongest effects were for genitourinary (+3.8% (2.9% to 4.7%)) and nervous system (+4.6% (3.7% to 5.4%)) disorders. 33.9% of heat deaths were attributable to cardiovascular causes, 24.7% to respiratory causes and 41.3% to all other causes combined	Moderate

(*Continued*)

Table 2. (Continued).

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Murage *et al.* (2020) London	Secondary data analysis- Case-crossover	Study to investigate how urban vegetation, housing characteristics and socio-economic factors modify the association between heat exposure and mortality in a large urban area.	Four-hourly temperature data were collected across a 500m resolution grid from a central London location. The four-hourly temperature were aggregated to give a 24 hour mean temperature. Analysis was limited to summer months (May to September)	A total of 185,397 deaths were registered during the study period. The median summer daily temperature was 15.34°C (5.52-26.08°C). Lower daily temperatures were recorded in areas with more trees and vegetation cover and where the proportion of properties owned outright was highest. The highest daily mean temperatures were recorded in areas with a high proportion of social housing, higher income and employment deprivation and in areas with a high proportion of non-native English speakers Findings show that mortality was lowest in the quartile with the lowest indoor temperature 1.034, 95%CI= 1.027-1.041 and highest in the quartile with the highest indoor temperature 1.042, 95% CI= 1.035-1.049. The difference between the 'best' and 'worst' quartile was greatest in the natural environment measures; tree cover (OR, 95%CI =1.033, 1.026-1.039 vs. 1.043, 1.037-1.050) and vegetation index (1.032, 95%CI= 1.025-1.040 vs. 1.043, 95%CI= 1.036-1.049). The result also shows variations in the odds of death by land use categories, but this wasn't statistically significant; the highest odds of death were in ports and airport areas (1.149, 0.959-1.376), and the lowest was in forested and agricultural land (0.986, 0.848-1.146)	Moderate

(*Continued*)

Table 2. (Continued).

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Petrou *et al.* (2015). Yorkshire and the Humber, West Midlands, North East, North West and South East regions	Secondary data analysis	Study to identify possible acute heat-induced summer mortality in five regions of England and reveal associations with specific airflow	Daily maximum temperature (DMAXT) and daily mean temperature (DMT) data referring to one representative county of each region ere provided in Celsius degrees (°C) by the ONS	A statistically significant 95% confidence interval increase in daily total mortality (DTMORT) was observed during the selected episodes in all five regions and thus, heat-induced mortality was indicated. Findings showed that in the Yorkshire and the Humber region, a 6.19% (95% CI = 3.65, 8.73%) increase in DTMORT was detected during the selected days. An 11.3% (95% CI = 8.7, 13.9%) rise in DTMORT was computed in the West Midlands region during the selected days. DTMORT in the North East region was increased by 4.7% (95% CI = 1.6, 7.9%) during the selected days. In the North West region, a 13.1% (95% CI = 10.8, 15.4%) increase in DTMORT was associated with high-temperature episodes. An 11.9% (95% CI = 10.1, 13.6%) increase in DTMORT corresponded to the selected days in the South East region	Moderate
Zhang *et al.* (2018) England and Wales	Secondary data analysis - time series (14 years)	Study to provide national estimates for DTR-associated effects on mortality and explore whether season and regional-level characteristics modify DTR-mortality relation in the United Kingdom.	The DTR-mortality association was investigated with a two-stage analytic approach using the 14-year time-series data from the 10 regions in England and Wales.	A total of 7,573,716 persons died in England and Wales between 1993 and 2006, with a daily average of 148.1 deaths per region (ranging from 79.8 in the North East to 221.5 in the South East). The annual average temperature and relative humidity were 10.4°C (range: 9.5-11.7°C) and 74.7% (range: 67.4-78.3%), respectively. Daily DTR varied greatly from 0.8°C to 20.2°C with an annual average of 7.3°C for the included regions. DTR extremes (both high and low DTR) exhibited a significant impact on mortality. Clear evidence of increased mortality associated with extremely high DTR was revealed for all regions except North East, whereas extremely low DTR tended to show some protective effects. RR displayed as images	Moderate
Kim *et al.* (2019). 132 study sites across 12 countries including the UK.	Secondary data analysis	A multicounty study to investigate the associations between suicide and high ambient temperature.	Daily data on weather conditions were obtained for 306 communities from 12 countries/regions. Weather data included daily minimum, mean and maximum temperatures, and relative humidity.	Mean summer temperature for the 10 UK locations= 15.6 (14.5-17.2). Suicide rate per 100,000= 6.9. The minimum suicide temperature (°C) (MinST) and maximum suicide temperature (°C) (MaxST) were −0.7 (1%ile) and 20.7 (99th percentile). The mean RR for suicide and temperature = 1.34 (1.22, 1.46)	Moderate

(*Continued*)

Table 2. (Continued).

