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**High Ambient Temperature and Mortality: A Review of Epidemiological Studies from 2001 to 2008**  
**~~A Review of the Epidemiologic Evidence of High Ambient Temperature and Mortality Accounting for Air Pollutants and Identifying Vulnerable Subgroups~~**

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## 1 **Abstract**

2 **Background:** This review examines recent evidence on mortality from elevated  
3 ambient temperature for studies published from January 2001 to September 2008.

4 **Methods:** Pub Med was used to search for the following keywords: temperature,  
5 apparent temperature, heat, heat index, and mortality. The search was limited to the  
6 English language and epidemiologic studies. Studies that reported mortality counts or  
7 excess deaths following heat waves were excluded so that the focus remained on  
8 general ambient temperature exposure in a variety of locations. Studies focusing on  
9 cold temperature effects were also excluded.

10 **Results:** Thirty-eight total studies were presented in three tables: 1) elevated ambient  
11 temperature and mortality; 2) air pollutants as confounders and/or effect modifiers of the  
12 elevated ambient temperature and mortality association; and 3) vulnerable subgroups of  
13 the elevated ambient temperature mortality association. The evidence suggests that  
14 particulate matter with less than 10um in aerodynamic diameter and ozone are both  
15 confounders, while ozone was also found to be an effect modifier in the warmer months  
16 in some studies. Elevated temperature was associated with increased risk for those  
17 dying from cardiovascular, respiratory, cerebrovascular, and some specific  
18 cardiovascular diseases, such as ischemic heart disease, congestive heart failure, and  
19 myocardial infarction. Vulnerable subgroups also included: Black racial/ethnic group,  
20 women, those with lower socioeconomic status, and several age groups, particularly the  
21 elderly over 65 years of age as well as infants and young children.

22 **Conclusions:** Many of these outcomes and vulnerable subgroups have not been  
23 identified previously and were dependent on the location and study population. Thus,

1 ~~region-specific policies, especially in urban areas, are vital to the mitigation of heat-~~  
2 ~~related deaths.~~

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4

## 1 Background

2

3 Although many studies of temperature have been conducted in other disciplines such as  
4 climatology, they have received greater attention in epidemiology in the past few years.

5 In 2002, a comprehensive epidemiologic review by Basu and Samet [1] summarized the  
6 findings from studies examining mortality from elevated ambient temperature and heat  
7 waves. Most of the evidence at that time was based on studies following heat waves.

8 Several studies have been conducted more recently using modern statistical

9 approaches, consisting primarily of the time-series ~~approach~~ and ~~the time-stratified~~  
10 case-crossover approaches ~~design~~. While other reviews have been conducted more

11 recently on heat and mortality, the focus has been on methodological issues and

12 approaches [2] and on climatology [3], leaving a number of important epidemiologic

13 ~~issues~~ ~~studies excluded~~ ~~largely unaddressed~~. Many studies ~~of~~ ~~included in the previous~~

14 ~~review of~~ ambient temperature and mortality did not account for air pollutants, and in the

15 previous review [1], it was not clear from the few studies conducted whether air

16 pollutants acted as confounders, effect modifiers, or both. It is critical to separate the

17 independent effects of both ambient temperature and air pollutants, since they may

18 often influence each other on a daily basis. Thus, ~~only after accounting for pollutants in~~

19 ~~the models with ambient temperature~~, the actual association between ambient

20 temperature and mortality can be observed, only after accounting for pollutants in the

21 models with ambient temperature. Furthermore, demographic characteristics, such as

22 poverty and age, can modify the severity of heat effects through various physiological

23 and behavioral pathways. Thus, certain subgroups may be particularly vulnerable to

1 heat effects, and identifying them for specific locations would be beneficial for targeting  
2 public health interventions.

3

4 Here, the epidemiologic evidence from ~~January the past decade~~2001 to September  
5 2008 of high ambient temperature and mortality is summarized, with a closer  
6 examination of studies of the potential effect of air pollution on the temperature-mortality  
7 association as a confounder and/or effect modifier, as well as vulnerable subgroups  
8 of the temperature-mortality association. A general discussion of harvesting-mortality  
9 displacement on the association between temperature and mortality is also included.

