Factors that modify heat- and cold-related mortality risk

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To inform the construction of a temperature-related health risk map

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Introduction and methods

For the development of a climate service, health risk needs to be considered from the perspectives of hazard (e.g. probability of extreme temperatures in a location), exposure (e.g. probability of an individual or community experiencing extreme temperatures when they occur) and vulnerability (i.e. susceptibility or sensitivity to adverse impacts caused by this exposure). The same extreme temperature event can have different consequences depending on the neighbourhood and population characteristics that determine the exposure and vulnerability.

In this report, we aim to identify and synthesise relevant epidemiological evidence regarding community and individual level measures affecting mortality risk from heat and cold in the UK context, covering both factors affecting vulnerability (understood as susceptibility) and exposure. These are referred to as effect modifiers: the factors that modify the effect of heat and cold on mortality. The goal is to include this information in the construction of a health risk map for the climate service.

Systematic review is a standardised literature review procedure commonly used in medical and related fields to synthesise published primary research to answer a predefined question (Moher et al. 2015, Higgins et al. 2020). To avoid duplication of effort, this is only appropriate when another review of the same research question(s) has not recently been undertaken. We initially undertook a preliminary scoping search of the literature to identify any relevant systematic reviews related to factors which affect the relationship between heat/cold and mortality (chosen as a representative measure of overall impact on public health).

These searches yielded a systematic review by Son et al. published in 2019 (hereafter referred to as SON19) in Environmental Research Letters which addresses our question of interest: namely, which factors or characteristics are important for determining the mortality risk posed by heat and cold to a given population. This review included exclusively peer-reviewed studies which: (1) are population-based; (2) consider exposure to heat or high temperature, cold, heat waves, or cold spells; (3) explore [temperature-related] mortality; (4) examine effect modification of this; (5) are written in English; and (7) were published from 1980 to 2017, inclusive.

They defined effect modifiers as factors that modify the effect of temperature exposure on a person or population's mortality risk. Given that the paper is recent, we decided to extract and synthesise the results of studies included in this review, with a focus on those of relevance to a potential UK climate service for health. For the future, periodic review updates and additional quality appraisal would be recommended, as described in more detail in the discussion section at the end of this report.

Due to the smaller number of cold-related primary research studies identified by SON19, a 2015 grey literature review on "Factors determining vulnerability to winter- and cold-related mortality/morbidity" produced for the National Institute for Health and Care Excellence (NICE) is also consulted where appropriate. For consistency with SON19, focus is placed on the mortality part of this review, though findings related to morbidity are also discussed where no evidence on mortality is available.

SON19 quantified the sufficiency of evidence for effect modification through a simple binary count of the number of primary research articles published anywhere in the world that supported or contradicted the claim. To ensure relevance for the UK, in this report we subset their findings to only those studies based on data from OECD countries. This was achieved by utilising Table S2 in SON19's supplemental material, which listed the primary research articles the authors identified as relevant along with notes on the following: time period, location, types of mortality studied (ICD codes), exposure type (heat/cold), exposure metric, time lags studied (days), exposure Increment, effect modifiers studied, and main findings. The extracted OECD studies were subsequently categorised according to the effect modifiers examined. A complete list of the OECD subset is provided in the appended table (pages 17-37), and studies considered for each effect modifier are separately listed on pages 38-45. For complete bibliographical information on these primary research articles, please refer to SON19's supplemental material.

Results

Summary of findings

SON19 identified consistent, strong evidence only for two measures of heat or cold effect modification: older age (for both heat and cold) and females (heat only). However, this provides a limited basis from which to construct meaningful risk maps, therefore we also investigated in more detail the effect modifiers examined by fewer primary research articles but where some evidence of effect modification was found.

The subsetting of SON19's included studies to the OECD group resulted in the exclusion of studies using data from Russia, Brazil, South Africa, and China. This generally led to a decrease in the number of studies investigating each effect modifier but not in the ratio of studies that found or did not find increased mortality risk. An exception is for socioeconomic status, where SON19 noted a greater proportion of studies that found evidence of effect modification for heat while re-examining the OECD subset yielded a less clear result. Exclusion of non-OECD-based studies also resulted in insufficient evidence supporting effect modification by pre-existing conditions and rurality for cold, and manual/blue-collar workers for heat.

Overall, of the 207 studies included in SON19, we extracted 137 studies. A further 3 studies cited by these studies but not included in SON19 were added (listed on page 37 under "additional"), and summarised evidence from the cold-focused evidence review conducted for NICE were included in this evidence synthesis.

A summary for each effect modifier is provided below.

Age

Older age (with varying definitions, from 60 to 85, and evidence of increasing risk at older ages within this) was consistently found to be associated with greater vulnerability to mortality from both heat and cold. Some studies indicated infants and/or children as a vulnerable part of the population, but this was often associated with a high degree of uncertainty due to the overall low childhood mortality in developed countries. Therefore, for constructing an overall risk/vulnerability map, children are not expected to contribute to a significant number of heat or cold related mortality in a region.

Sex

While some studies indicated the opposite, the majority of primary research pointed to females being more vulnerable to heat than males. Age was not consistently removed as a confounding factor for this relationship. For the purpose of creating a risk map where an overall female-to-male ratio in a region is likely to be used, however, minimal spatial variability is expected for this effect modifier. There is no consistent evidence of either males or females being more vulnerable to cold.

Education

15 studies included education level as a potential effect modifier. Of these, six (2 South Korea, 3 US, 1 Spain) found greater heat-related mortality risks associated with lower education level, two (1 US, 1 South Korea) found apparent but not statistically significant differences, and one study saw education-dependent risks in only one of three cities examined (São Paulo, but not for Santiago and Mexico City). The other six studies did not find an effect modification of heat exposure by education level.

All studies examined the effects of extreme heat on mortality, while five (1 South Korea, 4 US) out of the 15 also investigated the effect during cold extremes. Two out of these five studies found that higher level of education had a protective effect against cold-related mortality; one found the opposite, with suggestion of lower risk associated with a greater proportion of the community without a high school diploma (but not for without a college degree); and the last two found no significant association.

The threshold adopted to define low education level varied between studies, with definitions ranging from no education, without high school diploma, to without university degree.

Socioeconomic status

Suggestion of regional differences may be noted in the role of socioeconomic status on heat-related mortality risk. Of the ten studies that found an increased risk associated with lower socioeconomic status, eight were from North America (the other two from South Korea and Denmark). Two of these studies (US and Denmark) only found effect modification of cardiovascular mortality (but not for respiratory and/or cerebrovascular mortality). Eleven other studies (8 from Europe, 2 Australia, 1 US) found no effect modification, while another US study found a greater risk in high income communities. Low income and poverty were frequently used as measures of low socioeconomic status, but unemployment, education level (which is considered separately in SON19 and discussed above), and/or various comprehensive deprivation indices were sometimes also included or used instead.

For the role of socioeconomic status in cold-related mortality, no effect modification was found in one London study using the English Index of Multiple Deprivation and three US studies. Three other studies noted effect modifications only within specific population groups. A study for England and Wales (also noted below under occupation) found an increased cold mortality risk for women of unskilled social class compared to those classified as professionals, but did not observe the same association for men. Another study in England and Wales also noted an increased risk with deprivation in rural but not urban regions. Lastly, a Swedish study found an increased cold-related risk for people living in wealthier municipalities (greatest risk for those aged <65 with high wealth and those aged 65+ with medium wealth). The authors speculated that housing types may play a role (e.g. wealthier districts with older and less energy efficient houses).

Occupation

Greater percentage of manual or blue-collar workers in a geographic area was found to be associated with greater heat-related mortality risk in two studies (1 South Korea, 1 Barcelona, Spain). Working conditions and efforts by employers in the UK to mitigate health impacts during heatwaves may play a significant role in determining the level of heat-related health risks faced by working-age adults, particularly areas with greater percentage of manual workers. However, no studies on UK data were identified by SON19 investigating potential effect modification by occupation.

On the other hand, one UK study looking at cold-related mortality found greater mortality risk for unskilled women workers compared to professional women, while for men, unskilled workers had similarly low risks as professionals compared to other working classes (managerial and technical, non-manual skilled, manual skilled, partly skilled) for which the risks were higher.

Race/ethnicity

Of the eleven OECD studies that examined race as an effect modifier for heat, all but one was from the US. Most studies contrasted risks amongst Black people with those amongst White people, while Hispanics were sometimes also considered. (The remaining non-US study compared people of Nordic versus non-Nordic origin in Stockholm, Sweden.)

Three studies were identified that investigated the role of race in cold-related mortality risk. One examined non-white race as a potential effect modifier in the US, one analysed risk associated with Black versus White race also in the US, and the last analysed the cold-related mortality risk experienced by people of Nordic versus non-Nordic origin in Stockholm, Sweden. Only the first study found suggestions of a protective effect against cold-mortality (not statistically significant at the 95% level) for non-white race at an individual level (but not at the community level).

Given that race is often associated with differences in other neighbourhood characteristics such as building quality and socioeconomic status, with likely significant differences in these associations between country contexts, it may not be appropriate to extrapolate findings based on US data for the UK. The demographics and sociopolitical context of the UK differs substantially from those of the US, and the minoritised groups requiring consideration may differ. Current evidence extendeds to an England and Wales study which mentioned, without discussing in further detail, finding little evidence of effect modification of either heat or cold by proportion of ethnic minority groups in a given area. Further study of the UK population is needed to draw any conclusions.

Pre-existing conditions

Seven primary research studies (3 Italy, 3 US, 1 Sweden) examined the role of various pre-existing medical conditions in determining vulnerability to heat. The studies and their findings are summarised in Tables 1 and 2 below.

Table 1: Primary research from OECD countries that examined effect modification of temperature-related mortality by pre-existing conditions

	Study	Location	Pre-existing conditions determined by	Population subset
1	Medina-Ramon et al. (2006)	50 US cities	As listed on death certificates	Case-only (only those who died)
2	Rosenthal et al. (2014)	New York City, US	% with the condition in a neighbourhood	Age 65 and above
3	Rocklöv et al. (2014)	Stockholm, Sweden	Previous hospitalisation with the condition	
4	Schifano et al. (2009)	Rome, Italy	Previous hospitalisation with the condition	Age 65 and above
5	Stafoggia et al. (2006)	4 Italian cities (Bologna, Milan, Rome, Turin)	Hospitalisation with the condition in the last 2 years excluding the last 4 weeks	Age 35 and above
6	Stafoggia et al. (2008)	4 Italian cities (Bologna, Milan, Rome, Turin)	Hospitalisation with the condition in the last 2 years excluding the last 4 weeks	Age 65 and above who died in hospital
7	Zanobetti et al. (2013)	135 US cities	Previous hospitalisation with the condition	Case-only, age 65 and above with Medicare, except those who died in hospital after at least one day stay (in climate-controlled hospital environment)

Table 2: Summary of findings on effect modification of heat-related mortality by pre-existing conditions. Descriptions of the seven studies are provided in Table 1 above. Red indicates evidence of increased heat risk associated with the pre-existing condition; blue, no evidence of effect modification; purple, evidence of decreased risk; and white, not examined by the study. Where no notes are added, the finding applies to the entire population included in the study and for the pre-existing condition as listed. Only p-values greater than 0.05 are provided where relevant. RD: risk difference analysis, REM: relative effect modification.

Pre-existing condition	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7
Diabetes		% in those aged 65+		Suggestive positive association for those aged 75+ (only when using RD analysis) but not for 65-74		p-value = 0.246 (increased risk)	Close to statistical significance at 95% level (but not quite)

Hyper-tension		% in those aged 65+			Decreased risk (p-value = 0.141)	p-value = 0.331 (decreased risk)	
Heart attack			In the last 2 years excluding last 4 weeks, aged <65 but not for 65+				Close to statistical significance at 95% level
Conduction disorders				Aged 65-74, suggestive decreased risk for 75+ (REM p-value = 0.337)		p-value = 0.164	
(Other) cardio-vascular diseases				Ischaemic heart diseases, heart failure, and other heart disease, aged 65-74; decreased risk with cardiac dys-rhythmias (aged 65-74); decreased risk for all of the above for those aged 75+	Heart failure, cardiac dys-rhythmias, diseases of pulmonary circulation, other ischemic heart diseases	Heart failure, cardiac dys-rhythmias, diseases of pulmonary circulation, other ischemic heart diseases	Atrial fibrillation; congestive heart failure (close to statistical significance at 95% level)
COPD			Aged <65 but not for 65+	Aged 65-74 (REM p-value = 0.155), decreased risk for 75+ (REM p-value =	p-value = 0.203 (decreased risk)	p-value = 0.281 (decreased risk)	Close to statistical significance at 95% level

				0.095)			
Respiratory diseases		% asthmatic	In the last 2 years excluding last 4 weeks, aged 65+ but not for <65		Pneumonia	Pneumonia	Pneumonia
Mental/ psychiatric disorder			Aged 65+ but not for <65	Suggestive positive association: age 65-74 (REM p-value = 0.35); 75+ (only when using RD analysis)	Psychoses	Psychoses	Dementia, Alzheimer; close to statistical significance at 95% level for Parkinson
(Other) central nervous system diseases				Suggestive positive association for those aged 75+ (only when using RD analysis) but not for 65-74		p-value = 0.162	
Depression		% with frequent mental distress			p-value = 0.149		
Cerebro-vascular diseases/ stroke			In the last 2 years excluding last 4 weeks	Suggestive positive association for those aged 75+ (only when using RD analysis) but not for 65-74	p-value = 0.105	p-value = 0.063	Close to statistical significance at 95% level
Cancerous tumour				Decreased risk; aged 65-74 (REM p-value =	Decreased risk	Decreased risk	

				0.092) and 75+			
Liver diseases				Aged 65-74; decreased risk for 75+	Decreased risk (p-value = 0.150)	p-value = 0.299 (decreased risk)	
Kidney failure				Decreased risk; aged 65-74 (REM p-value = 0.177) and 75+	p-value = 0.322 (decreased risk)		
Hip/femur fracture						p-value = 0.156	

It should be noted that Studies 5 and 6 (Table 1) covered an overlapping population (to a lesser extent, this can also be said of Study 4, though the time frame was slightly different). Given that Study 6 examined only in-hospital deaths and to avoid double-counting, it would not be included in the counting when determining the sufficiency of evidence in support of an effect modification. However, it may still be of interest, especially where its results differed from those of Study 5. Caution should also be taken with Study 4, where the results from three different measures of risk/risk comparison used in this study did not always agree. The authors drew their conclusions mainly from the risk difference (RD) analysis, which yielded more notable effect modifications, but these were largely not statistically significant and not supported by the results using relative risk or relative effect modification (REM) index approaches, especially for conclusions concerning those aged 75 and over.

Overall, there is some evidence to suggest that pre-existing mental/psychiatric disorders and diabetes may be associated with increased heat-related mortality risk (Table 2). However, the picture is not clear-cut. It may be suggested that a stronger effect modification by diabetes was found in the US than in Europe, given that it is supported by three US studies while the other European studies did not find a significant effect.

On the other hand, evidence in support of effect modification by pre-existing mental/psychiatric disorders is mostly consistent, though it is not clear people of which age group and with which type of mental/psychiatric disorder would be most strongly affected. In a related UK study not included in SON19 and not included in Tables 1 and 2 that analysed solely data of patients with mental illness (psychosis, dementia, and/or substance misuse; Page et al. 2012), heat-related increase in mortality risk was found to be greatest for younger populations and those with substance misuse. The overall increase in mortality risk with heat for these patients was also noted to be greater than a previous study for the overall population.

Other pre-existing conditions of note (despite limited evidence) include COPD, which may be more associated with heat risk for the younger population, and cerebrovascular diseases. More detailed review focusing on these potential effect modifiers could be beneficial.

Studies 1, 3, and 7 above (Table 1) also investigated effect modification for cold-related mortality. Study 1 did not find evidence of effect modification by pre-existing conditions for cold. Study 3 found positive associations with mortality for previous hospitalisation for mental disorder and/or substance abuse in those under 65 years of age and for previous hospitalisation for heart attacks in those aged 65 and above. Lastly, Study 7, which examined people aged 65 and above, found that people with previous hospitalisation for dementia and peripheral nervous system diseases were more susceptible to cold.