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Gasparrini *et al*. (2015a p. 272) locations in Australia, Canada, South Korea, Spain and the UK	Secondary data analysis	Study to assess the temporal variation in heat-mortality associations in a multi-country data set using flexible modelling techniques.	The exposure index was chosen as mean daily temperature, computed as the 24-hr average. The data were restricted to the summer period, identified as the four warmest months of the year using average monthly temperatures. These months consistently correspond to the period December–March in Australia and to June–September in the other countries	Time-series daily weather data were collected from 272 locations in seven countries. Findings showed no statistically significant finding was observed for the UK	Moderate
Gasparrini *et al*. (2015b)	Secondary data analysis	Study to quantify the total mortality burden attributable to either heat or cold across 13 countries.	The exposure index was defined as daily temperature a calculated from central monitor stations, either as the average between maximum and minimum values or the 24 h average across 84 locations in 13 countries	The minimum mortality percentile in the UK is the 90th percentile. Total deaths due to heat=0.3% (0.25%-0.36%)	Moderate
de Schrijver *et al*. (2021). UK and Switzerland	Secondary data analysis	Study to critically assess the differences in temperature-related mortality risks and impacts derived from Gridded Climate Datasets GCDs of variable characteristics and weather stations across two heterogeneous regions	Mean daily temperature data from three different types of sources or exposure datasets: (1) weather station data, often used as the gold standard in environmental epidemiology, (2) local high-resolution GCDs, and (3) global GCD with coarser resolution were used	Excess deaths from heat in England and Wales= 2,979 (2,419, 3,493), 2,943 (2,404, 3,465), and 2,906 (2,425, 3,401) for the weather station and local and global GCD, respectively RR estimates for heat in Greater London were 1.25 (95% CI; 1.19-1.30), 1.24 (95% CI; 1.18-1.29), and 1.26 (95% CI; 1.20-1.33) for the weather station and local and global GCD, respectively.	Moderate
Heaviside *et al*. (2016). West-Midlands	Secondary data analysis plus modelling	Study to investigate the attribution of the UHI to heat-related mortality in the West Midlands during the heatwave of August 2003 by comparing health impacts based on two modelled temperature simulations.	Modelled, gridded air temperature at a horizontal resolution of 1 km x 1 km and a height of 2 m, covering an area of ~6,300 m2 within the West Midlands region was used. To investigate the effect that urban surfaces have on local temperature, and the associated health impacts, 2 different WRF (Weather Research Forecasting) model simulations were compared	The results suggest that the UHI contributed around 50% of the total heat-related mortality during the 2003 heatwave in the West Midlands. Following the HIA method, the estimated number of deaths during the 10 day heatwave period for the West Midlands was approximately 90, based on the population-weighted daily mean simulated temperature for Birmingham and the West Midlands, which includes the UHI effects. The HIA for the 'rural' simulation over the same heatwave period gives estimated mortality of 43. UHI effect could be accountable for around 52% of the total heat-related mortality in the West Midlands during the 2003 heatwave.	Moderate

(*Continued*)

Table 2. (Continued).

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Evangelopoulos *et al.* (2021). London	Secondary data-time series	Study to provide quantitative estimates of the effects of temperature increases on the risk of mortality by the climatic zone of the country of origin for people born outside the UK and compare the effects with those born in the UK.	climatic zone of birth was classified into five categories- UK, Tropical, Boreal, including countries with sub-polar or continental temperate climate, Sub-tropical including countries with arid-hot or Mediterranean climate and Mixed, including countries with varying climate within their borders. Meteorological data consisted of 24-hour averages of air temperature (oC), relative humidity (%) and wind speed (m/s) as measured from central monitoring stations	The total number of deaths analysed for the warm season (April to September) of the years 2004-2013 was 200,180 and 158,356 for all ages and those >65 years old respectively. The relationship between mean temperature and all-cause mortality was non-linear but of different shape and with varying minimum mortality temperature for each of the five climatic zone groups (UK, tropical, boreal, sub-tropical and mixed regions) The minimum mortality temperature (MMT) was 16.9 degrees. An increase from MMT to 21C resulted in an 8% increase in the risk of death for persons born in the UK 1.08 (95% CI=1.05-1.10). 25C Vs MMT1.26 (1.18-1.35) For those born in tropical regions, 21C Vs MMT=1.07 (1.01-1.13) and 25C Vs MMT= 1.35 (1.08-1.69) For those born in Boreal regions, 21C Vs MMT= 1.10 (1.03-1.16) and 25C Vs MMT=1.39 (1.13-1.71) For those born in sub-tropical regions, MMT was >25C For those born in mixed regions 21C Vs MMT= 1.14 (1.01-1.29) and 25C Vs MMT=1.12 (0.86-1.46) Findings suggest that UK, tropical and boreal climate born people have an increased risk of death from heat and migrants show little adaptation to their new climate zone	Moderate