10 Mortality displacement (also known as harvesting) refers to the phenomena suggesting  
11 that observed deaths from some environmental exposure, such as ambient  
12 temperature, occur in the most frail individuals whose deaths have only been brought  
13 forward by a few days.

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15

## 16 **Methodological issues**

17

### 18 ***Inclusion/exclusion criteria***

19 All studies included in this review were published in peer-reviewed journals between  
20 January 2001 and December 2008. Pub Med was used to search for the following  
21 keywords: temperature, apparent temperature, heat, heat index, and mortality. In  
22 addition, Table 2 had the keyword “air pollutants,” “ozone,” or “particulate matter”  
23 added, and Table 3 had “vulnerable”, “susceptible subgroups/groups” added. The

1 search was limited to the English language and epidemiologic studies. The review  
2 focused primarily on quantitative studies of ambient temperature, consisting of studies  
3 using the time-series and/or case-crossover methods. The outcomes from these  
4 studies generally reported a regression coefficient, relative risk (time series), odds ratio  
5 (case-crossover), or percent change in mortality, along with corresponding standard  
6 errors or confidence intervals. Studies that reported mortality counts or excess deaths  
7 following heat waves were excluded so that the focus remained on general ambient  
8 temperature exposure in a variety of locations, rather than on short time periods.  
9 Review articles or sStudies focusing on cold temperature effects -were also excluded.  
10 ~~Thirty-eight~~ Thirty-six studies published in peer-reviewed journals were selected for this  
11 epidemiologic review, with 5764 total studies in the references that included a general  
12 discussion of temperature and mortality.

13

#### 14 ***Exposure assessment***

15

16 Temperature data are often measured near airport monitoring stations, and analyzed at  
17 the city or county level. Thus, misclassification of exposure may occur, especially for  
18 larger geographic areas. Also, measuring ambient temperature outside of urban areas  
19 may artificially reduce the temperature measurement, since urban areas often have  
20 higher temperatures than suburban or surrounding areas because of heat absorbed by  
21 buildings and roadways (known as the urban heat-island effect). However, since the  
22 bias should be non-differential (i.e., not different by county or other unit of analysis), the  
23 bias in the estimate would be toward the null, where the results would be

1 underestimated. Misclassification of exposure may be reduced in future studies by  
2 using smaller buffer zones, such as five or ten kilometers around each monitor, if  
3 sufficient data are available.

4  
5 Exposure to ambient temperature is often defined as some combined metric of  
6 temperature and relative humidity or dew point temperature, such as heat index,  
7 humidex, or apparent temperature, depending on the study location and author's  
8 preference. In addition, other variables, such as day of the week, time trend, and  
9 barometric pressure, are often added to the model. In some studies, air pollutants have  
10 been assessed as confounders or effect modifiers in an attempt to tease apart the  
11 independent effect of temperature. A monitor or an average of monitors is often used to  
12 characterize exposure for a county, or a given distance from the home address using  
13 geospatial coding. Many investigators relied on mean daily average to classify  
14 exposure, although others used maximum or minimum temperature to capture daytime  
15 and nighttime exposures, respectively, since those have also been shown to play a role  
16 in heat-related mortality. Because the effect of temperature has been found to be  
17 immediate (i.e., same lagged day), exposure can be characterized by the place of  
18 death.

19

### 20 ***Case selection***

21

22 H~~Since~~ heat-related mortality is ~~still~~ often underestimated, and since a systematic  
23 definition still does not exist, it may only be indicated when heat waves occur, resulting

1 in (a signal detection bias). Thus, investigators often use all-cause mortality excluding  
2 mortality due to accidents, or other related outcome, such as mortality from  
3 cardiovascular or respiratory diseases in epidemiologic studies of heat or elevated  
4 ambient temperature. The underlying cause of death is usually used for epidemiologic  
5 studies and should be sufficient for characterizing the temperature-mortality association,  
6 although associated causes of death can also be used, ~~although the immediate cause~~  
7 ~~of death may be more useful since the effect of heat is imminent.~~

8  
9 The studies to date are often limited by information provided by the death certificate  
10 data. For example, information on income level, poverty, or air conditioning use is not  
11 offered on the individual level, so it is difficult to examine socioeconomic status. Thus,  
12 gathering data on individual characteristics, as has been done in a previous study [4],  
13 would be informative. In addition, medication use, time-activity patterns, and biologic  
14 mechanisms could be further understood.