Marital status

Four studies examined whether non-married status is associated with greater heat risk relative to married status. Three out of these (2 Italy, 1 US) found evidence of effect modification, with one study on those aged 65 years and above particularly noting stronger effect modification for the oldest group studied (75+). The utility of non-married status as a vulnerability factor would partly depend on the variability of marital status across geographical locations in the UK. A 2014 report from the ONS based on 2011 Census data indicated that local authorities with the greatest non-married to married ratios also tended to have a younger population on average (Office for National Statistics 2014). Direct inclusion of this measure in the risk map without accounting for confounding by age may therefore be misleading. No studies were identified that examined the effect of marital status on cold-related mortality risk.

Population density

Findings from two studies of various US cities and counties indicated a weak but statistically significant increase in heat risk with higher population density. A third US study noted a slight increase in risk that may not be statistically significant (authors did not specify result of significance testing), and a fourth US study found suggestive positive association that was not significant at the 95% level. All but two of these studies also examined urban/rural contrasts, which is tied to population density and discussed below.

Two of these studies also examined mortality risk during cold extremes and found no difference associated with population density.

Urban/rural

Seven studies (5 US, 1 England and Wales, 1 Czech Republic) examined rurality as an effect modifier with respect to heat-related mortality risk. All but two (both US) noted an increased heat-related risk in more urban environments, but the effects are generally small in magnitude and not statistically significant.

Four (2 US, 1 England and Wales, 1 Czech Republic) of the seven studies also investigated effect modification during cold extremes, finding no significant difference, though two (US and Czech Republic) studies noted suggestions of an association between cold-related mortality risk and rurality.

Home heating system (cold only)

Two US studies examined the influence of the percentage of heated homes or homes with central heating in an area on cold-related mortality, and in both cases, a non-statistically significant decrease in risk was found where more homes had heating. However, even when adequate heating systems are available, fuel poverty (influenced primarily by low income, high energy prices, home energy efficiency and under-occupancy; National Energy Foundation n. d.) may be an important concern. This is not considered separately from socioeconomic status or heating system in SON19. Complementing this, the review undertaken for NICE identified four English studies which found an adverse association between fuel poverty and respiratory and/or mental health outcomes, though it is not clear if these impacts on morbidity translate to increased mortality.

Housing quality

Three studies (2 US, 1 Spain) included housing quality or building age as a potential effect modifier and all noted a greater heat-related risk with greater prevalence of poor housing, though the difference was not statistically significant in one of the US studies. These findings may not be applicable in the UK, however, due to differences in the housing stock. Studies investigating indoor overheating in the UK indicated that newer buildings and those retrofitted for energy efficiency may be more likely to overheat in summer (e.g. Beizaee et al. 2013, Pathan et al. 2017). While some of these overheating risks may translate to mortality risk, the effect can be further modified by characteristics of the housing occupants. For instance, a recent study in the West Midlands by Taylor et al. (2018) found that, due to the greater proportion of elderly occupants, heat-related mortality rates were highest in bungalows despite it not being the dwelling type most likely to overheat. A more thorough review of the literature on indoor overheating in the UK and its implication for mortality risk is therefore advised before inclusion of this effect modifier in the risk map.

SON19 did not identify any studies that examined the role of building quality for cold-related risks. The review conducted for NICE noted a UK study which found increasing building age to be associated with greater winter excess mortality risk. Poorer energy efficiency rating was also associated with slightly greater winter excess mortality, which was partly supported by another study in Torbay, Devon. Other specific ill health outcomes, though not mortality, were also noted to be associated with poor housing properties (e.g. low energy efficiency) in a few other studies. However, a more recent study in England found that living in more energy efficient areas is associated with a slight increase in risk of hospitalisation for asthma, COPD, and cardiovascular disease (Sharpe et al. 2019), suggesting that the relationship between health and housing energy efficiency may be more complex.

Green space

Six (3 US, 1 Spain, 1 Portugal, 1 South Korea) of nine (+ 2 US, 1 Australia) studies that included consideration of green space and vegetation noted a protective role of greater green space coverage with lower heat-related mortality risk. Of these, one US study examined also green space in relation to cold-related risks but found no effect modification.

Blue space

Three slightly contradictory findings were noted with regards to proximity to water: a study of Lisbon, Portugal found an increased heat-related mortality risk in areas > 4 km from water; a study of California, US, found mortality risk during extreme heat to be greater in coastal counties than inland counties; and lastly, a study of 135 US cities did not find statistically significant effect modification for heat by area-level water cover. Only the last study examined also mortality during cold extremes, though no effect modification was found.

Air pollution

Air pollution was sometimes included as a confounder in temperature-mortality models, though some noted that it may have acted as a mediator variable in the causal relationship between temperature and mortality rather than, and/or in addition to being, a confounder. Part of this is related to the fact that heat catalyses ozone production, leading to poorer air quality and respiratory health concerns, and that low temperatures can be associated with high levels of air pollution (e.g. due to increased fuel combustion for heating and reduced evaporation of nitrate and volatile organic carbon particles).

14 studies (1 Germany, 1 Australia, 1 Netherlands, 1 including Mexico, Brazil, and Chili, 10 US) were identified that considered air pollutants either as confounders or effect modifiers. Ten studies investigated the role of ozone, six of which noted some role either as an effect modifier or confounder for heat, though the impact may not be significant. Five studies included PM_{10} as a measure of pollution, of which two noted some evidence of confounding or lowered heat-related mortality risk after adjusting for air pollution. Three studies examined $PM_{2.5}$, none of which identified statistically significant effect modification. Two studies included consideration of NO_2 and did not find it to be associated with heat-related mortality. Lastly, air quality was considered using an index (Air Domain of the Environmental Quality Index) in one study, which found air quality to be the most important effect modifier for heat compared to other domains (water, land, built, and socioeconomic). No impact on cold-related mortality was found, as examined in five of these studies.

Others

The following effect modifiers included in SON19 are excluded in the current report:

- *Not suitable for constructing a risk map*: place of death, previous winter mortality, reduced electricity consumption
- *Minimal variability across the UK*: latitude, climate
- *Not prevalent in UK housing*: air conditioning (may be important to consider in the future)
- *One or less primary research articles in OECD countries*: BMI, healthcare facilities

Summary on effect modifiers

Effect modifiers with at least half of all identified publications supporting their relevance for heat or cold, and where this amounts to at least three studies in support of effect modification, are suggested for consideration in the risk map. A summary is provided in Table 3. It should be stressed, however, that in many cases, conclusions had to be drawn from a small number of studies. This and other limitations are discussed in the next section.

Table 3: Summary list of effect modifiers for heat- and cold-related mortality suggested for inclusion in the risk map, along with a brief explanation of the reasoning.

Effect modifier	Reason for inclusion
Heat	
Older age	Large amount of evidence
Female	Large amount of evidence
Low green space coverage	6 of 9 studies found evidence
Low education	6 of 15 studies found evidence, 3 found suggestive/partial evidence

Non-married	3 of 4 studies found evidence
Urban/high population density	Urban: 5 of 7 studies found evidence, though effect was weak and not always statistically significant High population density: 4 of 4 studies (all from US) found evidence, though 2 were not statistically significant
High ozone concentration (poor air quality)	6 of 10 studies found evidence, though impact may not be significant
Pre-existing mental/psychiatric disorder	5 of 5 studies found at least suggestive evidence, 3 may be considered significant evidence, though the type of mental/psychiatric disorder examined differ
Cold	
Older age	Large amount of evidence
Poor housing (older building age/poor energy efficiency rating/fuel poverty)	From review conducted for NICE: 2 (plus 1 partial) evidence for mortality associated with building age/energy efficiency, 4 studies for morbidity (not mortality) associated with fuel poverty; however, a separate ecological study found slightly increased hospitalisation risk associated with energy efficiency

Discussion

It should be noted that the evidence summarised above may not comprehensively reflect the state of current scientific knowledge in each of the domains covered. The systematic review by SON19 has several strengths, but is limited in other respects; for example, based on the evidence reviewed we cannot comment on effect modifiers with respect to temperature-related morbidity, only mortality, as this was the focus of the review. Additionally, studies published from 2018-2021 are not covered by this synthesis as SON19's review only searched up to and including 2017, and it is possible that some relevant studies prior to this were not captured (e.g. due to publication bias, and studies published in non-English languages or listed only in databases not searched by SON19).

Other factors complicating interpretation and synthesis of the findings across multiple studies include the heterogeneity of measures used to assess both heat and cold exposure and constructs such as poverty or housing quality, and limitations of individual studies, which varied substantially in their quality. The latter include the fact that where null results are found, this is often difficult to interpret due to sometimes small sample sizes and the possibility of a type II error (false negative); a lack of formal hypothesis testing for effect modification in some cases; and issues of residual and unmeasured confounding (for example where age is not adjusted for in studies looking at the effect of sex or marital status). The introduction or presence of protective intervention programmes can also have an impact on the perceived effect modification, leading to regional and/or temporal differences in the findings.

Scientific knowledge regarding many of the potential effect modifiers reviewed here remains incomplete, with a number of important research gaps remaining. These include for example with regard to the influence of ethnicity and socioeconomic status in the UK context (as it is not wholly clear that findings from other OECD settings can be generalised to the UK), and the role played by different air pollutants in heat-related mortality. It is also possible that some factors are important but have not yet been well-studied (for example, undocumented migrants and populations experiencing homelessness may be at increased risk, but such research is limited by factors including availability of reliable data, small sample sizes and research funding). It should be emphasised that the lack or shortage of available research on a specific effect modifier (e.g. certain pre-existing medical conditions and effect modifiers for cold-related mortality in general), and therefore its exclusion from Table 3, does not imply no effect modification.

In view of the incomplete and continually evolving nature of current knowledge in this area, it may be appropriate for health-focused risk maps for heat and cold related risks to incorporate evidence for some effect modifiers, even where the evidence base for these effects, or regarding their magnitude, remains somewhat uncertain. Where the evidence for a putative effect modifier appears equivocal, detailed critical appraisal of the individual studies in question may be beneficial, since high-quality studies should carry more weight than low-quality ones. A rapid review of additional evidence published since 2017 (on selected specific effect modifiers) may also assist in decision-making, and it is likely that the wider evidence base would benefit from being reviewed on a regular basis (e.g. every 3-4 years) to inform iterative improvements.

Final judgments about precisely which factors, and data sources, to include and how to prioritise between or weight them will need to be informed by a range of considerations, not only epidemiological evidence. They should ideally be informed by consultation with appropriate stakeholders including both communities affected and intended future users, to incorporate considerations such as usability for decision-making, limitations of potential data sources, and geographic scale.

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OECD subset from SON19

Studies	Period	Location	Mortality (ICD codes)	Exposure Type	Exposure Metric	Lag	Exposure Increment	Effect Modification Studied	Main Findings
Ha et al. 2011b	June–Aug., 1991-2008	Seoul, Daegu, and Incheon, South Korea	all-cause (A00–U99) for all cities; CVD (I00–I99) for Seoul only	heat	daily mean temperature	30 days	1°C increment above threshold	age	high temperature associations with mortality continued for about 5 days; 30 days after high temperature exposure, cumulative effects were still high in Seoul and Incheon.
Ha et al. 2009	Dec.-Feb., 1994-2006	Seoul, South Korea	all-cause (A00-U99); cardiorespiratory (I00–I99, J00–J99); CVD (I00–I99)	cold	cold wave index (CWI)	lag 0, 1, 2	1°C decrease < threshold	age	effects of daytime CWI lagged by 0-2 days were the strongest. The most significant mortality outcomes were CVD-related. Those ≥65 yrs were more vulnerable.
Ha and Kim 2013	1993–2009	Seoul, South Korea	all-cause (A00–U99); CVD (I00-I99)	heat	daily mean temperature	lag 0-1	1°C increase in summer temperatures above threshold	age, summer group (all, early, late summer)	temperature-related mortality during summer over past 17 yrs has declined, but significant association remained; declines in temperature-related mortality particularly noteworthy for late summer.
Heo et al. 2016	1996-2000, 2008-2012	South Korea	all-cause except accidents (V00-Y99); CVD (I00-I99); respiratory (J00-J99)	heat	Tmax	lag 0, 1, 2, 3, 4-7	1 °C increase above the threshold	heat cluster, sex, education, job status	Temporal increases in mortality risk were larger for some subgroups: those <75 yrs, those with a lower education and blue-collar workers, in hottest cluster as well as all combined regions
Kim et al. 2015	1995-2011	Seoul, South Korea	all-cause (A00-R99, 1-799); CVD (I20–52, 410–429); cerebrovascular (I60–I69, 430–438); respiratory (J00–J99, 460–519)	heat, cold	daily mean temperature	heat: lag 0; cold: lag 4; heat, cold: lag 0-21	heat: 99th percentile relative to 90th percentile (29°C vs. 25°C); cold: 10th vs. 25th percentile (−1°C vs. 4°C)	age	Decreasing trend of heat effect on concurrent days whereas the risk of CVD deaths increased over time; Cumulative risks of deaths increased recently except for respiratory disease
Kim et al. 2011	June-Sep., 2001-2008	Seoul and Daegu, South Korea	all-cause (A00-U99); CVD (I00-I99); respiratory (J00-J99)	heat	mean, min, and max temperature; mean, min, and max Tapp; and mean, min, and max perceived temperature (PT)	lag 0 to lag 3	1°C increase in temperature	age	For all-cause mortality: Seoul: 2.99% (95% CI 2.43-3.54%) for Tmax; Daegu: 3.52% (2.23-4.80%) for Tmin
Kim et al. 2006	summers for 1994-2003	6 major cities, Korea	non-accidental	heat	daily mean temperature and heat index	lag 0, lag 1	1°C increase above threshold	age	For daily mean temperature increase of 1°C above the thresholds in Seoul, Daegu, Incheon, and Gwangju, 16.3% (95% CI 14.2–18.4%), 9.10% (5.12–13.2%), 7.01% (4.42–9.66%), and 6.7%3 (2.47–11.2%) mortality increases, respectively.
Kim et al. 2017	May to Sep., 2008-2012	Tokyo, Japan	all-cause; CVD; respiratory	heat	daily mean temperature	lag 0 to lag 10	95th and 99th percentile of daily mean temperature compared with 50th percentile of temperature	age (all ages, 65+ yrs), reduced electricity consumption	A 5–9% reduction in all-cause heat-related mortality after the earthquake in the 15 prefectures with the greatest reduction in electricity consumption, and little change in other prefectures. The % reduction in observed vs. expected daily electricity consumption after the earthquake did not significantly modify daily heat-related mortality in Tokyo.
Kim and Joh	2000-2002	Seoul, South Korea	total (exclude V01–	heat	daily max, mean and	lag 0 to lag	1°C increase in	age, income	High temperature associated with daily mortality in