Table 3. Main findings from studies on extreme heat and emergency hospital admission.

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Kovats *et al.* (2004)/London	Secondary data analysis- Time-series	Study to examine the effects of hot weather and heatwaves on emergency hospital admissions in Greater London.	Daily meteorological data (minimum and maximum temperature and relative humidity) were provided by the MET office using data for Heathrow meteorological station Daily mean temperature value was created by getting an average of the daily minimum and maximum value	Data on emergency hospital admission were obtained from the hospital episode statistics. Daily admissions were stratified into eight age groups and six diagnostic groups- cardiovascular disease, respiratory disease, cerebrovascular disease, renal disease, acute renal failure and calculus of the kidney and ureter. The mean of daily emergency admission during the study period of 6 years for all causes =2644.5. 5th percentile=1639, 95th percentile=3464. The mean temperature for the study period=11.6C. 5th centile=3.1, 95th centile=26.7. Ozone ppb mean=17.7, 5th centile=3, 95th centile=33. PM10 mean =26.0, 5th centile=13, 9th centile=50. Relative humidity % mean=75.2, 5th centile=52.8. 95th centile =90.6. Findings for most of the age groups were not statistically significant. However, in those aged 75 years and above, respiratory admissions increased by 10.86% (95%CI=4.44 to 17.67) for each degree rise in daily mean temperature above 23 degrees An increase in daily mean temperature above 12°C was associated with increased emergency hospital admissions (0.24% 95% CI=0.02%-0.46%) in infants and children under 5 years.	Moderate

Table 4. Main findings from studies on extreme heat and YLL.

Study, location	Study design	Aim(s)	Exposure	Main findings	Quality of study
Arbuthnott *et al.* (2020) Greater London, the West Midlands and Greater Manchester	Secondary data analysis- ecological time series regression analysis	Study to (a) to determine the nature of the relationship between YLL and temperature in the studied conurbations, (b) to estimate (and compare) the proportion of total yearly mortality and YLL attributable to heat and cold	Daily mean temperature obtained from the UK Met Office UKCP09 gridded observation datasets	Findings show that in London, each 1°C above the heat threshold the YLL increased by 3.0% (2.5%, 3.5%). Greater Manchester YLL= 1.5% (1.07-2.4%). West Midlands 2.4% (1.6-3.3%). Between 1996 and 2013, the proportion of YLL attributable to heat in London was 0.40%. The percentage of year-round YLL attributable to heat was 0.391% for Greater London, 0.309% in the West Midlands and 0.206% in Greater Manchester	Strong

Discussion

Main findings of this research

The most consistent finding of this review is the impact of extreme heat on mortality. The evidence presented in this review on the *projected* impacts of extreme heat on mortality is also an important finding with significant implications for future planning.

This review also suggests there is relatively limited evidence on the adverse impact of UHI on mortality in the UK. UHI is a growing problem globally as well as in the UK and could be of greater concern without clear mitigation strategies to promote more sustainable urban development. For example, studies have reported the need for clear guidance for planners on how to mitigate the effects of UHI (O'Malley *et al.*

2014). Anthropogenic heat from vehicular sources also contributes to the urban heat island effect and should be considered in planning (Ebi *et al.* 2021).

Beyond outcomes relating to mortality, however, there was very limited evidence on the impacts of extreme heat on the incidence of NCDs and mental health issues. This is corroborated by findings from existing research which conclude that investigations into the impact of extreme heat on the development of a range of NCDs have received far less attention compared to outcomes relating to deaths (Friel *et al.* 2011).