15

## 16 ***Study design***

17

18 Most of the studies conducted in the past decade rely on the time-series or case-  
19 crossover study designs, with the exception of the studies of the 2003 European heat  
20 wave, which are not included in this review. Regardless of the method chosen, the  
21 time-series and case-crossover study designs should yield similar results, as has been  
22 shown in some temperature-mortality studies [5-7][4-6].

23

1 The time-series is a widely accepted approach in both air pollution and temperature  
2 studies, ~~while the case-crossover design has been employed more recently~~. The time-  
3 series study generally encompasses large populations in multiple geographic areas  
4 over a given time period, ~~Mortality where mortality~~ counts or rates are compared to  
5 exposure measurements collected at regular time intervals (e.g., daily, weekly), ~~usually~~  
6 ~~daily~~. Seasonality and other confounding factors that fluctuate over time are accounted  
7 for by adding the covariates to the model (i.e., day of the week, air pollutants) and using  
8 smoothing functions to the model using specified degrees of freedom.

9  
10 The ~~case-crossover design has been employed more recently, gaining widespread~~  
11 ~~popularity for studying air pollution and temperature in the past decade. This case-~~  
12 ~~crossover~~ study design is similar to a matched case-control study; however, each case  
13 in the case-crossover study serves as his/her own control. Thus, biases due to  
14 measured and unmeasured confounders, such as genetics, health behaviors, and  
15 physiologic differences, are ~~-~~ controlled for by study design. The case-crossover study  
16 design has been refined since its introduction in 1991, from the unidirectional, to the  
17 bidirectional, and ~~most recently~~ currently, to the time-stratified approach. The time-  
18 stratified approach limits the bias from selecting control periods only previously to the  
19 case period (unidirectional), or from not selecting control periods at random from the  
20 time at which the case occurred (bidirectional). Most commonly, control periods are  
21 selected within the same month and the same year that the case period occurred in the  
22 time-stratified approach to inherently minimize biases that may occur from time trends.  
23 Day of the week is also matched for by study design by choosing control periods every

1 seven days, or may be added to the model as an indicator variable, especially if data  
2 are sparse (e.g., if using particulate matter in the model, data are often collected every  
3 third day, and thus, would warrant control periods to be selected every third day).—In  
4 the studies listed in the following tables, all case-crossover studies used the time-  
5 stratified approach.

6  
7 Multi-city analyses are preferred, since bias from a single city analysis may result and  
8 the findings from multiple areas may be more generalizable [6]. Thus, city or county-  
9 level estimates are usually combined into one overall estimate using meta-analytic  
10 techniques using a random effects model.

11

### 12 ***Mortality displacement***

13

14 In epidemiologic studies of temperature or air pollution and mortality or morbidity,  
15 mortality displacement/harvesting has been addressed in several different ways [8-13].  
16 Among the more intuitive approaches, one can examine very long cumulative averages  
17 (i.e., 20 to 40 days of exposure) to determine whether a positive association found over  
18 the first few days is offset by a negative association over subsequent days. This would  
19 suggest that a pool of frail individuals was the only or major subgroup that was impacted  
20 by the exposure. However, if harvesting is not found, then the exposure under study is  
21 a real public health issue.

22

1 In studies of temperature and mortality, very few studies have addressed the harvesting  
2 issue. The evidence is mixed and may depend on: (1) whether one is examining heat  
3 waves versus a more general rise in temperature; (2) the study design and lag structure  
4 used for temperature effects; (3) the potential interactions with air pollution; (4) the  
5 baseline health status of the population; (5) the population at risk; and (6) other local  
6 factors that might determine vulnerability.

### 7

### 8 **Summary of Studies Results**

9

10 Fourteen studies were epidemiologic studies of ambient temperature and mortality,  
11 while 14 other studies considered air pollutants as potential confounders/effect  
12 modifiers, and six considered vulnerable subgroups. Most of these studies used either  
13 the time-series method (n = 29), while fewer used the case-crossover approach (n =  
14 10). Eleven studies were conducted in the US. Ten studies were published using  
15 European data, three in Latin America, three in Australia, two in Canada, and  
16 elsewhere. The studies are all summarized in the following Tables 1 to 3 by year of  
17 publication, with the most recent studies first, followed by alphabetical order of the first  
18 author's last name. Since some studies included an examination of general ambient  
19 temperature and mortality, accounted for air pollutants, and/or identified vulnerable  
20 subgroups, the same study may be listed in multiple tables with the relevant results.