2006			Y89)		min temperature	3	temperature		Seoul; association could be higher in low-income group
Lim et al. 2015	1991-2010	Japan	all-cause	heat, cold	apparent temperature (Tapp); temperature deviation index (TDI)	lag 0	per 1-unit (around 1 standard deviation [SD]) and 1°C increase in the TDI and Tapp; at Tapp distribution (0–24th, 25–49th, 50–74th, 75–94th, and ≥95th percentile of AT)	latitude	national avg of TDI effects: 0.5% (95% CI 0.1, 1.0%) for the elderly; on summer days with moderate temperature (25th-49th percentile, mean temperature 22.9°C): 1.9 % (1.1-2.6) for the elderly
Onozuka and Hagihara 2015	1973-2012	Fukuoka, Japan	all cause (A00-U99, <800)	heat and cold extremes	heat extremes: days with 2-day moving avg of mean temperature >98th percentile (30.0°C) for the entire period; cold extremes: days with 26-day moving avg of mean temperature < 2nd percentile (5.0°C)	heat extremes: lag 0-1; cold extremes: lag 0-25	risk during extreme temperatures compared with non-extreme temperatures	decade, sex, age	RR increased during heat extremes in all decades, with declining trend over time. Mortality risk higher during cold extremes for the entire study period, with dispersed pattern across decades. Meta-analysis showed that heat and cold extremes increased mortality risk.
Son et al. 2011	2000-2007	Seoul, South Korea	all-cause (A00–R99); CVD (I00–I99); respiratory (J00–J99)	heat, cold	daily mean temperature	heat: lag 0; cold: lag 0–25	heat: 90th percentile relative to 50th percentile (25°C vs. 15 °C) and 99th vs. 90th percentile (29°C vs. 25°C); cold: 10th vs. 50th percentile (−1°C vs. 15°C) and 1st vs. 10th percentiles (−4°C vs. −1°C)	sex, age, education, place of death	90th relative to 50th percentiles (25°C vs. 15 °C): 10.2% (95% CI 7.43-13.0%); 10th vs. 50th percentiles (-1°C vs. 15°C): 12.2% (3.6-21.3%)
Son et al. 2016b	2000-2009	Seoul, South Korea	total (A00-R99)	heat	24-h avg	lag 0-1	% change for a 1°C increase in temperature above the threshold (90th percentile or 25.1°C)	urban vegetation, sex, age	The association between total mortality and a 1°C increase in temperature > 90th percentile (25.1°C) (heat effect) was the highest for gus with low NDVI; The heat effect was a 4.1% (95% CI 2.3, 5.9%), 3.0% (95% CI 0.2, 5.9%), and 2.2% (95% CI -0.5, 5.0%) increase in mortality risk for low, medium, and high NDVI group, respectively. Estimated risks were similar by sex and age.
Anderson and Bell 2009	1987-2000	107 US communities	CVD (390-448); respiratory (480-486, 490-497, or 507)	heat, cold	daily mean, max, and min temperature, and mean Tapp	heat: lag 0-1; cold: lag 0-25	cold: 1st percentile relative to 10th percentile, 4.4°C vs. 15.6°C; heat: 99th vs. 90th percentile, 26.7°C vs. 15.6°C	age, socioeconomic conditions, urbanicity, and central AC	Heat: 3.0% (95% PI 2.4%–3.6%) comparing community's 99th and 90th temperature percentiles; cold: 4.2% (3.2%–5.3%) comparing 1st and 10th percentiles
Basu et al. 2015	May-Oct., 1999-2011	California, US	all-cause; respiratory (J00-J98, U04); circulatory (I00-I99)	heat	mean daily Tapp	lag 0 to 6, 0-1, 0-3, 0-6	per 5.6°C increase for avg of same day and previous 3 days Tapp	black infants/white infants, costal and non-coastal regions	all-cause mortality: 4.4% (95% CI −0.3, 9.2) per 5.6°C increase for lag 0-3
Basu and Malig 2011	warm season for 1999-2006	13 counties in California	non-accidental (A00-U99); CVD (I00-I99); respiratory (J00-J98)	heat	daily mean Tapp	lag 0 to 20, 0-4, 0-9	per 5.6°C increase in Tapp	age, sex	excess risk 4.3% (95% CI 3.4, 5.2) per 5.6°C increase in Tapp, for non-accidental mortality

Braga et al. 2002	1986-1993	12 U.S. cities	CVD (390–429)	heat, cold	daily mean temperature	lag 4–6, 3, 4	% increase at 30°C and at –10°C for difference between the 90th and 10th percentiles in AC, variance of summer temperature, and variance of winter temperature	hot cities/cold cities	In cold cities, high and low temperatures associated with CVD. For CVD, hot day effect 5 times smaller than cold day effect. In hot cities, neither hot nor cold temperatures associated with CVD deaths.
Cagle and Hubbard 2005	1980-2001	King County, Washington, US	cardiac-related (390–398.9, 402.*, 404.*, 410–419, 420–429, I00–I11.9, I13.0–I13.9, I20.0–I59.9)	heat	daily avg temperature	lag 0 to 5	5˚C increase	sex, season	significant negative association between daily avg temperature and cardiac mortality for those >55 yrs; 5˚C increase in temperature associated with decreased mortality rate by factor of 0.971 (95% CI 0.961-0.982).
Chen et al. 2017	1990-2011	12 Texas Metropolitan Areas, US	all-cause; CVD (390-429, I01-I52); respiratory (460-519, J00-J99)	cold	mean temperature	lag 0-25	1 °C decrease below the threshold	age (0-64, 65-74, 75+ yrs)	Higher mortality generally observed in MSAs with higher average daily mean temperatures and lower latitudes. Pooled effect estimate was 1.58% (95% CI [0.81, 2.37]) increase in all-cause mortality risk with a 1 °C decrease in temperature. Effects of cold on all-cause mortality were highest among people >75 yrs (1.86%, 95% CI 1.09, 2.63).
Curriero et al. 2002	1973–1994	11 large eastern US cities	CVD (390–459); respiratory (460–519)	heat, cold	avg temperature	lag 0, 1-3, 4-10	per 10°F per 10-unit change in effect modifier; avg slope of estimated RR curves at temperatures lower/higher than MMT	latitude, city-specific characteristics such as % of elderly persons and % of homes with heating and/or air conditioning	weather components most strongly predictive of mortality: current and recent days' temperatures. Mortality risk generally decreased as temperature increased from coldest days to a threshold temperature, which varied by latitude, above which mortality risk increased as temperature increased.
Goldberg et al. 2011	1984-2007	Montreal, Canada	non-accidental; cardio-respiratory	heat, cold	Tmax	30 days	1st percentile relative to 10th percentile, 99th vs. 75th percentile, 99th vs. 90th percentile	sex, age	across all lags daily non-accidental mortality increased 28.4% (95% CI 13.8–44.9%) when temperatures 22.5 to 31.8˚C (75th to 99th percentiles)
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	natural (<800, 992, E900.0, A-R, T67, X30); CVD (390-429, I0-I52); respiratory (460-466, 480-487, 490-492, 494-496, J9-J18, J40-J44, J47)	heat	EH (indicator for 4-day mean, min, max or Tapp above 97th or 99th percentiles)	lag 0-1, 2-3, 4-5, 6-7	mortality during EH vs. non-EH	personal marital status, age, race, sex, education, and ZIP-code % non-green space, income, living alone, and housing age	EH vs. non-EH, for CVD: higher among non-married individuals (OR 1.21, 95% CI 1.14-1.28 vs. 0.98, 95% CI 0.90-1.07 among married individuals) and individuals in ZIP codes with high (91%) non-green space (1.17, 95% CI 1.06-1.29 vs. 0.98, 95% CI 0.89-1.07 for ZIP codes with low (39%) non-green space.
Harlan et al. 2014	May–Oct., 2000-2008	central Arizona desert cities, US	all-cause (excluding S00-99, T00-66, T68-98, U00-99, V01-99, W00-99, X00-29, 31, 33-53, 55-84, Y00-98, Z00-99 and including T67.x, X30, X32 and X54)	heat	daily max Tapp	lag 0, 1, 2, 3	RR above threshold per 1°F	age, sex	The most robust relationship was between max Tapp on day of death and mortality from direct exposure to high environmental heat; the heat thresholds in all gender and age groups (max Tapp 90–97 °F; 32.2–36.1 °C) were below local median seasonal temperatures in the study period (max Tapp 99.5 °F; 37.5 °C).
Ho et al. 2017	1998-2014	Vancouver, Canada	all deaths excluding accidents (V01-V99)	heat	daily mean humidex	not specified	1°C increase in daily mean humidex at	The Vancouver Area Neighborhood	The heat exposure and social vulnerability variables with the strongest spatially stratified results were the

							Vancouver International Airport (YVR)	Deprivation Index (VANDIX) based on % of population that did not finish high school, unemployment rate, % of population with university education, % of single-parent families, average income, % of homes owned, and labor participation rate (% of adult population that is either employed or actively looking for work)	apparent temperature and the labor nonparticipation rate. Areas at higher risk had values ≥ 34.4°C for the max Tapp and ≥ 60% of the population neither employed nor looking for work. These variables were combined in a composite index to quantify their interaction and to enhance visualization of high-risk areas.
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	non-traumatic (001-799, A01-R99); all-cause (000+, A00+); circulatory (390-459, I00-I99, G45, G46); CVD (393-429, I05-I52); respiratory (460-519, J00-J99)	heat	humidex (daily Tmax and avg RH values)	lag 0	99th percentile (36.1°C) heat day compared with non-heat day; per degree increase in county-wide avg daily max humidex (°C) above 36.0°C	age (0–4, 5–14, 15–44, 45–64, 65–84, 85+), gender, race, high school graduation, marital status, Hispanic origin, and tobacco use; type of synoptic weather (ambient weather conditions) on a given heat day	For all ages, all-causes, a 10% (1.10, 95% CI 1.06-1.14) increase on a heat day vs. non-heat day. When considering the intensity effect of heat on all-cause mortality, a 1.69 % (0.69-2.70) increase per unit of humidex >36.0°C. All-cause mortality was modified by synoptic weather type. Age was the only individual-level characteristic found to modify mortality risks.
Rosenthal et al. 2014	1997-2006	New York City, US	natural	heat	heat index	lag 0	comparing death rate (per days) on extremely hot days (max heat index >100 °F) to death rate on all days in the warm season (May-Sep.)	place-based characteristics (socioeconomic/demographic and health factors, as well as the built and biophysical environment)	Significant positive associations between mortality rate ratio among those >65 yrs and neighborhood-level characteristics: poverty, poor housing, lower access to AC, impervious land cover, surface temperatures, and seniors' hypertension. % Black/African American and household poverty were strong negative predictors of seniors' AC access.
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	non-accidental	heat, cold	modeled daily mean temperature	not specified	1 °C decrease/increase in temperature below −1 °C/above 28 °C	age group, sex, race, residence, and education	Children <15 yrs had the largest % increase per 1 °C increase in temperature (8.19%, 95% CI -0.38 to 17.49%) followed by Blacks (4.35%, 95% CI 2.22 to 6.53%). Higher education was protective for the effect of extreme temperature. Results suggest that people in less urban areas were more susceptible to extreme temperature. The association between temperature and mortality was stronger when using exposure data with more spatial variability than using exposure data based on existing monitors alone.
Madrigano et al. 2015b	1988-1999	counties in northeastern US	non-accidental	heat	daily Tmax	lag 0-1	increase in mortality comparing 90°F to 70°F	population density, urban/non-urban, County characteristics, such as population density, % of families living in poverty, and	8.88% increase in mortality (95% PI 7.38, 10.41) in urban counties, 8.08% increase (95% PI 6.16, 10.05) in nonurban counties

								% of elderly residents	
Medina-Ramon et al. 2006	1989–2000	50 US cities	CVD (390–429, I01–I51)	heat	daily Tmin and Tmax in each city to define extremely hot days (with a daily Tmin > 99th percentile) and extremely cold days (with daily Tmax < 1st percentile)	lag 0, 0-1, 1, 2, 0-2	relative odds comparing extreme temperature day for persons with the condition (e.g., being female) compared with persons without the condition	age, sex, race, education, place of death, chronic condition	Older subjects (OR 1.020; 95% CI 1.005–1.034), blacks (1.037, 1.016–1.059), and those dying outside a hospital (1.066, 1.036–1.098) more susceptible to EH, with some differences between those dying from CVD and other causes. CVD (1.053, 1.036–1.070) had higher relative increase on extremely cold days, whereas increase in heat-related mortality was marginally higher for those with coexisting atrial fibrillation (1.059, 0.996–1.125).
Medina-Ramon and Schwartz 2007	1989-2000	50 US cities	all-cause	heat &cold	1) extremely cold days: daily Tmax ≤1st percentile, extremely hot days: daily Tmin ≥99th percentile; 2) cold: value 0 when daily Tmax ≥17°C and then increased with increasing cold, heat: value 0 when the daily Tmin ≤17°C and increased with increasing hot temperature	2-day cumulative risk estimate by summing the estimates for lag 0 and lag 1	% change in mortality on extreme temperature days relative to other days; % change in mortality per each degree of max daily temperature < 17°C for heat exposure, % change in mortality per each degree of min daily temperature > 17°C	several city characteristics as effect modifiers	Mortality increases associated with extreme cold (2-day cumulative increase 1.59%, 95% CI 0.56-2.63%) and EH (5.74%, 3.38-8.15%) were found.
Metzger et al. 2010	May-Sep., 1997-2006	New York City, US	natural-cause (A00–R99, 001–799)	heat	max heat index; min, max, and avg (mean of min and max) temperature; spatial synoptic classification (SSC) of weather type	lag 0 to lag 3	unit increase	effect modification of temperature by time of year (interaction terms with day of year and month)	A model with cubic functions of max heat index on lag 0 to lag 3 provided the best fit, compared to models using max, min or avg temperature, or SSC of weather type.
Nordio et al. 2015	1962-2006	211 US cities	all-cause (A00-U99, 1-799)	heat, cold	daily mean temperature	heat: lag 0; cold: moving avg lag 1-5	heat: risk at 26.7°C (80 °F) relative to 15.6°C (60 °F); cold: risk at 4.4°C (40 °F) vs. 15.6°C (60 °F); heat: compare 99th to 50th percentiles; cold: compare 1st to 50th percentiles	AC	Effect of hot days diminished with increasing summer mean temperature within city; effect of cold days increased with increasing winter mean temperature
O'Neill et al. 2005b	1986-1993	4 US cities	non-injury mortality	heat	mean daily Tapp	lag 0, lag 1-3	% change in mortality at 29°C, relative to 15°C	AC prevalence, race	Heat-related mortality reduced with increasing central AC prevalence; substantially higher heat effects among Blacks compared with Whites
Petkova et al. 2014	1900-1948 and 1973-2006	New York, NY, US	total	heat	mean daily temperature	lag of 5 days for the main model	RR at 29°C vs. 22°C	age, decade-specific estimates	decade-specific RR ranged from 1.30 (95% CI 1.25-1.36) in 1910s to 1.43 (95% CI 1.37-1.49) in 1900s. Since 1970s, gradual and substantial decline in RR, from 1.26 (95% CI 1.22-1.29) in 1970s to 1.09 (95% CI 1.05-1.12) in 2000s.
Rainham and Smoyer-Tomic 2003	1980–1996	Toronto, Canada	non-accidental (<800); combined cardiac and respiratory (390–459,	heat	daily humidex using daily max dry-bulb temperature and	lag 0, lag 1, lag 0-1	both 1°C and 50–95th percentile increases in humidex	age group, sex	RR narrowly exceeded 1.0 for all groups, with adjustment for air pollution. Humidex effects most apparent for females (RR 1.006, 95% CI 1.004–1.008