This review also provides evidence of significant gaps in research on the impact of *indoor* extreme heat on population health and well-being. A recent review on the effects of indoor temperatures above 24°C on health reported a lack of evidence to establish the link between indoor temperatures and all-cause mortality, heat stroke, hyperthermia, dehydration or hospital admission (Head *et al.* 2018). The lack of reliable longitudinal evidence on indoor heat and health has also been reported in studies conducted within the UK (Anderson *et al.* 2013). A study by A report from the Department of Communities and Local Government (2012) also concluded that although the evidence on the relationship between health impacts and outdoor temperature is well advanced, especially in relation to deaths/hospital admissions during heatwave events, there is a scarcity of longitudinal evidence linking indoor temperatures and health impacts. This highlights the need for further research into the health and well-being impacts of extreme heat indoors.

What is already known about this topic

Extreme heat has previously been reported as a major environmental hazard of global concern (Houghton and English 2014). The actual and projected impacts of heat exposure on mortality in the UK have been widely reported in previous literature reviews (Arbuthnott and Hajat 2017). Other studies, such as, Wondmagegn *et al.* (2019) have discussed the global economic burden of heat exposure on health-care systems.

What this study adds

Previous narrative reviews on this topic have literature review methodology (Houghton and English 2014, Arbuthnott and Hajat 2017, Wondmagegn *et al.* 2019) which is less transparent, less robust and subject to methodological bias. This review utilised a well-established form of evidence synthesis with clear documentation of methods and processes leading to the generation of robust evidence.

This study distinguishes itself by its specific geographic focus at the national level, in contrast to the broader global or regional scopes often seen in existing reviews. The examination of climate change and extreme heat impacts at the country level offers a finer-grained analysis, enabling a more in-depth exploration of their effects on health within unique geographic and sociodemographic contexts. This approach, zooming in on individual countries, yields valuable insights into region-specific vulnerabilities and adaptation strategies, ultimately supporting the development of more precisely targeted policy and public health interventions.

This study also adds to the growing body of evidence calling for more longitudinal and experimental studies to assess the impact of indoor heat exposure on health and well-being (Taylor *et al.* 2018). Findings from this study also highlight the importance of taking a holistic approach to investigating the impacts of extreme heat on a broader range of NCDs including mental health, and respiratory outcomes. It is, however, acknowledged that the detection and attribution of the impacts of extreme heat on the development of NCDs are complex due to the influence and interaction of multiple layers of risk factors (Ebi *et al.* 2020, Mitchell 2021). The emergence of advanced tools to evaluate detection and attribution would no doubt prove useful to provide a more robust analysis of the impacts of climate change on NCDs; however, as Ebi *et al.* (2020) argue, investigating causal links using detection and attribution study designs/tools relies on the availability of long-term data sets.

What this study adds to the UK context

In the UK, the adverse impact of Urban Heat Island (UHI) on mortality appears to be a growing concern, and there is limited evidence connecting it to fatalities (Heaviside *et al.* 2016). Urban development that is sustainable becomes paramount to combat this concern, and the country's planners require clearer guidance on how to alleviate the effects of UHI. Interestingly, vehicular sources, which contribute to the UHI effect, should also be a focal point when planning urban spaces (Keat *et al.* 2021). This study provides evidence underpinning the need for a better understanding of the links between the indoor and outdoor overheating on health and wellbeing.

Limitations of this study

This review aims to synthesise and appraise existing evidence on the known and projected impacts of extreme heat (indoor and outdoor) on NCDs and related outcomes in the UK. The lack of evidence on the health impacts of indoor extreme heat is a limitation of this study which probably reflects the nature of existing evidence. Another key limitation is that most of the studies included in the review did not necessarily consider the issue of attribution and detection and so makes it difficult to highlight clear causal pathways.

Conclusion

This study aims to provide a comprehensive review of the known and projected impacts of both indoor and outdoor extreme heat on non-communicable diseases (such as diabetes, respiratory illness, cardio-vascular disease, mental health) and related outcomes in the UK. Findings from the review strengthen and provide strong and consistent evidence that extreme heat is associated with increased mortality. However, there is a need to further explore detection and attribution in relation to these findings. The lack of evidence on the health impacts of extreme heat indoors calls for further investigation.

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References

Anderson, M., *et al.*, 2013. Defining indoor heat thresholds for health in the UK. *Perspectives in public health*, 133 (3), 158–164. doi:10.1177/1757913912453411.

Arbuthnott, K., *et al.*, 2020. Years of life lost and mortality due to heat and cold in the three largest English cities. *Environment international*, 144, 105966. doi:10.1016/j.envint.2020.105966

Arbuthnott, K.G. and Hajat, S., 2017. The health effects of hotter summers and heat waves in the population of the United Kingdom: a review of the evidence. *Environmental health*, 16 (1), 1–13. doi:10.1186/s12940-017-0322-5.