21

### 22 ***General Ambient Temperature and Mortality***

23

1 In Table 1, the recent studies of high ambient temperature and mortality are  
2 summarized. To focus on the effects of warmer temperatures, most investigators  
3 limited their data above a threshold value ~~around 29C (equivalent to 85F)~~, or have  
4 compared ~~the~~ effect estimates from temperatures above a threshold value to another  
5 lower value ~~those effects from lower temperatures (i.e., 1<sup>st</sup> or 5<sup>th</sup> percentile)~~. The  
6 threshold value is often ~~established a priori or~~ based on some percentile of the data  
7 (i.e., 90<sup>th</sup> or 95<sup>th</sup> percentile), after visual inspection of the exposure-response curves or  
8 by mathematical (i.e., through derivatives) or statistical (i.e., by maximum likelihood)  
9 methods. The data are often limited to the summer months or warm season to establish  
10 heat effects. Limiting the data to summer months or the warm season is also employed  
11 to exclude possible (negative or positive) effects from cold temperatures on mortality in  
12 the attempt to estimate the actual risk from heat effects. Because of these several  
13 classifications of temperature exposure, it is difficult to directly compare the values  
14 resulting from these studies. However, few comparisons can be made. For example, in  
15 Europe and Korea, where different levels of temperature and humidity ~~levels~~ were  
16 experienced, ~~and therefore, different acclimatization patterns exist~~, the mortality  
17 estimates above a threshold of (23.3C to 29.7C) resulted in different effect estimates  
18 [12][7]. With similar threshold values in the Mediterranean (29.4C) and Korea (27-  
19 29.7C), a 1C increase of apparent temperature corresponded to a 3.12% increase in  
20 daily mortality in Mediterranean cities, and a much higher effect in Korea (6.73%-16.3%  
21 in 6 cities) for a similar time period. Two recent studies conducted by Basu et al. [6,  
22 14][5, 8] and Zanobetti and Schwartz [7][6] using identical methods suggested that the  
23 effect estimates throughout California and other parts of the US are similar, even with

1 different ranges of apparent temperature. They both found approximately a 2%  
2 increase in mortality associated with a 10F increase in apparent temperature.

3

#### 4 ***Air Pollutants as Confounders/Effect Modifiers***

5

6 Table 2 includes recent studies that have evaluated air pollutants as a potential  
7 confounder and/or effect modifier of the high ambient temperature and mortality  
8 association. The pollutants that have been examined include ozone (O<sub>3</sub>O<sub>3</sub>), particulate  
9 matter less than 10 ug/m<sup>3</sup> in aerodynamic diameter (PM<sub>10</sub>), fine particulate matter  
10 (PM<sub>2.5</sub>PM<sub>2.5</sub>), carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), and nitrogen dioxide (NO<sub>2</sub>).

11 Most investigators who considered pollutants evaluated PM and O<sub>3</sub>O<sub>3</sub>, since these  
12 pollutants have been found to be associated with mortality and are often correlated with  
13 high temperature. ~~The results remain mixed, with some investigators reporting air  
14 pollutants as confounders or effect modifiers while others reported no significant  
15 confounding or effect modification in their studies.~~

16

17 Although the effect estimates changed with pollutants in the model, no significant  
18 confounding [15][9] or effect modification by pollution on the association between  
19 temperature and mortality was reported in some recent studies conducted in the US [6,  
20 7][5,6]. The studies conducted by Bell et al. and Zanobetti and Schwartz considered  
21 PM<sub>10</sub> (as well as PM<sub>2.5</sub>PM<sub>2.5</sub> in the Zanobetti and Schwartz study) and O<sub>3</sub>O<sub>3</sub>, while the  
22 study by Basu et al. considered O<sub>3</sub>O<sub>3</sub>, PM<sub>2.5</sub>PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, CO, and SO<sub>2</sub>.  
23 Stafoggia [16] and Rainham and Smoyer-Tomic [17] also reported no confounding by