			480–519)		dewpoint temperature that occurred at same hour as max air temperature				per 1°C humidex and RR 1.089 (1.058–1.121) for 50th to 95th percentiles humidex). Without air pollution adjustment, RR in the 50–95th percentile increased less than 1.71% for all groups except females, for which RR decreased 1.42%. Differences in RR per 1°C humidex were <0.12%.
Ren et al. 2008	June-Sep., 1987-2000	95 large US communities	CVD (390-448, I000-I799)	heat	daily Tmax	lag 0, lag 1	per 10°C increase in Tmax	region, ozone level	Increase in CVD mortality by 1.17% and 8.31% for areas with lowest and highest ozone levels in all communities, respectively
Smargiassi et al. 2009	summers, 1990–2003	Montreal, Canada	non-accidental (excluding 800–999 and S00–T98); CVD (360–459, I00–I99); respiratory (460–519, J00–J99)	heat	daily mean temperature	lag 0, 1, 0-1	increments of 2°C in daily mean temperature	residential dwelling values (proxy for the socioeconomic status) and categories of surface temperatures at place of death	Risk of death on warm summer days in areas with higher surface temperatures higher than in areas with lower surface temperatures
Xiao et al. 2015	1987–2000	13 eastern US cities	non-external (<800, A00-R99)	heat, cold	daily mean, max, and min temperature	lag 0, 0–6, 0–13, 0–20, 0–27, 0–34; cold: lag 0–27; heat: lag 0–6	per 1°C decrease or increase; per interval increase in a city-specific characteristic	city-level characteristics (such as the % of population >65 yrs, poverty of individuals, education level <9th grade, and latitude of city)	latitude modified cold and heat effects (statistically significant). Cold effect decreased (−0.11 % change of mortality effect f)or 1° latitude increment, while heat effect increased 0.18 % 1° latitude increment.
Zanobetti and Schwartz 2008	May-Sep., 1999 to 2002	9 US cities	all-cause excluding accidental causes (V01-Y98, 1-799)	heat	Tapp	lag 0, 0-3, 1-3	5.5°C increase in Tapp	air pollution, various temperature definitions	1.8% (95% CI 1.09-2.5%) using case-crossover analysis, 2.7% (2.0-3.5%) using time-series
Zhan et al. 2017	1987-2000	106 communities, US	non-accidental; CVD; respiratory	heat, cold	Tapp; temperature change between neighboring days: subtracting the previous day's mean temperature from the current day's mean temperature	lag 0-21	A temperature change between neighboring days (TCN) of 0°C was used as a reference for calculating RRs; 1st and 99th percentiles of daily TCN distribution as extremely negative and positive TCNs	age (<75, 75+ yrs), geographic regions	At national level, a monotonic increasing curve of TCN-mortality association was observed, which indicated that negative TCN was associated with reduced mortality and positive TCN elevated mortality risk. RR for lag 0-21 was 0.63 (95% CI 0.59-0.68) for extremely negative TCN (1st percentile) and 1.46 (1.39-1.54) for extremely positive TCN (99th percentile) for non-accidental mortality. Prominent effects of extreme TCNs for CVD and respiratory mortality. People ≥75yrs and those with respiratory disease were identified as particularly vulnerable to TCN. The TCN-mortality association was modified by season and region.
Almeida et al. 2013	April-Sep., 2000-2004	Lisbon and Oporto, Portugal	all natural (<800, A00-R99); CVD (390–459, I00–I99); respiratory (460–519, J00–J98)	heat	max Tapp, Tmax	lag 0-3	for every 1°C elevation in max Tapp above city-specific threshold	age	all-cause mortality rate: 7.13%% (95% CI 5.9-8.4%) in Lisbon and 4.31% (3.2-5.4%) in Oporto
Almeida et al. 2010	Lisbon (April-Sep., 2000-2004), Oporto (2000-2004)	Greater Lisbon and Greater Oporto, Portugal	all-cause (<800, A00-R99); CVD (390-459, I00-I99); respiratory (460-519, J00-J98)	heat	Tapp	lag 0 to 3, lag 0-3	per 1°C increase in mean daily Tapp	age	In Lisbon: 2.1% (95% CI 1.6, 2.5), 2.4% (1.7-3.1), and 1.7% (0.1-3.4) for all-causes, CVD, and respiratory, respectively. In Oporto: 1.5% (1.0-1.9), 2.1% (1.3-2.9) and 2.7% (1.2-4.3), respectively.
Antunes et al. 2017	Nov. to March, 1992-2012	Lisbon and Oporto, Portugal	All-causes (A00-Y98, 000-999); circulatory (I00-I99, 390-459) plus respiratory (J00-	cold	Tmin	max lag: lag 31	1st vs. 99th percentile of Tmin; 1°C decrease from reference temperature	age (0-64, 65+)	The overall effect was generally higher and more persistent in Lisbon than Oporto, particularly for circulatory and respiratory mortality and for the elderly.

			J99, 460-519)						
Ballester et al. 1997	1991-1993	Valencia, Spain	total (001–799); circulatory (390–459); respiratory (460–519)	heat, cold	mean daily temperature	lag 0, 1-2, 3-6, 7-14	1°C decrease/increase in daily temperature below 15°C/above 24°C	warm/cold months, age	The effect of temperature greater in persons > 70 yrs, and in cases of circulatory and respiratory diseases.
Breitner et al. 2014a	1990-2006	3 cities of Bavaria, Germany	non-accidental (1-799, A00-R99); CVD (390-459, I00-I99); respiratory (460-519, J00-J99)	heat, cold	mean daily temperature	lag 0-1; lag 0-14	heat: 90th percentile relative to the 99th percentile (20.0°C vs. 24.8°C); cold: 10th vs. 1st percentile (−1.0°C vs. -7.5°C)	sex, age, ambient air pollution	in non-accidental mortality, heat: 11.4% (95% CI 7.6-15.3%) increase; cold: 6.2% (95% CI 1.8–10.8%) increase
Breitner et al. 2014b	1990-2006	Bavaria, Germany	CVD (390–459, I00-I99)	heat, cold	24-h mean values	lag 0-1, lag 0-14	heat: 90th percentile relative to 99th percentile (20.0°C vs. 24.8°C) in 2-day avg temperature; cold: 10th vs. 1st percentile (−1.0°C) vs. −7.5°C) in 15-day avg temperature	Breitner et al. 2014	1990-2006
Burkart et al. 2016	1998-2008	Lisbon, Portugal	total	heat	UTCI	lag 0-2	1°C increase in UTCI above 95th or 99th percentiles	vegetation (urban green), proximity to water (urban blue)	For areas in lowest NDVI quartile (14.7%; 95% CI 1.9-17.5%) for 1°C increase in UTCI above 99th percentile (24.8°C); for areas in highest quartile (3.0%, 2.0-4.0%); In areas > 4 km from water, 1°C UTCI increase >99th percentile associated with 7.1% (6.2-8.1%); for areas ≤ 4 km from water, 2.1% (1.2-3.0%).
Carson et al. 2006	4 periods (1900–1910, 1927–1937, 1954–1964, and 1986–1996)	London, UK	all-cause; CVD respiratory	heat, cold	daily mean temperatures as mean of daily max and min temperatures	mean of lag 0 and 1 week	% increase in deaths per °C above/below 15°C	age	increase in mortality per 1°C decrease below 15°C was 2.52% (95% CI 2.00-3.03), 2.34% (1.72-2.96), 1.64% (1.10-2.19), and 1.17% (0.88-1.45) in the 4 time periods. Heat deaths also diminished over time.
Diaz et al. 2006	1986-1997	Madrid, Spain	non-accidental (1–799); circulatory (390–459); respiratory (460–519)	heat, cold	max, min; heat waves: Tmax > 36.5°C, cold waves: Tmax < 6.0°C	lag 0, 1, 2, 3, 7, 8	for each degree of Tmax above 36.5°C/below 6°C	sex, summer/winter	Mortality association limited to temperatures from 5th to 95th percentiles, and increased sharply thereafter. During summer, heat wave effect detected solely among males 45-64 yrs, with AR of 13.3% for circulatory causes. During winter, the impact of cold exclusively observed among females with AR of 7.7%.
Donaldson and Keatinge 2003	1998-2000	England and Wales	all cause	cold	daily mean temperature	lagged 3 days	% change in mortality/°C	sex, social class in working and retired age groups	Cold related mortality was generally low in unskilled class men of working age (50–59 yrs) only, compared with men in other classes, and unskilled class women or housewives.
Gasparrini et al. 2012	June-Sep., 1993-2006	10 regions in England and Wales	all-cause	heat	Tmax	lag 0-1	1°C increase in temperature above region-specific thresholds	age	all-cause mortality 2.1% (95% CI 1.6-2.6%); steepest increase in risk for respiratory (4.1%, 3.5-4.8%). smaller for CVD (1.8%, 1.2-2.5%).
Goodman et al. 2004	April-Dec., 1980-1996	Dublin, Ireland	total non-trauma deaths (<800); CVD (390–448); respiratory (460–496, 507)	heat, cold	Tmin	heat: lag 0; cold: lag 0-39	each increase/decrease of 1°C	age	1°C increase in lag 0 temperature associated with 0.4% increase in total mortality; each 1°C decrease associated with 2.6% increase in the following 40 days
Gómez-Acebo	2003-2006	Cantabria, Spain	mortality	heat, cold	Tmin, Tmax	lag 0	1°C increase or	sex, age	1°C increase in max or min temperatures associated

et al. 2012							decrease		with 2% excess mortality risk in whole population throughout the warm period
Gómez-Acebo et al. 2010	2004-2005	Cantabria, Spain	total	cold	avg, max, min temperature	lag 0 to lag 6	temperatures below 5th percentile compared with temperatures above 5th percentile	lag, age group, temperature quintile group	Temperatures <5th percentile strongly associated with mortality compared with temperatures >5th percentile (OR 3.40, 95% CI 2.95-3.93 for lag 6).
Hajat et al. 2007	1993-2003	England and Wales	CVD (390.0–459.9, I); respiratory (460.0–519.9, J)	heat, cold	Daily mean temperature as mean of daily max and min temperature; heat threshold derived from 95th percentile of mean temperature, cold threshold from the 5th percentile for each region separately	heat: lag 0-1; cold: lag 0-13	increase 1°C above heat threshold and below cold threshold	region, sex, age, urban or rural, long-term care status (home, nursing home, or none), region-specific quintiles of census and area-level measure of deprivation	strongest heat effects in London, strongest cold effects in the Eastern region. For all regions, heat: mean RR of 1.03 (95% CI 1.02-1.03); cold: 1.06 (1.05-1.06)
Hajat et al. 2016	Oct.-Mar., 1993-2006	England	all-cause; CVD (I00-I99); respiratory (J00-J99); COPD (J40-J44); external (V01-Y99)	cold	daily mean temperature	lag 0-28	every 1°C decrease in temperature below thresholds	age (0-15, 16-64, 65-74, 75-84, 85+ yrs)	Nationally, 3.44% (95% CI: 3.01, 3.87) increase in all-cause deaths for every 1 °C decrease in temperature below identified thresholds; The very elderly and people with COPD were most at risk from low temperatures.
Huynen et al. 2001	1979–1997	Netherlands	respiratory (AM 33–35); CVD (AM 25–32)	heat, cold	avg daily temperature as avg of min and max temperatures	lag 0, 1-2, 3-6, 7-14, 15-30	1oC increase/decrease above/below the optimum in preceding month	age	For temperatures above optimum, mortality increased 1.86%, 12.82%, and 2.72% for CVD, respiratory, and total mortality, respectively. For temperatures below optimum, mortality increased 1.69, 5.15, and 1.37%, respectively.
Iñiguez et al. 2010	1990-1996	13 Spanish cities	natural (0–799); cardiorespiratory (390–519)	heat, cold	daily mean temperature (avg of lag 0 min and max values)	lag 0, lag 1-3, lag 4-10	1°C increase/decrease in temperature from MMT	cold/mild/warm cities grouping, age	Cold and heat effects depended on climate: effects higher in hotter cities and lower in cities with higher variability. In general, effect of cold and MMT higher for cardiorespiratory than total mortality, while the effect of heat generally higher among the elderly.
Kunst et al. 1993	1979-1987	Netherlands	all-cause, CVD (380-459); respiratory (460-519)	heat, cold	avg temperature; cold: avg temperatures < 16.5°C, warm: > 16.5°C	lag 0, 1-2, 3-6, 7-14, 15-30, aggregate (5 lag periods)	1°C increase below/above 16.5°C	wind speed, humidity	Direct effects of cold and heat on mortality suggested: 1) control for influenza incidence reduced cold-related mortality by 34% and reduced heat-related mortality by 23% (role of air pollution and "season" was negligible); 2) 62% of "unexplained" cold-related mortality, and all heat-related mortality, occurred within 1 week; and 3) effect modification by wind speed was in expected direction.
Mackenbach et al. 1993	1979-1987	Netherlands	all-cause; CVD (AM 25-32); respiratory (AM 33-35)	heat, cold	avg temperature as difference between max and min temperatures; cold: < 16.5°C, warm: >16.5°C	lag 0, 1-5, 6-10, 11-15	1°C increase below/above 16.5°C	sex, age	Low temperatures had strongest lagged effects on mortality. Results similar for other causes of death.
Milojevic et al. 2016	1993-2006	London, UK	all-cause	heat, cold	daily mean temperature	heat: lag 0-1; cold: lag 0-13	RRs for hot and cold days with daily mean temperatures > 22.3°C or < 6.4°C,	urban heat island decile groups	RR on hot vs. normal days differed little across UHI decile groups. A 1°C UHI anomaly multiplied risk of heat death by 1.004 (95% CI: 0.950, 1.061) compared with expected value of 1.070 (1.057, 1.082) if there was

							respectively, compared with days with daily mean temperatures ≥ 6.4 and ≤ 22.3°C		no acclimatization. The corresponding UHI interaction for cold was 1.020 (0.979, 1.063) vs.1.030 (1.026, 1.034) (actual vs. expected under no acclimatization, respectively). Fitted splines for heat shifted little across UHI decile groups, suggesting acclimatization. For cold, splines shifted somewhat in the direction of no acclimatization, but did not exclude acclimatization.
Morabito et al. 2012	1999–2008	Tuscany, Central Italy	non-accidental (<800)	heat, cold	daily avg temperature	lag 0 to lag 30	1°C decrease/increase in temperature below/above threshold	age	cold: 2.27% (95% CI 0.17–4.93%); heat: 15.97% (7.43–24.51%) in coastal plain cities
Oudin et al. 2016	June to Sep, 1997–2013	Estonia	total	heat	Tmax	lag 0-2, lag 0-10	risk above MMT (75th percentile of Tmax)	age (0-74, 75+), gender, region	An immediate increase in mortality associated with temperatures > 75th percentile of summer Tmax, corresponding to ~23°C. The total effect of elevated temperatures was not lessened by significant mortality displacement.
Pattenden et al. 2010	May-Sep., 1993-2003	15 conurbations in England and Wales	all-cause except external causes; CVD (3900-4599, I); respiratory (4600-5199, J)	heat	daily mean temperature	lag 0-1	comparing adjusted mortality rates at 97.5th and 75th percentiles	age	mean mortality rate ratio for heat effect across conurbations: 1.071 (1.050-1.093)
Rabczenko et al. 2016	May - Sep, 2008-2013	Warsaw, Poland	all-cause	heat	Tmax	lag 0-7	RRs associated with temperature increase by 1°C below/above change point temperature (20-24°C)	sex, age	RR associated with increase of temperature above the calculated optimum is equal to 1.6%, being higher in females (2.7%) than in males (1.5%).
Ragettli et al. 2017	1995-2013	8 Swiss cities, Switzerland	non-external deaths (A00-R99, V01-V99, W00-X59)	heat	mean, max, min, max Tapp	lag 0-6	increases in temperature from the median to the 98th percentile of the warm season temperature distribution	gender, age (0-74, 75+ yrs)	Over the whole time period, significant temperature-mortality relationships were found for all temperature indicators (RR (95% CI): max Tapp: 1.12 (1.05; 1.18); Tmax: 1.15 (1.08–1.22); Tmean: 1.16 (1.09–1.23); Tmin 1.23 (1.15–1.32)). Mortality risks higher at beginning of summer, especially for Tmin. In the more recent time period, a non-significant reduction in the effect of high temperatures on mortality, with those >74 yrs remaining the population at highest risk.
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	total	heat	Tmax	lag 0-1, lag 0-6	OR associated with degree increase of temperature	sex, age, pre-existing disease, country of origin, municipality level wealth	Gradual increases in summer temperatures associated with mortality in those >80 yrs, and with mortality in those with previous myocardial infarction and with COPD in those <65 yrs; During winter, mortality associated with decreased temperature particularly in men and with duration of cold spells for those >80 yrs. History of hospitalization for myocardial infarction increased OR associated with cold among those >65 yrs.
Rocklöv et al. 2011	1990-2002	Stockholm County, Sweden	total (except 800-999, E); CVD (390-459, I); respiratory (460-519, J)	heat, cold	max and min Tapp	lag 0-1, 0-6, 0-13	1°C increase (or decrease) in min Tapp	age, summer/winter	Extreme heat associated with higher death rates in adults and for CVD death, compared with increased temperature. Warmer temperatures increase daily total mortality, while decreasing colder temperatures increase risk of CVD deaths.
Rocklöv et al. 2009	1990-2002	Stockholm, Sweden	all-cause excluding violent deaths,	heat, cold	daily mean temperature	lag 0-1	per 1°C increase above/below the	previous winter mortality	Cumulative effect 0.95% below and 0.89% above threshold (21.3°C) after winter with low CVD and