Carbon Brief, 2021. *The impacts of climate change at 1.5C, 2C and beyond*. Available from: https://interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two-degrees/?utm_source=web&utm_campaign=Redirect# [Accessed 7 May 2021].

Centers for disease Control and Prevention, 2019. *CDC's tracking network in action: extreme heat*. Available from: https://www.cdc.gov/nceh/features/trackingheat/index.html#:~:text=%20CDC's%20Tracking%20Network%20in%20Action%3A%20Extreme%20Heat,or%20death%20are%20preventable%20if%20you. . .%20More%20

de Schrijver, E., *et al.*, 2021. A comparative analysis of the temperature-mortality risks using different weather datasets across heterogeneous regions. *GeoHealth*, 5 (5), e2020GH000363. doi:10.1029/2020GH000363.

Department of Communities and Local Government, 2012. *Investigation into Extreme heat in Homes*. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/7604/2185850.pdf [Accessed 19 May 2022].

Ebi, K.L., *et al.*, 2020. Using detection and attribution to quantify how climate change is affecting health: study explores detection and attribution to examine how climate change is affecting health. *Health affairs*, 39 (12), 2168–2174. doi:10.1377/hlthaff.2020.01004.

Ebi, K.L., *et al.*, 2021. Hot weather and heat extremes: health risks. *The lancet*, 398 (10301), 698–708. doi:10.1016/S0140-6736(21)01208-3.

Effective Public Healthcare Panacea Project, 2023. [online]. Available from: https://www.ephpp.ca/quality-assessment-tool-for-quantitative-studies/ [Accessed 20 March 2023].

Evangelopoulos, D., *et al.*, 2021. Does climatic zone of birth modify the temperature-mortality association of London inhabitants during the warm season? A time-series analysis for 2004–2013. *Environmental research*, 193, 110357.

Friel, S., *et al.*, 2011. Climate change, noncommunicable diseases, and development: the relationships and common policy opportunities. *Annual review of public health*, 32 (1), 133–147. doi:10.1146/annurev-publhealth-071910-140612.

Gasparrini, A., *et al.*, 2015a. Temporal variation in heat–mortality associations: a multicountry study. *Environmental health perspectives*, 123 (11), 1200–1207. doi:10.1289/ehp.1409070.

Gasparrini, A., *et al.*, 2015b. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet*, 386 (9991), 369–375. doi:10.1016/S0140-6736(14)62114-0.

Gasparrini, A., *et al.*, 2012. The effect of high temperatures on cause-specific mortality in England and Wales. *Occupational and environmental medicine*, 69 (1), 56–61.

Hajat, S., *et al.*, 2014. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *Journal of epidemiology and community health*, 68 (7), 641–648. doi:10.1136/jech-2013-202449.

Hansen, A., *et al.*, 2018. The effect of heat waves on mental health in a temperate Australian city. *Environmental health perspectives*, 116 (10), 1369–1375. doi:10.1289/ehp.11339.

Head, K., *et al.*, 2018. Report of the systematic review on the effect of indoor heat on health. *In: WHO housing and health guidelines*. Geneva: World Health Organization. Available from: https://www.ncbi.nlm.nih.gov/books/NBK535282/

Heaviside, C., Vardoulakis, S., and Cai, X.M., 2016. Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. *Environmental health: A global access science source*, 15 (no. Suppl 1), 27-016-0100–9. doi:10.1186/s12940-016-0100-9.

Houghton, A. and English, P., 2014. An approach to developing local climate change environmental public health indicators, vulnerability assessments, and projections of future impacts. *Journal of environmental and public health*, 2014, 1–7. doi:10.1155/2014/132057

Ige, J., *et al.*, 2019. The relationship between buildings and health: a systematic review. *Journal of public health*, 41 (2), e121–e132. doi:10.1093/pubmed/fdy138.

Ige-Elegbede, J., *et al.*, 2020. Designing healthier neighbourhoods: a systematic review of the impact of the neighbourhood design on health and wellbeing. *Cities & health*, 6 (5), 1–16. doi:10.1080/23748834.2020.1799173.

IPCC, 2018. Summary for policymakers. In *global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V]*.

Jadad, A.R., *et al.*, 1996. Assessing the quality of reports of randomized clinical trials: is blinding necessary? *Controlled clinical trials*, 17 (1), 1–12. doi:10.1016/0197-2456(95)00134-4.