1 O<sub>3</sub> in Italy and Canada, respectively, and Pattenden did not find confounding by markers  
 2 of PM in both Sofia (total suspended in particulates) and London (black smoke).  
 3 However, PM<sub>10</sub> was found to be confounder in Monterrey, Mexico [18][10], Sydney,  
 4 Australia [19], and in regions throughout the United States, especially in the summer  
 5 [5][4]. Ren and Tong, and an effect modifier in Australia [20][11] also observed PM10 to  
 6 modify the association in their study conducted in Brisbane, Australia. O<sub>3</sub>O<sub>3</sub> was found  
 7 to be a confounder especially on hot days [18, 21][10, 12], a but not in another Italian  
 8 study [16][13], and three other investigators studies also showed O<sub>3</sub>O<sub>3</sub> to be a positive  
 9 effect modifier of temperature and mortality, at least in some study locations [22-24][14-  
 10 16] [22, 23].

11  
 12 The results for confounding and/or effect modification by air pollutants on the  
 13 temperature-mortality association remain mixed; as stated, some investigators reported  
 14 air pollutants as confounders or effect modifiers while others found no significant  
 15 confounding or effect modification in their studies.

16

### 17 ***Cause-specific Outcomes and Vulnerable Subgroups***

18

19 Much of the focus of epidemiologic studies has been identifying cause-specific  
 20 outcomes and vulnerable subgroups of mortality from high ambient temperature (Table  
 21 33). Some investigators have examined specific diseases as outcomes, such as  
 22 cardiovascular (CVD), respiratory, cerebrovascular, and diabetes. Education, gender,

1 racial/ethnic group, and indicators for socioeconomic status have also been examined in  
2 fewer studies.

3

4

### 5 Cause-specific outcomes

6 Some investigators have reported greater risks for deaths from cardiovascular  
7 (CVD)CVD [5, 14, 24][4, 8, 17], respiratory [5, 12, 24-26][4, 17, 18], cerebrovascular  
8 [16][13], diabetes [27, 28][19, 20], or pre-existing psychiatric disorders [16, 29, 30][13,  
9 21, 22]. Other studies also showed elevated risk from mortality subcategories of CVD  
10 diseases, such as myocardial infarction [8, 14, 31][8, 23, 24], ischemic heart disease  
11 [14][8], and congestive heart failure [14, 30, 32][8, 22, 25],

12

### 13 Age

14 Age has been found to modify the association between ambient temperature and  
15 mortality. The elderly have been~~were~~ reported to be at greater risk from mortality  
16 following heat waves, as well as ambient temperature. In addition to the elderly who  
17 were at least 75 years [12], 70 years [31][23] or 65 years [5, 14, 15, 19, 24-26, 33, 34][4,  
18 8, 9, 17, 18, 26] of age, children under 15 years [18, 33][10, 26], children five years and  
19 younger [14][8], and infants one year of age and under [14, 35][8, 27] have been  
20 identified to be at increased risk for mortality from high ambient temperature. One  
21 investigator also reported 15 to 64 years of age to be at a significantly increased risk,  
22 although still lower than the elderly or young children [33][26].

23

## Gender

Modifications by gender has also been studied, and some investigators reported no difference by gender [14][8], while others found men in Santiago and Sao Paulo [15][9] specifically for circulatory causes [35][27] or women in various locations [15-17, 19, 24, 36][9, 13, 17, 28, 29] to be at higher risk for mortality.

## Race/ethnic group

Other recent epidemiologic studies also reported Black racial ethnic group [14, 37][8, 30] and non-Whites [28][20] to be at greater risk than Whites in the US. Hispanic subgroups, however, have not been identified as being at greater risk in one study, partially explained by more social networking among this ethnic group [14][8].

## Socioeconomic factors

Other factors that provoked greater risk included indicators for lower socioeconomic status, including the less educated, persons living in lower income areas [16][13] and dying out of the hospital [14, 27, 38][8, 19, 31]. Also, increased poverty [39], and lack of air conditioner [11, 37, 39] or heater [39] were observed risk factors. However, lower socioeconomic status [33][26] and education level were not found to be a risk factor in all studies [14][8].