			influenza (487, J10-11); respiratory (460-519, J); CVD (390-459, I); CVD plus respiratory (390-519, I-J)				threshold		respiratory mortality, and -0.23% below and 0.21% above threshold after winter with high CVD and respiratory mortality.
Rocklöv and Forsberg 2010	1998-2005	Stockholm, Göteborg and Skåne, Sweden	natural causes excluding external causes	heat	daily mean temperature	lag 0–1, 2–6 7–13	1°C above 90th percentile of summer temperature	age, RH	Effect of temperature on mortality was found distributed over lag 0 or lag 1, with cumulative combined RR of about 5.1% (95% CI 0.3-10.1)
Rocklöv and Forsberg 2008	1998-2003	Stockholm, Sweden	non-external; CVD respiratory	heat, cold	daily mean temperature	lag 0 to lag 10, lag 0-10	1°C increase/decrease in temperature above/below optimal temperature (11–12°C)	age	heat: cumulative general RR 1.4% increase (95% CI 0.8–2.0%); cold: 0.7% (0.5–0.9%) decrease
Schaeffer et al. 2016	2000-2006 excluding heat wave of 2003 (Aug. 1-31)	Paris, France	non-accidental (A00-R99)	heat, cold	min, max and mean daily temperature	lag 0, lag 1-7	heat: 99th percentile relative to 90th percentile; cold: 1st vs. 10th percentile	study zone, age	heat: for those >75 yrs (RR 1.10, 95 % CI 1.07-1.14); cold: for those <75 yrs (1.04, 1.01-1.06)
Stafoggia et al. 2009	1987-2005	Rome, Italy	natural (1–799); CVD (390–459); respiratory (460–519)	heat	Tapp	lag 0-1	30°C relative to 20°C	previous winter mortality	Effect stronger in years characterized by low mortality in previous winter (RR for days at 30°C vs. 20°C: 1.73 (95% CI 1.50 –2.01), contrasted with years with medium (1.32, 1.25–1.41) or high previous winter mortality (1.34, 1.17–1.55).
Stafoggia et al. 2008	1997-2004	4 Italian cities	non-injury (1–799)	heat	Tapp	lag 0-1	30°C relative to 20°C	age, sex, socioeconomic characteristics, hospital ward, and type of hospital	OR for total 1.32 (95% CI 1.25-1.39); age, marital status and hospital ward were important risk indicators.
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	non-injury (1–799)	heat	mean Tapp	lag 0-1	pooled ORs at 30°C relative to 20°C	age, sex, marital status, income, hospital admission in the 2 previous yrs, place of death	OR 1.34 (95% CI 1.27–1.42) at 30°C relative to 20°C; OR increased with age; OR higher among women (1.45, 1.37–1.52) and among widows and widowers (1.50, 1.33–1.69). Low area-based income modestly increased effect.
Tobias et al. 2014	June–Sep., 1990-2004	50 Spanish cities	all-cause (1–799)	heat	daily mean, min and max temperatures	lag 0-2	o1C increments at 99th percentile compared to 90th percentiles of whole-year temperature distributions	geographic (altitude, latitude, longitude and surface), socio-demographic (total population, proportion of population >65 yrs and per capita income), climatic characteristics (yearly and summer temperatures, RH)	Risk increased 3.3% per 1°C between 90th and 99th percentiles. Although risk increments varied by city, the range of temperature (from 90th to 99th percentiles) was the only characteristic independently significantly associated with risks. Heat increment did not depend on other city climatic, socio-demographic and geographic determinants.
Urban et al. 2014	1994-2009	Czech Republic	CVD (I00–I99)	heat, cold	avg daily temperature; days with avg temperature above/below the 90%/10% quantile of empirical distribution in summer (June-	up to 14 days	risk on warm days (10% warmest days in summer)/cold days (10 % coldest days in winter)	sex, urban/rural region	Generally higher relative excess CVD mortality on warm days than cold days in both regions

					Aug.) and winter (Dec.-Feb.) defined as warm/cold days.				
Vigotti et al. 2006	1980-1989	Milan, Italy	all natural (1–799)	heat	daily mean temperature	lag 0-1	1°C increase above estimated thresholds	birthplaces	mortality risks differ by birthplace, regardless of place of residence.
Wichmann et al. 2011	1999–2006	Copenhagen, Denmark	respiratory; CVD	heat	max Tapp	lag 0 to 5, 0-1, 0-5	IQR (7°C) increase	age, sex, socio-economic status and place of death	Inverse association with CVD (−7%, 95% CI −13%, −1%) and no association with respiratory and cerebrovascular. In cold period all associations were inverse, although insignificant.
Zeka et al. 2014	1984-2007	Republic of Ireland (ROI) and Northern Ireland (NI)	non-accidental (001-799, A00-R99); CVD (390–429; I01-I52); respiratory (460–519, J0-J99)	cold	daily max temperature	lag 0, means of lag 1-2, 3–5, 6–9, 10–14, 15–21, 22–28 and 29–35	1°C decrease	sex, age	In ROI, cumulative mortality increase for all-cause 6.4% (95% CI 4.8-7.9%); similar increases for CVD, and twice as much for respiratory; In NI, associations less pronounced for CVD causes.
O'Neill et al. 2005a	1996–1998 (Mexico City), 1996–1999 (Monterrey)	Mexico City and Monterrey, Mexico	non-external (excluding >E800, V01-Y89)	heat, cold	Tapp	heat: lag 0-2; cold: lag 0-6	% change in daily mortality at 35–36°C Tapp relative to 25–26°C /at 10–11°C Tapp vs. 25–26°C /at 10–11°C Tapp vs. 15–16°C	age	Mexico City: cold effect 12.4% (95% CI 10.5-14.5%); Monterrey: cold effect 11.7% (3.7-20.3%), heat effect 18.7% (11.7-26.1%)
Cheng et al. 2017	2000-2009	5 cities (Sydney, Melbourne, Brisbane, Perth and Adelaide), Australia	all causes	heat	mean temperature; TV as SD of hourly temperature within 2 days	lag 2-3 for Perth, lag 0-1 for other cities	each 1 °C and IQR increases in TV	city-specific climate, geographic, demographic, health-related (chronic disease prevalence status), behavioral pattern, socioeconomic status for regions	Significant associations between TV and mortality in all cities; Deaths associated with each 1 °C rise in TV elevated by 0.28% (95% CI: 0.05, 0.52%) in Melbourne to 1.00% (0.52, 1.48%) in Brisbane, with a pooled estimate of 0.51% (0.33, 0.69%) for Australia; Subtropical and temperate regions showed no apparent difference in TV impacts; mortality risk could be influenced by city-specific factors: latitude, mean temperature, population density and the prevalence of several chronic diseases.
Hales et al. 1999	June 1988 - Dec. 1993	Christchurch, New Zealand	all cause; CVD (402-429); respiratory (460-519)	heat	Tmax	lag 1	increase of 1°C above the 3rd quartile (20.5°C) of Tmax	age	1% (95% CI 0.4-2.1%) for all-cause; 3% (0.1-6.0%) for respiratory
Qiao et al. 2015	Jan. 1996 - Nov. 2004	Brisbane, Australia	non-accidental (1–799, A00–R99); CVD (390–459, I00–99); respiratory (460–519, J00–99)	heat	mean temperature	lag 0-1	1°C increase above 28°C in summers that followed a winter with low mortality, compared with following winter with high mortality	previous winter mortality	heat effect generally stronger with low preceding winter mortality; 22% (95% CI 14-30%) increase in non-accidental mortality followed winter with low mortality, compared with 12% (7-17%) following winter with high mortality
Vaneckova et al. 2010	Oct.-March, 1993-2004	Sydney, Australia	non-external (001-799, A00-R99)	heat	daily avg temperature	running mean of 30 previous days	10°C increase in avg temperature during study period	socioeconomic status, proportion of vegetation or developed land, region specific, air pollutants	Spatial variation in mortality on unusually hot days observed among those >65 yrs; Elderly living within 5–20 km south-west and west of Sydney Central Business District more vulnerable.
Vaneckova et al. 2008	Oct.-March, 1993-2004	Sydney, Australia	all-cause (001–799, A00–R99); circulatory	heat	max daily temperature	not specified	10°C increase	age	With adjustment for air pollution, change in mortality was between 4.5% and 12.1% depending on mortality

			(390–459, I00–I99); respiratory (460–519, J00–J99)						data set. Without air pollution adjustment, effect on mortality percentages changed by -1.1% to 0.9%. Tmax significantly associated with mortality in Sydney, with confounding by PM10 and O3.
Williams et al. 2012	July 1993 – March 2009	Adelaide, South Australia	all	heat	daily max and min temperatures	not specified	10°C increase in max temperature above threshold and extreme temperatures (≥40 °C Tmax; ≥26 °C Tmin)	age	Association between temperature over thresholds and daily mortality not significant when adjusted for O3 and PM10. At extreme temperatures mortality increased significantly with increasing heat duration.
Yu et al. 2011a	1996-2004	Brisbane, Australia	non-external (001–799, A00–R99); CVD (390–459, I00-I79); respiratory (460–519, J00-J99)	heat, cold	mean, min, and max temperature	heat: 3 days; cold: 20 days	1o increase/decreases above/below threshold	age, different temperature indicators	AIC minimized when mean temperature used for non-external deaths and deaths for those 75-84 yrs; when Tmin used for those 0-64, 65–74, ≥85 yrs, and from respiratory diseases; and when Tmax was used for CVD. Effect estimates using certain temperature indicators were similar as mean temperature both for current day and lag effects.
Yu et al. 2011b	1996-2004	Brisbane, Australia	CVD (390-499, I00-I99)	heat, cold	daily mean temperature	lag 0-1, 0-7, 0-15, 0-21, 0-30	1°C increase (or decrease) above (or below) 24°C	age	heat: 3.7% (95% CI 0.4% to 7.1%) for people ≥65 yrs and 3.5% (0.4-6.7%) for all ages; cold: 3.1% (0.7-5.7%) for people >65 yrs and 2.8% (0.5-5.1%) for all ages
Yu et al. 2011c	1996-2004	Brisbane, Australia	all-cause (001-799, A00-R99); CVD (390-459, I00-I79); respiratory (460-519, J00-J99)	heat, cold	daily mean temperature	heat effect: lag 0, lag 0-2; cold effect: lag 0, lag 0-20	1°C increase above 24°C, 1°C decrease below 24°C	age	heat: highest % increase in mortality on lag 0 among people >85 yrs (7.2% (95% CI 4.3-10.2%)); cold: % increases in mortality at lag 0-20 3.9% (1.9-6.0%) and 3.4% (0.9-6.0%) for those >85 yrs and with CVD diseases, respectively.
Yu et al. 2010	Jan. 1, 1996 – Dec. 17, 2004	Brisbane, Australia	all-cause (001–799, A00–R99)	heat	daily mean temperature	not specified	1 degree increase in avg temperature (≥24°C)	age, sex, socioeconomic status	Clear increasing trend of harmful effect of high temperature on mortality with age. Effect estimate among women >20 times that of men. Did not find effect modification by SES.
Analitis et al. 2008	Oct.–March, 1990-2000	15 European cities	natural (1–799); CVD (390–459); respiratory (460–519)	heat	min Tapp	lags 0-15	1°C increase	age	1.35% (95% CI 1.16-1.53), 1.72% (95% CI 1.44-2.01), 3.30% (2.61-3.99), and 1.25% (0.77-1.73) increase in total, CVD, respiratory, and cerebrovascular deaths, respectively.
Baccini et al. 2011	April-Sep., 1990-2001	15 European cities	natural (1-799)	heat	max Tapp	lag 0-3	1°C increase in max Tapp above the threshold	age	Mean AF of deaths 2%. Highest impact in 3 Mediterranean cities (Barcelona, Rome and Valencia) and 2 continental cities (Paris and Budapest).
Baccini et al. 2008	April-Sep., 1990-2000	15 European cities	all-cause (1–799); CVD (390–459); respiratory (460–519)	heat	max Tapp	lag 0 to lag 40	1°C increase in max Tapp above city-specific threshold	region, age	all-cause: 3.12% (95% credibility interval 0.60-5.72%) in Mediterranean region, 1.84% (0.06-3.64%) in north-continental region
Bell et al. 2008	1998-2002	Mexico City, Mexico; São Paulo, Brazil; Santiago, Chile	non-accidental (excluding ICD-10 codes S and above); respiratory (J 100–118, 120–189, 209–499 and 690–700); CVD (I<800)	heat	mean Tapp	lag 0 to lag 3; lag 0-1, 0-2, 0-3, 0-4, 0-5, 0-6	95th percentile relative to 75th percentile	confounding by air pollution, cause of death and susceptibilities by educational attainment, age and sex	For those ≥65 yrs: 2.69% (95% CI 2.06-7.88%) for Santiago, 6.51% (3.57–9.52%) for São Paulo, and 3.22% (0.93–5.57%) for Mexico City
De' Donato et al. 2015	April-Sep., 1996-2010	9 European cities	all-cause (1–799); CVD (390–459); respiratory (460–519)	heat	mean temperature	up to 40 days	increases in mean temperature from the 75th to 99th percentile of the summer distribution; two 7-	age	In the recent period (2004-2010), reduction in mortality risk associated with heat only in Athens, Rome and Paris, especially among the elderly. In Helsinki and Stockholm, suggestion of increased heat effect. An effect of heat was still present in the recent years in all

							year periods were compared: 1996–2002, 2004–2010		cities, ranging from +11% to +35%.
Guo et al. 2014	Australia (3 cities 1988-08), Brazil (18 cities 1997–11), Thailand (62 provinces 1999-08), China (6 cities 2002-11), Taiwan (3 cities 1994–07), South Korea (7 cities 1992–10), Japan (7 cities 1972–09), Italy (10 cities 1987-10), Spain (51 cities 1990-10), UK (10 regions 1993-06), US (108 cities 1987-00), Canada (21 cities 1986-09)	306 communities from 12 countries/regions	total	heat, cold	mean temperature	max lag: up to lag 21	cold: RRs (1st percentile vs. MMT); heat: RRs (99th percentile vs. MMT)	avg temperature, avg latitude	Temperatures associated with lowest mortality around 75th percentile of temperature in all countries/regions, ranging from 66th (Taiwan) to 80th (UK) percentiles. Estimated effects of cold and heat varied by community and country. Meta-analysis found that cold and hot temperatures increased risk in all the countries/regions.
Guo et al. 2011	summer: Brisbane (1996–2004), Los Angeles (1987–2000)	Brisbane, Australia; Los Angeles, US	non-external (001-799, A00-R99); CVD (390–459, I00–I79); respiratory (460–519, J00–J99)	heat	temperature change as lag 0 mean temperature minus lag 1 mean	lag 0	1°C increase in temperature change	sex, age	In Brisbane, a decrease of >3°C in temperature between days associated with RRs of 1.157 (95% CI 1.024-1.307) for non-external mortality (NEM), 1.186 (1.002-1.405) for NEM in females, and 1.442 (1.099-1.892) for those 65–74 yrs. An increase >3°C associated with RRs of 1.353 (1.033-1.772) for CVD mortality and 1.667 (1.146-2.425) for <65 yrs. In Los Angeles, only a decrease of >3°C was significantly associated with RRs of 1.133 (1.053-1.219) for total NEM, 1.252 (1.131-1.386) for CVD mortality, and 1.254 (1.135-1.385) for ≥75 yrs.
Ishigami et al. 2008	Budapest 1993–2001; London 1993–2003; Milan 1999–2004	3 European cities	all-cause; CVD (390.0–459.9, I); respiratory (460.0–519.9, J)	heat	avg temperature	lag 0-1	1°C increase in temperature above threshold	socioeconomic status, census data	RRs: Budapest (≥24°C): (i) Male 1.10 (95% CI 1.07–1.12) and female 1.07 (1.05–1.10) for 75–84 yrs, (ii) Male 1.10 (1.06–1.14) and female 1.08 (1.06–1.11) for ≥85 yrs; London (≥20°C): (i) Male 1.03 (1.01–1.04) and female 1.07 (1.05–1.09) for 75-84 yrs, (ii) male 1.05 (1.03–1.07) and female 1.08 (1.07–1.10) for ≥85 yrs; and Milan (≥26°C): (i) male 1.08 (1.03–1.14) and female 1.20 (1.15–1.26) for 75-84 yrs, (ii) male 1.18 (1.11–1.26) and female 1.19 (1.15–1.24) for ≥85 yrs.
Lim et al. 2015	Taiwan: 3 cities (1994-07); Korea: 7 cities (1992-10, with	3 cities in Taiwan; 7 cities in Korea; 6 cities in Japan	non-accidental (A00-S99)	heat	mean temperature	lag 0-1	% changes in mortality risk per 1°C increase in mean temperature during extremely-	city-level GDP per capita as a proxy of city income level	In cities with a low GDP per capita (<20,000 $USD), effects of temperature detrimental when long-term avg summer temperature was high. In cities with high GDP per capita, temperature-related mortality risk not