Keat, W.J., Kendon, E.J., and Bohnenstengel, S.I., 2021. Climate change over UK cities: the urban influence on extreme temperatures in the UK climate projections. *Climate dynamics*, 57 (11–12), 3583–3597. doi:10.1007/s00382-021-05883-w.

Kim, Y., *et al.*, 2019. Suicide and Ambient Temperature: A Multi-Country Multi-City Study. *Environmental health perspectives*, 127 (11), 117007–117001; 117007–10. doi:10.1289/EHP4898.

Kovats, R.S., Hajat, S., and Wilkinson, P., 2004. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. *Occupational and environmental medicine*, 61 (11), 893–898. doi:10.1136/oem.2003.012047.

Maramba, P.J., *et al.*, 2004. Discharge planning process: applying a model for evidence-based practice. *Journal of nursing care quality*, 19 (2), 123–129. doi:10.1097/00001786-200404000-00009.

McMichael, A.J., Neira, M., and Heymann, D.L., 2008. World Health Assembly 2008: climate change and health. *Lancet*, 371 (9628), 1895–1896.

Met Office, 2021. *UK climate projections: headline findings*. Available from: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18_headline_findings_v3.pdf

Mitchell, D., 2021. Climate attribution of heat mortality. *Nature climate change*, 11 (6), 467–468. doi:10.1038/s41558-021-01049-y.

Moher, D., *et al.*, 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of internal medicine*, 151 (4), 264–269. doi:10.7326/0003-4819-151-4-200908180-00135.

Mulrow, C.D., Cook, D.J., and Davidoff, F., 1997. Systematic reviews: critical links in the great chain of evidence. *Annals of internal medicine*, 126 (5), 389–391. doi:10.7326/0003-4819-126-5-199703010-00008.

Murage, P., *et al.*, 2020. What individual and neighbourhood-level factors increase the risk of heat-related mortality? A case-crossover study of over 185,000 deaths in London using high-resolution climate datasets. *Environment international*, 134, 105292. doi:10.1016/j.envint.2019.105292

O'Malley, C., *et al.*, 2014. An investigation into minimizing urban heat island (UHI) effects: a UK perspective. *Energy procedia*, 62, 72–80. doi:10.1016/j.egypro.2014.12.368

Ormandy, D. and Ezratty, V., 2016. Thermal discomfort and health: protecting the susceptible from excess cold and excess heat in housing. *Advances in building energy research*, 10 (1), 84–98. doi:10.1080/17512549.2015.1014845.

Page, L.A., Hajat, S., and Kovats, R.S., 2007. Relationship between daily suicide counts and temperature in England and Wales. *The British journal of psychiatry: The journal of mental science*, 191 (2), 106–112. doi:10.1192/bjp.bp.106.031948.

Pattenden, S., *et al.*, 2010. Ozone, heat and mortality: acute effects in 15 British conurbations. *Occupational & Environmental medicine*, 67 (10), 699–707. doi:10.1136/oem.2009.051714.

Petrou, I., Dimitriou, K., and Kassomenos, P., 2015. Distinct atmospheric patterns and associations with acute heat-induced mortality in five regions of England. *International journal of biometeorology*, 59 (10), 1413–1424. doi:10.1007/s00484-014-0951-0.

Taylor, J., *et al.*, 2018. Comparison of built environment adaptations to heat exposure and mortality during hot weather, West Midlands region, UK. *Environment international*, 111, 287–294. doi:10.1016/j.envint.2017.11.005

Tham, S., *et al.*, 2020. Indoor temperature and health: a global systematic review. *Public health*, 179, 9–17. doi:10.1016/j.puhe.2019.09.005

Vardoulakis, S., *et al.*, 2014. Comparative assessment of the effects of climate change on heat- and cold-related mortality in the United Kingdom and Australia. *Environmental health perspectives*, 122 (12), 1285–1292. doi:10.1289/ehp.1307524.

Vardoulakis, S. and Heaviside, C., eds., 2012. *Health effects of climate change in the UK 2012*. London: Health protection agency.

Wondmagegn, B.Y., *et al.*, 2019. What do we know about the healthcare costs of extreme heat exposure? A comprehensive literature review. *Science of the total environment*, 657, 608–618. doi:10.1016/j.scitotenv.2018.11.479

Zhang, Y., *et al.*, 2018. Association of diurnal temperature range with daily mortality in England and Wales: a nationwide time-series study. *Science of the total environment*, 619–620, 291–300. doi:10.1016/j.scitotenv.2017.11.056