	1997–10 for Ulsan); Japan: 6 cities (1979-09)						high-temperature (≥95% of daily mean temperature) days		significantly related to avg summer temperature.
The Eurowinter Group 1997	1988-1992	north Finland, south Finland, Baden-Württemburg, the Netherlands, London, and north Italy	all-cause (0–999); CVD (430.0–438.9); respiratory (460.0–519.9)	cold	mean temperature	lagged by 5 days for CVD; 12 days for respiratory; and 3 days for all-cause	per 1°C decrease below 18°C	sex, age, population characteristics	% increases in all-cause mortality higher in warmer regions than in colder regions (e.g., Athens 2.15% [95% CI 1.20–3.10] vs south Finland 0.27% [0.15–0.40])
Son et al. 2012	May-Sep., 2000-2007	7 major cities, South Korea	all-cause (A00–R99); CVD (I00–I99); respiratory (J00–J99)	heat waves	heat waves (≥ 2 consecutive days with daily mean temperature >98th percentile for warm season in each city)	lag 0	heat wave days compared to non-heat wave days	individual characteristics (sex, age, education level, place of death); heat wave characteristics (intensity, duration, and timing in season)	all-cause mortality: 4.1% (95% CI –6.1, 15.4%); for Seoul 8.4% (0.1-17.3)
Anderson and Bell 2011	May-Sep., 1987–2005	108 U.S. urban communities	non-accidental	heat waves	heat waves (≥ 2 consecutive days with daily mean temperature > community's 95th percentile warm season mean temperature)	lag 0	heat wave days vs. non-heat wave days; 1°F increase in avg mean temperature during heat waves (intensity); 1-day increase in heat waves duration; first vs. later heat waves	heat wave characteristics (intensity, duration, timing in season)	Mortality increased 3.74% (95% PI 2.29–5.22%) comparing heat wave and non-heat wave days; Heat wave mortality risk increased 2.49% for every 1°F increase in heat wave intensity; 0.38% for every 1-day increase in heat wave duration; Heat wave risk 5.04% (3.06–7.06%) for the 1st heat wave of summer vs. 2.65% (1.14–4.18%) for later heat waves.
Barnett et al. 2012	1987–2000	99 US cities	all-cause; CVD respiratory	heat waves, cold waves	cold waves (temperature < cold threshold for >2 consecutive days (1st to 5th percentiles); heat waves (temperature > heat threshold for >2 consecutive days (95–99percentiles))	max lag: lag 21	risk during heat/cold waves	age, cold/heat waves characteristics	Cold waves associated with generally small and not statistically significant increases in mortality. Heat waves generally associated with increased mortality risk, particularly for hottest heat threshold. Cold waves of colder intensity or longer duration did not have higher effect estimates; cold waves earlier in the cool season had higher risk estimates, as did heat waves earlier in the warm season.
Bobb et al. 2011	1987–2005	105 U.S. cities	all-cause excluding known accidental causes	heat waves	heat waves (2 temperature thresholds: 97.5th and 81st percentile of daily max temperature)	lag 0, 1, 2	% increase in mortality on heat wave days compared to non-heat waves days	age	No single model best predicted risk across the majority of cities; for some cities heat wave risk estimation was sensitive to model choice. While model averaging led to posterior distributions with increased variance as compared to statistical inference conditional on a model obtained through model selection. Posterior mean of heat wave mortality risk is robust to accounting for model uncertainty over a broad class of models.
Chen et al. 2017	1990-2011	12 Texas Metropolitan Areas, US	all-cause; CVD (390-429, I01-I52); respiratory (460-519, J00-J99)	cold waves	cold waves as daily mean temperature < 1st, 5th, or 10th percentiles with periods of >2	lag 0-25	risk comparing cold wave days to non-cold wave days	age (0-64, 65-74, 75+ yrs)	Several metropolitan areas along the Texas Gulf Coast showed statistically significant cold wave-mortality associations.

					consecutive days				
Jian et al. 2017	May-Sep., 1997-2010	Alabama, US	non-accidental deaths (< 800, A–R) + heat-related death (E900, X30)	heat waves	3 heat wave indices: (1) used 1.645×SD + mean of daily mean temperature (95th percentile of a normal distribution); (2) used 1.282×SD + mean of daily mean temperature, as threshold (90th percentile of a normal distribution); (3) defined by 2 thresholds: 97.5th (T1) and 81st percentiles (T2) of daily Tmax. Heat wave period defined as (1) > 3 days with a daily Tmax > T1, (2) daily Tmax > T2 for each day of the period, and (3) average of daily Tmax over the entire period > T1	not specified	percent differences in the odds between heat wave days and non-heat wave days	different cumulative environmental qualities (based on 5 domain indices (air, water, land, built, and sociodemographic))	Found significant associations between heat waves and non-accidental deaths and a significant effect modification of this relationship by environmental quality index (EQI). Higher ORs in counties with the worst cumulative environmental qualities compared to counties with the best cumulative environmental qualities. For example, the % change in OR (mean and 95% CI) between heat wave days and non-heat wave days was −10.3% (−26.6, 9.6) in counties with an overall EQI of 1 (best overall environment) and 13.2% (4.9, 22.2) in counties with an overall EQI of 3 (worst overall environment). Among the five domains, air quality had the strongest effect modification on the association.
Joe et al. 2016	June-Aug., 2006	California, US	internal (A00-R94); external (V01-Y89.9)	heat waves	HW: 18-day period (July 15-Aug. 1, 2006); reference period: from the same summer (June 1 to 30, July 6 to 14, and Aug. 8 to 31, 2006)	not specified	RRs during heat wave in 2006 comparing reference period	place of death, gender, race, age, climate zones	Total mortality risk higher among those 35–44 yrs than ≥65, and among Hispanics than whites; Deaths from external causes increased more sharply (RR 1.18, CI 1.10–1.27) than from internal causes (1.04, 1.02–1.07). Risk varied by building climate zone; highest risks of at-home death occurred in northernmost coastal zone (1.58, 1.01–2.48) and the southernmost zone of California's Central Valley (1.43, 1.21–1.68).
Kaiser et al. 2007	1993-1997	Cook County (containing Chicago), IL, US	non-accidental (excluding >800, except 900); CVD (390–429)	heat waves	the 1995 Chicago heat waves	lag 0 to lag 3	risk during Chicago heat waves	age, sex, race, education, sudden death	RR for all-cause mortality on the day with peak mortality was 1.74 (95% CI 1.67-1.81).
Kent et al. 2014	1990-2010	Alabama, US	non-accidental (< 800, A–R)	heat waves	different heat waves index definitions (15 versions) (Table 1)	lag 0 to lag 6	heat wave days relative to non–heat wave days	rurality	Associations varied by heat wave definition. Heat waves defined as >2 consecutive days with mean daily temperatures >90th percentile: 3.7% (95% CI 1.1-6.3%).
Madrigano et al. 2015a	2000-2011, warm season (May-Sep.)	New York, NY, US	non external (A00-R99, 001–799); CVD (I00–I99)	heat waves	heat waves days: days with max temperature or max heat index >95°F for > 2 consecutive days	lag 1-2	heat wave days compared to other warm-season days	race/ethnicity, neighborhood characteristics	Heat wave deaths more likely in black non-Hispanic persons than others (OR 1.08; 95% CI 1.03-1.12), deaths at home than in institutions and hospital settings (1.11, 1.06-1.16), and among those living in census tracts that received more public assistance (1.05, 1.01-1.09). Heat wave deaths more likely among residents in areas with higher relative daytime summer surface temperature and less likely among residents living in areas with more green space.

Sheridan and Lin 2014	1991–2004	New York City, US	respiratory (J00-99); CVD (I00-99)	heat waves	SSC categories based on weather conditions from temperature, dew point, wind speed and direction, pressure, and cloud cover; hot days (categorized either as Moist Tropical Plus (MT+) or Dry Tropical (DT) weather type); length of heat waves: threshold of 3 consecutive days of MT+ or DT weather type	lag 0, cumulative 15-day lag	RR for heat wave days compared to non-heat wave days	heat wave characteristics	The impacts of heat are higher during longer heat events and during middle of summer, when increased mortality is statistically significant after accounting for mortality displacement. Early-season heat waves have increases in mortality that appear to be largely short-term displacement.
Zhang et al. 2015	2007-2011	Houston, Texas, US	all-cause (below S)	heat waves	2011 heat wave (Aug. 2–30, 2011); for > 2 consecutive days in 2011 Aug. with daily mean temperature > 95th, 97th, or 99th percentiles	max lag: lag 7	risk of heat waves compared to warm months (May to Sep.) from 2007 through 2011	age	2011 heat waves in Houston associated with 0.6% (95% CI −5.5%, 7.1%) mortality increase.
Basagaña et al. 2011	May 15-Oct. 15, 1983–2006	Spain	total; CVD (I00-I99, 390-459); respiratory (J00-J99, 460-519)	heat waves	extremely hot days (max temperature >95th percentile, 3 consecutive hot days)	lag 0-2, 3-6, 0–6	during extremely hot days vs. non-extremely hot days	age, sex	3 consecutive hot days associated with 19% increase in total mortality. In infants, heat effect observed only for conditions originating in the perinatal period (RR 1.53, 95% CI 1.16–2.02).
Borrell et al. 2006	June-Aug., 1999-2003	Barcelona, Spain	all deaths	heat waves	daily max temperature	not specified	2003 compared to 1998–2002	age, sex, educational level	RR during 2003 summer compared to summers of 5 previous yrs higher for women than men and among older women (≥65 yrs).
Hutter et al. 2007	May–Sep., 1998-2004	Vienna, Austria	total	heat waves	heat wave (>3 consecutive days with daily max temperature >30 °C)	not specified	during heat wave days compared to non-heat wave days	sex, age	Heat wave days between 1998 and 2004 associated with increased RR 1.13 [95% CI 1.09–1.17].
Huynen et al. 2001	1979–1997	Netherlands	respiratory (AM 33–35); CVD (AM 25–32)	heat waves, cold spells	heat waves (>5 days each with max temperature >25°C, including >3 days with max temperature >30°C); cold spells (>9 days with min temperature <–5°C, of which >6 days have min temperature <-10°C)	lag 0, 1-2, 3-6, 7-14, 15-30; lag 0-30	risk during heat waves/cold spells days compared to non-heat waves/cold spells days	age	All heat waves studied were associated with increased mortality. The elderly were most effected by EH. Heat waves were associated with all causes of mortality studied, especially respiratory mortality. Avg total excess mortality during the heat waves studied was 12.1%, or 39.8 deaths/day. The avg excess mortality during cold spells was 12.8% or 46.6 deaths/day, which was mostly attributable to increased CVD mortality and mortality among the elderly.
Kysely et al. 2009	1986-2006	Czech Republic	CVD (390–459, I00–I99)	cold spells	cold spells (>3 consecutive days with daily temperature max < -3.5°C)	max lag: lag 20	excess mortality during cold spells relative to baseline	age, sex	Cold spells associated with positive mean excess CVD mortality in all age groups (25–59, 60–69, 70–79 and >80 yrs and in men and women. Relative mortality effects most pronounced and most direct for men 25–59 yrs, which contrasts most studies on cold-related

									mortality in other regions.
Monteiro et al. 2013	2002-2007	Porto, Portugal	all-cause; respiratory	heat waves	heat waves (>2 consecutive days with a (41<heat index<54))	max lag: lag 7	1°C increase in heat index during the heat waves week, previous week and following week	age, sex	all-causes: 2.7 % (95% CI 1.7–3.6 %)
Oudin et al. 2015	May 15-Sep. 15, 2000-2008	Rome, Italy and Stockholm, Sweden	all-cause	heat waves	heat waves (>2 days exceeding the city-specific 95th percentile of max Tapp)	not clearly specified	% increase in daily mortality during heat wave days compared to non-heat wave days	age, sex	heat waves compared to non-heat wave days for those >50 yrs: 22% (95% CI 18-26%) in Rome and 8% (3-12%) in Stockholm
Rabczenko et al. 2016	May - Sep., 2008-2013	Warsaw, Poland	all-cause	heat waves, hot periods	heat waves defined as at least 3 consecutive days with max temperature higher than 30°C; Hot periods were defined as at least 3 consecutive days with average max temperature ≥30°C, among them hot days (Tmax ≥ 30°C) constitute at least half of the days and possible series of warm days (25°C≤Tmax < 30°C) among hot days cannot exceed 3 days.	lag 0-7	risk during heat waves compared to non-heat wave period	sex, age	Heat waves have additional (to temperature effect itself) effect on male mortality however, only in males aged 70 yrs; the effect was statistically significant.
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	total	heat waves, cold waves	max temperature	lag 0-1, lag 0-6	OR associated with per additional day of heat or cold waves duration	sex, age, pre-existing disease, country of origin, municipality level wealth	Higher heat wave effect for: lower ages, areas with lower wealth, hospitalized patients <65 yrs. Odds elevated among females <65 yrs, those with previous hospital admission for mental disorders, and persons with previous CVD disease. Gradual increases in summer temperatures associated with mortality in those >80 yrs, those with previous myocardial infarction, and those with COPD <65 yrs. During winter, decrease in temperature associated with mortality particularly in men and with duration of cold spells for those >80 yrs. History of hospitalization for myocardial infarction increased odds associated with cold temperatures among those >65 yrs. Previous mental disease or substance abuse associated with higher odds of death among those <65 yrs.
Schifano et al. 2009	2005-2007	Rome, Italy	non-injury causes (1-799)	heat waves	max Tapp	during heat episode or in following 3 days	heat wave days compared to non-heat wave days	socio-demographic characteristics and pre-existing medical conditions	For those 65-74 yrs, risk was higher among unmarried persons and those with previous hospitalization for chronic pulmonary disease or psychiatric disorders. Those >75 yrs, women, and unmarried subjects were more susceptible to heat.
Urban et al.	1994-2015	Czech Republic	natural-cause (A00-	heat waves	heat waves: at least 3	not	risk during the	gender, age (0-64, 65+	Excess mortality was comparable among the younger

2017			R99)		consecutive days with mean daily temperature higher than the 95th percentile of annual distribution	specified	summer of 2015 compared with the summer of 1994	yrs)	age group (0–64 yrs) and the elderly (65+ yrs) in the 1994 major heat wave while it was significantly larger among the elderly in 2015.
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	all-cause	heat waves	3 consecutive hot days (defined as those >95th percentile of max temperature)	lag 0, 1, 2	heat wave days compared with non-heat wave days	sociodemographic and urban landscape characteristics (% manual workers; % unemployed; % of those 16–29 yrs who are illiterate or did not complete primary school education (low education level), % ≥65 yrs; % of old buildings (built before 1920); % of houses without AC, % of residents perceiving little surrounding greenness, % single dwellings)	Effect of 3 consecutive hot days: 30% increase in all-cause mortality (RR 1.30, 95% CI 1.24-1.38).
Nitschke et al. 2007	1993–2004	metropolitan Adelaide, Australia	total; CVD (390–4599, I00–I99); respiratory (460–5199, J00–J99)	heat waves	heat waves (daily max temperature >35°C for >3 consecutive days)	not specified	daily mean incidence of mortality during heat waves	age	Total mortality, disease- and age-specific mortality did not increase with heat waves; Significant decreases were observed in CVD related mortality.
Nitschke et al. 2011	July 1993 - Dec. 2007	Adelaide, South Australia	total; CVD (390-4599, I00-99); respiratory (460-5199, J00-J99)	heat waves	daily max temp; heat waves (≥35°C for >3 days)	heat waves days	mortality rates during heat waves occurring 2008-2009 and 1993-2008 were compared with rates during all non-heat waves days (Oct. to Mar.).	age	2009 heat wave was associated with considerable increases in total mortality that particularly affected those 15-64 yrs (1.37, 95% CI 1.09-1.71), without associations in older age groups.
Tong et al. 2015	1988-2009	3 largest Australian cities	non-accidental	heat waves	heat waves (95th and 99th percentile of mean temperature for >2 consecutive days)	lag 0 to lag 3, lag 0-3	risk during heat waves compared to non-heat waves	sex, age	Consistent and significant increase in mortality during heat waves was observed in all cities. RR began to increase around 95th percentile of temperature, increased sharply at 97th percentile and rose at 99th percentile.
Tong et al. 2014a	Jan. 1996 – Nov. 2004	Brisbane, Australia	non-external (< 800, A00-R99); CVD (390–459, I00-I99); respiratory (460–519, J00-J99)	heat waves	heat waves (>2 consecutive days with mean temperature > specified percentile) in warm season (Nov. to Mar.)	lag 0, 1, 2 or 3, lag 0–1, 0–2 or 0–3	RR during heat waves compared to non-heat wave days	warm, early warm, late warm season, age, intensity, duration	Higher risk for mortality in the 2nd half of warm season than that in the 1st half
Tong et al. 2014b	1988-2009	3 largest Australian cities: Brisbane, Melbourne, and Sydney	non-external causes	heat waves	heat waves (mean temperature above a heat threshold (90th, 95th and 99th percentiles of mean	lag 0 to lag 7, lag 0-2	mortality during heat waves compared to non-heat waves	sex, age	Using the heat waves definition as 95th percentile of mean temperature for >2 days in summer season, RR for total mortality at lag1 in Brisbane, Melbourne and Sydney was 1.13 (95% CI 1.08-1.19), 1.10 (1.06-1.14), and 1.06 (1.01-1.10), respectively.

					temperature) for >2 consecutive days in summer season)				
Wang et al. 2015	1988-2011	3 largest Australian cities (Brisbane, Melbourne and Sydney)	non-accidental; circulatory	heat waves	heat waves (mean temperature > specified percentile (e.g., 90th, 95th, 98th and 99th percentiles of mean temperature) for >2 consecutive days in the summer, the warm season and the whole year)	lag 0-3	RR during heat waves compared to non-heat wave days	sex, age	Non-accidental and circulatory mortality significantly increased across the 3 cities under different heat wave definitions and study periods. Using the summer data resulted in the largest increase in effect estimates compared use of the warm season or whole year data.
Wang et al. 2012	Jan. 1996 - Nov. 2004	Brisbane, Australia	non-external (<800, A00-R99); cardiovascuar (390-459, I00-I99); respiratory (460-519, J00-J99)	heat waves	heat waves (daily max ≥37°C for >2 consecutive days)	lag 1, 2, 0-2	ORs comparing heat waves to non-heat waves	age	non-external mortality (OR 1.46, 95% CI 1.21-1.77), CVD mortality (1.89, 1.44-2.48)
Williams et al. 2012	July 1993 - Mar. 2009	Adelaide, South Australia	all-cause	heat waves	hot days as max temperature >90th, 95th, or 99th percentile for warm season	not specified	risk for hot days compared to all other days during the warm season	age	Associations between temperature over thresholds and daily mortality not statistically significant when adjusted for ozone and PM10; at extreme temperatures mortality increased significantly with increasing heat wave duration.
Wilson et al. 2013	July 1997 - Dec. 2007	Sydney Greater Metropolitan Region, Australia	all-cause (A00-R99); CVD (I00-I99); respiratory (J00-J99)	heat waves	heat waves: daily max Tapp, daily max temperature >95th percentile	lag 0 to lag 3, lag 0-2	heat-event days compared to non-heat event days	age	All-cause mortality had similar magnitude associations with single day and 3 day extreme and severe events as did CVD mortality. Respiratory mortality associated with single day and 3 day severe events (95th percentile, lag 0 OR1.14 (95% CI 1.04-1.24).
Xu and Tong 2017	Nov.-Mar., 1988-2011	Sydney, Melbourne and Brisbane, Australia	non-accidental	heat waves	HW 4 types: 1) Type I: extremely-hot days followed by extremely-hot nights (HWboth); 2) Type II: extremely-hot days followed by not-extremely-hot nights (HWday); 3) Type III: not extremely-hot days followed by extremely-hot nights (HWnight); and 4) Type IV:not-extremely-hot days followed by not-extremely-hot nights (HWwarm); extremely-hot temperature refers to temperature at least	lag 0-7	risk during heat wave days compared to non-heat wave days	HW intensity, duration	Mortality in Brisbane increased significantly during HWboth and HWwarm, and mortality in Melbourne increased significantly during HWboth and HWday. For Sydney, HWboth, HWwarm, and HWday were associated with mortality increase, although no appreciable difference in the magnitudes of mortality increase among these 3 heatwave types was observed. HWnight was not associated with significant mortality increase in these cities. Mean temperature was the best temperature indicator for heatwaves in Brisbane and Tmax in Melbourne.

					≥96th percentile of the monthly temperature distribution and 3 percentiles (96th, 97th, and 98th) were used as the intensity, and 3 durations (2, 3 and 4 days) were used as the duration.				
Guo et al. 2017	limited to hot season (4 hottest adjacent months) for each community; Australia (3 cities 1988–2008), Brazil (18 cities 1997–2011), Canada (26 cities 1986–2009), China (6 cities 2002–07), Colombia (5 cities 1998–2013), Iran (1 city 2004– 13), Ireland (all Irish Island national data, including 6 regions: 2 in Northern Ireland and 4 in Republic of Ireland 1984–2007), Italy (10 cities 1987–2010), Japan (47 prefectures, 1985–2012), Moldova (4 cities 2001–2010), Philippines (4 cities during 2006–2010), South Korea (7	400 communities in 18 countries/regions	all causes/nonaccidental	heat waves	12 types of heat waves by combining community-specific daily mean temperature ≥90th, 92.5th, 95th, and 97.5th percentiles of temperature with duration ≥2, 3, and 4 d	lag 0-10	risk during heat wave days comapred to non-heat wave days	heat wave characteristics (intensity and duration); regional differences (4 groups (cold, moderate cold, moderate hot, and hot areas) by the quantiles of temperature based on the hot season mean temperature distribution of all 400 communities); community-specific hot season avg temperature, temperature range, temperature variability, latitude, longitude	Heat waves of all definitions had significant cumulative associations with mortality in all countries, but varied by community. Higher heat wave associations with higher temperature thresholds used to define heat waves. Heat wave duration did not modify the impacts. Association between heat waves and mortality appeared acutely and lasted for 3 and 4 d. Heat waves had higher associations with mortality in moderate cold and moderate hot areas than cold and hot areas. There were no added effects of heat waves on mortality in all countries/regions, except for Brazil, Moldova, and Taiwan. Heat waves defined by daily mean and Tmax produced similar heat wave-mortality
D'Ippoliti et al. 2010	June-Aug., 1990-2004	9 European cities	all natural causes (1-799, group A-R); CVD (390-459, group I);	heat waves	heat waves (considered both max Tapp and min	not specified	risk during heat wave days compared to non-heat wave days	sex, age	Large geographical heterogeneity of effects among cities; Considering all years, except 2003, mortality increase ranged from 7.6% in Munich to 33.6% in

			respiratory (460-519, group J)		temperature, 1) >2 days with max Tapp >90th percentile of monthly distribution or 2) >2 days with Tmin > 90th percentile and max Tapp > median monthly value)				Milan; The increase was up to 3-times greater during heat waves of long duration and high intensity; higher pooled impact in Mediterranean (21.8% for total mortality) than in North Continental (12.4%) cities.

additional

publications identified elsewhere but not included in Son et al. 2019
Hattis et al. 2012, The spatial variability of heat-related mortality in Massachusetts, Applied Geography, https://doi.org/10.1016/j.apgeog.2011.07.008
Basu et al. 2008, Characterizing Temperature and Mortality in Nine California Counties doi: 10.1097/EDE.0b013e31815c1da7
Zanobetti et al. 2013, Susceptibility to Mortality in Weather Extremes: Effect Modification by Personal and Small-Area Characteristics, Epidemiology, doi: 10.1097/01.ede.0000434432.06765.91
Evidence review & economic analysis of excess winter deaths for the National Institute for Health and Care Excellence (NICE) - Review 1: Factors determining vulnerability to winter- and cold-related mortality/morbidity. https://www.nice.org.uk/guidance/ng6/evidence/evidence-review-1-factors-determining-vulnerability-to-winter-and-coldrelated-mortalitymorbidity-pdf-544621933

age

Ha et al. 2011b	June–Aug., 1991-2008	Seoul, Daegu, and Incheon, South Korea	heat
Ha et al. 2009	Dec.-Feb., 1994-2006	Seoul, South Korea	cold
Ha and Kim 2013	1993–2009	Seoul, South Korea	heat
Kim et al. 2015	1995-2011	Seoul, South Korea	heat, cold
Kim et al. 2011	June-Sep., 2001-2008	Seoul and Daegu, South Korea	heat
Kim et al. 2006	summers for 1994-2003	6 major cities, Korea	heat
Kim et al. 2017	May to Sep., 2008-2012	Tokyo, Japan	heat
Kim and Joh 2006	2000-2002	Seoul, South Korea	heat
Onozuka and Hagihara 2015	1973-2012	Fukuoka, Japan	heat and cold extremes
Son et al. 2011	2000-2007	Seoul, South Korea	heat, cold
Son et al. 2016b	2000-2009	Seoul, South Korea	heat
Anderson and Bell 2009	1987-2000	107 US communities	heat, cold
Basu and Malig 2011	warm season for 1999-2006	13 counties in California	heat
Chen et al. 2017	1990-2011	12 Texas Metropolitan Areas, US	cold
Curriero et al. 2002	1973–1994	11 large eastern US cities	heat, cold
Goldberg et al. 2011	1984-2007	Montreal, Canada	heat, cold
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Harlan et al. 2014	May–Oct., 2000-2008	central Arizona desert cities, US	heat
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	heat
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	heat, cold
Medina-Ramon et al. 2006	1989–2000	50 US cities	heat
Petkova et al. 2014	1900-1948 and 1973-2006	New York, NY, US	heat
Rainham and Smoyer-Tomic 2003	1980–1996	Toronto, Canada	heat
Xiao et al. 2015	1987–2000	13 eastern US cities	heat, cold
Zhan et al. 2017	1987-2000	106 communities, US	heat, cold
Almeida et al. 2013	April-Sep., 2000-2004	Lisbon and Oporto, Portugal	heat

Almeida et al. 2010	Lisbon (April-Sep., 2000-2004), Oporto (2000-2004)	Greater Lisbon and Greater Oporto, Portugal	heat
Antunes et al. 2017	Nov. to March, 1992-2012	Lisbon and Oporto, Portugal	cold
Ballester et al. 1997	1991-1993	Valencia, Spain	heat, cold
Breitner et al. 2014a	1990-2006	3 cities of Bavaria, Germany	heat, cold
Carson et al. 2006	4 periods (1900–1910, 1927–1937, 1954–1964, and 1986–1996)	London, UK	heat, cold
Donaldson and Keatinge 2003	1998-2000	England and Wales	cold
Gasparrini et al. 2012	June-Sep., 1993-2006	10 regions in England and Wales	heat
Goodman et al. 2004	April-Dec., 1980-1996	Dublin, Ireland	heat, cold
Gómez-Acebo et al. 2012	2003-2006	Cantabria, Spain	heat, cold
Gómez-Acebo et al. 2010	2004-2005	Cantabria, Spain	cold
Hajat et al. 2007	1993-2003	England and Wales	heat, cold
Hajat et al. 2016	Oct.-Mar., 1993-2006	England	cold
Huynen et al. 2001	1979–1997	Netherlands	heat, cold
Iñiguez et al. 2010	1990-1996	13 Spanish cities	heat, cold
Mackenbach et al. 1993	1979-1987	Netherlands	heat, cold
Morabito et al. 2012	1999–2008	Tuscany, Central Italy	heat, cold
Oudin et al. 2016	June to Sep, 1997–2013	Estonia	heat
Pattenden et al. 2010	May-Sep., 1993-2003	15 conurbations in England and Wales	heat
Rabczenko et al. 2016	May - Sep, 2008-2013	Warsaw, Poland	heat
Ragettli et al. 2017	1995-2013	8 Swiss cities, Switzerland	heat
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat
Rocklöv et al. 2011	1990-2002	Stockholm County, Sweden	heat, cold
Rocklöv and Forsberg 2010	1998-2005	Stockholm, Göteborg and Skåne, Sweden	heat
Rocklöv and Forsberg 2008	1998-2003	Stockholm, Sweden	heat, cold
Schaeffer et al. 2016	2000-2006 excluding heat wave of 2003 (Aug. 1-31)	Paris, France	heat, cold

Stafoggia et al. 2008	1997-2004	4 Italian cities	heat
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Wichmann et al. 2011	1999–2006	Copenhagen, Denmark	heat
Zeka et al. 2014	1984-2007	Republic of Ireland (ROI) and Northern Ireland (NI)	cold
O'Neill et al. 2005a	1996–1998 (Mexico City), 1996–1999 (Monterrey)	Mexico City and Monterrey, Mexico	heat, cold
Hales et al. 1999	June 1988 - Dec. 1993	Christchurch, New Zealand	heat
Vaneckova et al. 2008	Oct.-March, 1993-2004	Sydney, Australia	heat
Williams et al. 2012	July 1993 – March 2009	Adelaide, South Australia	heat
Yu et al. 2011a	1996-2004	Brisbane, Australia	heat, cold
Yu et al. 2011b	1996-2004	Brisbane, Australia	heat, cold
Yu et al. 2011c	1996-2004	Brisbane, Australia	heat, cold
Yu et al. 2010	Jan. 1, 1996 – Dec. 17, 2004	Brisbane, Australia	heat
Analitis et al. 2008	Oct.–March, 1990-2000	15 European cities	heat
Baccini et al. 2011	April-Sep., 1990-2001	15 European cities	heat
Baccini et al. 2008	April-Sep., 1990-2000	15 European cities	heat
Bell et al. 2008	1998-2002	Mexico City, Mexico; São Paulo, Brazil; Santiago, Chile	heat
De' Donato et al. 2015	April-Sep., 1996-2010	9 European cities	heat
Guo et al. 2011	summer: Brisbane (1996–2004), Los Angeles (1987–2000)	Brisbane, Australia; Los Angeles, US	heat
Ishigami et al. 2008	Budapest 1993–2001; London 1993–2003; Milan 1999–2004	3 European cities	heat
The Eurowinter Group 1997	1988-1992	north Finland, south Finland, Baden-Württemburg, the Netherlands, London, and north Italy	cold
Son et al. 2012	May-Sep., 2000-2007	7 major cities, South Korea	heat waves
Barnett et al. 2012	1987–2000	99 US cities	heat waves, cold waves
Bobb et al. 2011	1987–2005	105 U.S. cities	heat waves
Joe et al. 2016	June-Aug., 2006	California, US	heat waves
Kaiser et al. 2007	1993-1997	Cook County (containing Chicago), IL, US	heat waves
Zhang et al. 2015	2007-2011	Houston, Texas, US	heat waves
Basagaña et al. 2011	May 15- Oct. 15, 1983–2006	Spain	heat waves
Borrell et al. 2006	June-Aug., 1999-2003	Barcelona, Spain	heat waves
Hutter et al. 2007	May–Sep., 1998-2004	Vienna, Austria	heat waves
Huynen et al. 2001	1979–1997	Netherlands	heat waves, cold spells
Kysely et al. 2009	1986-2006	Czech Republic	cold spells
Monteiro et al. 2013	2002-2007	Porto, Portugal	heat waves
Oudin et al. 2015	May 15- Sep. 15, 2000-2008	Rome, Italy and Stockholm, Sweden	heat waves
Rabczenko et al. 2016	May - Sep., 2008-2013	Warsaw, Poland	heat waves, hot periods
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat waves, cold waves
Urban et al. 2017	1994-2015	Czech Republic	heat waves
Xu et al. 2013	May 15- Oct. 15, 1999–2006	Barcelona, Spain	heat waves
Nitschke et al. 2007	1993–2004	metropolitan Adelaide, Australia	heat waves
Nitschke et al. 2011	July 1993 - Dec. 2007	Adelaide, South Australia	heat waves
Tong et al. 2015	1988-2009	3 largest Australian cities	heat waves
Tong et al. 2014a	Jan. 1996 – Nov. 2004	Brisbane, Australia	heat waves
Tong et al. 2014b	1988-2009	3 largest Australian cities: Brisbane, Melbourne, and Sydney	heat waves
Wang et al. 2015	1988-2011	3 largest Australian cities (Brisbane, Melbourne and Sydney)	heat waves
Wang et al. 2012	Jan. 1996 - Nov. 2004	Brisbane, Australia	heat waves
Williams et al. 2012	July 1993 - Mar. 2009	Adelaide, South Australia	heat waves
Wilson et al. 2013	July 1997 - Dec. 2007	Sydney Greater Metropolitan Region, Australia	heat waves
D'Ippoliti et al. 2010	June-Aug., 1990-2004	9 European cities	heat waves

sex

Heo et al. 2016	1996-2000, 2008-2012	South Korea	heat
Onozuka and Hagihara 2015	1973-2012	Fukuoka, Japan	heat and cold extremes
Son et al. 2011	2000-2007	Seoul, South Korea	heat, cold
Son et al. 2016b	2000-2009	Seoul, South Korea	heat
Basu and Malig 2011	warm season for 1999-2006	13 counties in California	heat
Cagle and Hubbard 2005	1980-2001	King County, Washington, US	heat
Goldberg et al. 2011	1984-2007	Montreal, Canada	heat, cold
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Harlan et al. 2014	May–Oct., 2000-2008	central Arizona desert cities, US	heat
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	heat
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	heat, cold
Medina-Ramon et al. 2006	1989–2000	50 US cities	heat
Rainham and Smoyer-Tomic 2003	1980–1996	Toronto, Canada	heat
Breitner et al. 2014a	1990-2006	3 cities of Bavaria, Germany	heat, cold
Diaz et al. 2006	1986-1997	Madrid, Spain	heat, cold
Donaldson and Keatinge 2003	1998-2000	England and Wales	cold
Gómez-Acebo et al. 2012	2003-2006	Cantabria, Spain	heat, cold
Hajat et al. 2007	1993-2003	England and Wales	heat, cold
Mackenbach et al. 1993	1979-1987	Netherlands	heat, cold
Oudin et al. 2016	June to Sep, 1997–2013	Estonia	heat
Rabczenko et al. 2016	May - Sep, 2008-2013	Warsaw, Poland	heat
Ragettli et al. 2017	1995-2013	8 Swiss cities, Switzerland	heat
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat
Stafoggia et al. 2008	1997-2004	4 Italian cities	heat
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Urban et al. 2014	1994-2009	Czech Republic	heat, cold
Wichmann et al. 2011	1999–2006	Copenhagen, Denmark	heat
Zeka et al. 2014	1984-2007	Republic of Ireland (ROI) and Northern Ireland (NI)	cold
Yu et al. 2010	Jan. 1, 1996 – Dec. 17, 2004	Brisbane, Australia	heat
Bell et al. 2008	1998-2002	Mexico City, Mexico; São Paulo, Brazil; Santiago, Chile	heat
Guo et al. 2011	summer: Brisbane (1996–2004), Los Angeles (1987–2000)	Brisbane, Australia; Los Angeles, US	heat
Ishigami et al. 2008	Budapest 1993–2001; London 1993–2003; Milan 1999–2004	3 European cities	heat
The Eurowinter Group 1997	1988-1992	north Finland, south Finland, Baden-Württemburg, the Netherlands, London, and north Italy	cold
Son et al. 2012	May-Sep., 2000-2007	7 major cities, South Korea	heat waves
Joe et al. 2016	June-Aug., 2006	California, US	heat waves
Kaiser et al. 2007	1993-1997	Cook County (containing Chicago), IL, US	heat waves
Basagaña et al. 2011	May 15-Oct. 15, 1983–2006	Spain	heat waves
Borrell et al. 2006	June-Aug., 1999-2003	Barcelona, Spain	heat waves
Hutter et al. 2007	May–Sep., 1998-2004	Vienna, Austria	heat waves
Kysely et al. 2009	1986-2006	Czech Republic	cold spells
Monteiro et al. 2013	2002-2007	Porto, Portugal	heat waves
Oudin et al. 2015	May 15-Sep. 15, 2000-2008	Rome, Italy and Stockholm, Sweden	heat waves
Rabczenko et al. 2016	May - Sep., 2008-2013	Warsaw, Poland	heat waves, hot periods
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat waves, cold waves
Schifano et al. 2009	2005-2007	Rome, Italy	heat waves
Urban et al. 2017	1994-2015	Czech Republic	heat waves
Tong et al. 2015	1988-2009	3 largest Australian cities	heat waves

Tong et al. 2014b	1988-2009	3 largest Australian cities: Brisbane, Melbourne, and Sydney	heat waves
Wang et al. 2015	1988-2011	3 largest Australian cities (Brisbane, Melbourne and Sydney)	heat waves
D'Ippoliti et al. 2010	June-Aug., 1990-2004	9 European cities	heat waves
Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

education

Heo et al. 2016	1996-2000, 2008-2012	South Korea	heat
Son et al. 2011	2000-2007	Seoul, South Korea	heat, cold
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Ho et al. 2017	1998-2014	Vancouver, Canada	heat
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	heat
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	heat, cold
Medina-Ramon et al. 2006	1989–2000	50 US cities	heat
Xiao et al. 2015	1987–2000	13 eastern US cities	heat, cold
Bell et al. 2008	1998-2002	Mexico City, Mexico; São Paulo, Brazil; Santiago, Chile	heat
Son et al. 2012	May-Sep., 2000-2007	7 major cities, South Korea	heat waves
Kaiser et al. 2007	1993-1997	Cook County (containing Chicago), IL, US	heat waves
Borrell et al. 2006	June-Aug., 1999-2003	Barcelona, Spain	heat waves
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves
Anderson and Bell 2009	1987-2000	107 US communities	heat, cold
Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

place of death

Son et al. 2011	2000-2007	Seoul, South Korea	heat, cold
Medina-Ramon et al. 2006	1989–2000	50 US cities	heat
Smargiassi et al. 2009	summers, 1990–2003	Montreal, Canada	heat
Stafoggia et al. 2008	1997-2004	4 Italian cities	heat
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Wichmann et al. 2011	1999–2006	Copenhagen, Denmark	heat
Son et al. 2012	May-Sep., 2000-2007	7 major cities, South Korea	heat waves
Joe et al. 2016	June-Aug., 2006	California, US	heat waves
Madrigano et al. 2015a	2000-2011, warm season (May-Sep.)	New York, NY, US	heat waves

occupation

Heo et al. 2016	1996-2000, 2008-2012	South Korea	heat
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves
Donaldson and Keatinge 2003	1998-2000	England and Wales	cold

race

Basu et al. 2015	May-Oct., 1999-2011	California, US	heat
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	heat
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	heat, cold
Medina-Ramon et al. 2006	1989–2000	50 US cities	heat
O'Neill et al. 2005b	1986-1993	4 US cities	heat
Joe et al. 2016	June-Aug., 2006	California, US	heat waves
Kaiser et al. 2007	1993-1997	Cook County (containing Chicago), IL, US	heat waves
Madrigano et al. 2015a	2000-2011, warm season (May-Sep.)	New York, NY, US	heat waves
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat waves, cold waves
Hajat et al. 2007	1993-2003	England and Wales	heat, cold

Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

marital status

Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	heat

Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Schifano et al. 2009	2005-2007	Rome, Italy	heat waves

chronic conditions

Medina-Ramon et al. 2006	1989–2000	50 US cities	heat,cold
Rosenthal et al. 2014	1997-2006	New York City, US	heat
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat,cold

Schifano et al. 2009	2005-2007	Rome, Italy	heat waves
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Stafoggia et al. 2008	1997-2004	4 Italian cities	heat

SES

Kim and Joh 2006	2000-2002	Seoul, South Korea	heat
Anderson and Bell 2009	1987-2000	107 US communities	heat, cold
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Ho et al. 2017	1998-2014	Vancouver, Canada	heat
Rosenthal et al. 2014	1997-2006	New York City, US	heat
Madrigano et al. 2015b	1988-1999	counties in northeastern US	heat
Smargiassi et al. 2009	summers, 1990–2003	Montreal, Canada	heat
Xiao et al. 2015	1987–2000	13 eastern US cities	heat, cold
Donaldson and Keatinge 2003	1998-2000	England and Wales	cold
Hajat et al. 2007	1993-2003	England and Wales	heat, cold
Rocklöv et al. 2014	1990-2002	Stockholm County, Sweden	heat, cold
Stafoggia et al. 2008	1997-2004	4 Italian cities	heat
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Tobias et al. 2014	June–Sep., 1990-2004	50 Spanish cities	heat

Wichmann et al. 2011	1999–2006	Copenhagen, Denmark	heat
Vaneckova et al. 2010	Oct.-March, 1993-2004	Sydney, Australia	heat
Yu et al. 2010	Jan. 1, 1996 – Dec. 17, 2004	Brisbane, Australia	heat
Ishigami et al. 2008	Budapest 1993–2001; London 1993–2003; Milan 1999–2004	3 European cities	heat
Jian et al. 2017	May-Sep., 1997-2010	Alabama, US	heat waves
Madrigano et al. 2015a	2000-2011, warm season (May-Sep.)	New York, NY, US	heat waves
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves
Milojevic et al. 2016	1993-2006	London, UK	heat, cold
Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

population density

Madrigano et al. 2015b	1988-1999	counties in northeastern US	heat
Medina-Ramon and Schwartz 2007	1989-2000	50 US cities	heat & cold

Kent et al. 2014	1990-2010	Alabama, US	heat waves
Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

latitude

Lim et al. 2015	1991-2010	Japan	heat, cold
Curriero et al. 2002	1973–1994	11 large eastern US cities	heat, cold
Xiao et al. 2015	1987–2000	13 eastern US cities	heat, cold
Tobias et al. 2014	June–Sep., 1990-2004	50 Spanish cities	heat
Guo et al. 2014	Australia (3 cities 1988-08), Brazil (18 cities 1997–11), Thailand (62 provinces 1999-08), China (6 cities 2002-11), Taiwan (3 cities 1994–07), South Korea (7 cities 1992–10), Japan (7 cities 1972–09), Italy (10 cities 1987-10), Spain (51 cities 1990-10), UK (10 regions 1993-06), US (108 cities 1987-00), Canada (21 cities 1986-09)	306 communities from 12 countries/regions	heat, cold

urban rural

Anderson and Bell 2009	1987-2000	107 US communities	heat, cold
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	heat, cold
Madrigano et al. 2015b	1988-1999	counties in northeastern US	heat
Hajat et al. 2007	1993-2003	England and Wales	heat, cold
Urban et al. 2014	1994-2009	Czech Republic	heat, cold
Kent et al. 2014	1990-2010	Alabama, US	heat waves
Hattis et al. 2012	May through September from 1990 to 2008	Massachusetts, US	heat

AC

Anderson and Bell 2009	1987-2000	107 US communities	heat, cold
Curriero et al. 2002	1973–1994	11 large eastern US cities	heat, cold
Rosenthal et al. 2014	1997-2006	New York City, US	heat
Medina-Ramon and Schwartz 2007	1989-2000	50 US cities	heat
Nordio et al. 2015	1962-2006	211 US cities	heat, cold
O'Neill et al. 2005b	1986-1993	4 US cities	heat
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves

heating

Curriero et al. 2002	1973–1994	11 large eastern US cities	heat, cold
Medina-Ramon and Schwartz 2007	1989-2000	50 US cities	heat

climate

Braga et al. 2002	1986-1993	12 U.S. cities	heat, cold
Cagle and Hubbard 2005	1980-2001	King County, Washington, US	heat
Isaksen et al. 2016	May-Sep., 1980-2010	King County, Washington, US	heat
Medina-Ramon and Schwartz 2007	1989-2000	50 US cities	heat
Zhan et al. 2017	1987-2000	106 communities, US	heat, cold
Iñiguez et al. 2010	1990-1996	13 Spanish cities	heat, cold
Tobias et al. 2014	June–Sep., 1990-2004	50 Spanish cities	heat
Cheng et al. 2017	2000-2009	5 cities (Sydney, Melbourne, Brisbane, Perth and Adelaide), Australia	heat
Guo et al. 2014	Australia (3 cities 1988-08), Brazil (18 cities 1997–11), Thailand (62 provinces 1999-08), China (6 cities 2002-11), Taiwan (3 cities 1994–07), South Korea (7 cities 1992–10), Japan (7 cities 1972–09), Italy (10 cities 1987-10), Spain (51 cities 1990-10), UK (10 regions 1993-06), US (108 cities 1987-00), Canada (21 cities 1986-09)	306 communities from 12 countries/regions	heat, cold
The Eurowinter Group 1997	1988-1992	north Finland, south Finland, Baden-Württemberg, the Netherlands, London, and north Italy	cold

Joe et al. 2016	June-Aug., 2006	California, US	heat waves

Guo et al. 2017	limited to hot season (4 hottest adjacent months) for each community; Australia (3 cities 1988–2008), Brazil (18 cities 1997–2011), Canada (26 cities 1986–2009), China (6 cities 2002–07), Colombia (5 cities 1998–2013), Iran (1 city 2004–13), Ireland (all Irish Island national data, including 6 regions: 2 in Northern Ireland and 4 in Republic of Ireland 1984–2007), Italy (10 cities 1987–2010), Japan (47 prefectures, 1985–2012), Moldova (4 cities 2001–2010), Philippines (4 cities during 2006–2010), South Korea (7	400 communities in 18 countries/regions	heat waves

meteorology

Kunst et al. 1993	1979-1987	Netherlands	heat, cold
Rocklöv and Forsberg 2010	1998-2005	Stockholm, Göteborg and Skåne, Sweden	heat

Xu and Tong 2017	Nov.-Mar., 1988-2011	Sydney, Melbourne and Brisbane, Australia	heat waves

healthcare

Hajat et al. 2007	1993-2003	England and Wales	heat, cold	long-term care status (home, nursing home, or none)

green space

Son et al. 2016b	2000-2009	Seoul, South Korea	heat
Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Rosenthal et al. 2014	1997-2006	New York City, US	heat
Burkart et al. 2016	1998-2008	Lisbon, Portugal	heat
Vaneckova et al. 2010	Oct.-March, 1993-2004	Sydney, Australia	heat

Madrigano et al. 2015a	2000-2011, warm season (May-Sep.)	New York, NY, US	heat waves
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves
Kent et al. 2014	1990-2010	Alabama, US	heat waves
Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

blue space

Burkart et al. 2016	1998-2008	Lisbon, Portugal	heat

Basu et al 2008	May to September 1999–2003	California, US	heat
Zanobetti et al. 2013	1985-2006	135 US cities	heat, cold

housing

Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Rosenthal et al. 2014	1997-2006	New York City, US	heat

Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves

living alone

Gronlund et al. 2015	May-Sep., 1990-2007	8 Michigan cities, US	heat
Xu et al. 2013	May 15-Oct. 15, 1999–2006	Barcelona, Spain	heat waves

air pollution

Ren et al. 2008	June-Sep., 1987-2000	95 large US communities	heat
Zanobetti and Schwartz 2008	May-Sep., 1999 to 2002	9 US cities	heat
Breitner et al. 2014a	1990-2006	3 cities of Bavaria, Germany	heat, cold
Kunst et al. 1993	1979-1987	Netherlands	heat, cold
Vaneckova et al. 2010	Oct.-March, 1993-2004	Sydney, Australia	heat
Bell et al. 2008	1998-2002	Mexico City, Mexico; São Paulo, Brazil; Santiago, Chile	heat
Jian et al. 2017	May-Sep., 1997-2010	Alabama, US	heat waves
Medina-Ramon and Schwartz 2007	1989-2000	50 US cities	heat & cold
Madrigano et al. 2015b	1988-1999	counties in northeastern US	heat
Anderson and Bell 2009	1987-2000	107 US communities	heat, cold
Lee et al. 2016	2007-2011	Georgia, North Carolina, and South Carolina, US	heat, cold
Basu et al 2008	May to September 1999–2003	California, US	heat

prev winter mortality

Rocklöv et al. 2009	1990-2002	Stockholm, Sweden	heat, cold
Stafoggia et al. 2009	1987-2005	Rome, Italy	heat
Stafoggia et al. 2006	1997–2003	4 Italian cities (Bologna, Milan, Rome, and Turin)	heat
Qiao et al. 2015	Jan. 1996 - Nov. 2004	Brisbane, Australia	heat

reduced electricity consumption

Kim et al. 2017	May to Sep., 2008-2012	Tokyo, Japan	heat

time of year

Metzger et al. 2010	May-Sep., 1997-2006	New York City, US	heat
Son et al. 2012	May-Sep., 2000-2007	7 major cities, South Korea	heat waves
Anderson and Bell 2011	May-Sep., 1987–2005	108 U.S. urban communities	heat waves
Anderson and Bell 2011	May-Sep., 1987–2005	108 U.S. urban communities	heat waves
Barnett et al. 2012	1987–2000	99 US cities	heat waves, cold waves
Sheridan and Lin 2014	1991–2004	New York City, US	heat waves
Tong et al. 2014a	Jan. 1996 – Nov. 2004	Brisbane, Australia	heat waves

birth place

Vigotti et al. 2006	1980-1989	Milan, Italy	heat

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