## Latitude Variations

1 Some studies reported variation by latitude, supporting the evidence for acclimatization.  
2 People who live in cities where the temperatures are generally elevated in the summer  
3 were found to have higher minimum mortality temperatures, or less risk given the same  
4 level of temperature, than people who live in cities with milder climates [7, 21, 39]. A  
5 similar finding was reported in California, where slightly higher estimates were found for  
6 coastal counties where milder temperatures are generally experienced [6]. Although  
7 coastal areas in California are usually more expensive, many of the homes lack air  
8 conditioning, since they have not been needed. Therefore, air conditioning prevalence  
9 is not an indicator of socioeconomic status in California, as it is in the remainder of the  
10 U.S.

11 ~~——— *Harvesting*~~

12  
13 ~~Harvesting refers to the phenomena suggesting that observed deaths from some~~  
14 ~~environmental exposure occur in the most frail individuals whose deaths have only been~~  
15 ~~brought forward by a few days. In epidemiologic studies of temperature or air pollution~~  
16 ~~and mortality, harvesting has been addressed in several different ways [9, 10][32, 33].~~  
17 ~~Among the more intuitive approaches, one can examine very long cumulative averages~~  
18 ~~(i.e., 20 to 40 days of exposure) to determine whether a positive association found over~~  
19 ~~the first few days is more than offset by a negative association over subsequent days.~~  
20 ~~This would suggest that a pool of frail individuals was the only (or major) group that was~~  
21 ~~impacted by the exposure. Such a phenomenon would have important consequences~~  
22 ~~for attempts to apply economic valuation to this outcome since it would indicate that the~~  
23 ~~lost of life was on the order of a few days, rather than several years.~~

1  
2 In studies of temperature and mortality, very few studies have addressed the harvesting  
3 issue. Braga et al. [8, 11][24, 34] considered the effect of temperature on various  
4 causes of mortality, and reported a harvesting effect on very hot days, but not on cold  
5 days. Schwartz et al. [38][35] reached a similar conclusion in their study of temperature  
6 and hospitalizations for myocardial infarction. In another study, a similar effect was  
7 found in Sofia, but for both cold and hot temperatures, and less of a harvesting effect  
8 was observed at high temperatures in London [39][36] and Dublin [40][37]. In a study of  
9 Sao Paulo, Delhi and London, Hajat et al. [41][38] reported mixed results. Short-term  
10 mortality displacement was apparent in London, but in both Delhi and Sao Paulo, the  
11 risk for mortality remained high at comparatively longer lag periods, partially due to the  
12 larger impact on infants and children. Among the several studies following the 2003  
13 European heat wave, Le Tertre et al. [42][39] examined the possibility of harvesting in 9  
14 French cities, and concluded that the harvesting effect was not found, and thus, could  
15 not solely explain the excess mortality (determined by the number of observed cases  
16 subtracted from the number of expected cases based on previous years). Toulemon  
17 and Barbieri [43][40] reported a modest harvesting effect following the 2003 heat wave  
18 and attributed most of the deaths in the elderly to other factors, such as social isolation.  
19 In Germany, harvesting did not play a role for all-cause or respiratory mortality, but have  
20 impacted deaths due to neoplasms [44][41].

21  
22 Thus, the evidence is mixed and may depend on: (1) whether one is examining heat  
23 waves versus a more general rise in temperature; (2) the study design and lag structure

1 ~~used for temperature effects; (3) the potential interactions with air pollution; (4) the~~  
2 ~~baseline health status of the population; (5) the population at risk; and (6) other local~~  
3 ~~factors that might determine vulnerability.~~

4

## 5 ConclusionsDiscussion

6

7 In the past few years, several epidemiologic studies have been conducted in various  
8 locations to characterize temperature and mortality. In the US, similar effects were  
9 found in nine counties in California and in nine counties outside of California in two  
10 separate studies using the same methods [6, 7][5, 6]. In Europe and Korea, however,  
11 the effect estimates were larger [12, 40][7, 42], further supporting the need to conduct  
12 temperature-mortality studies for specific areas. The results from future studies can be  
13 more readily compared if estimates are reported per degree Celsius or Fahrenheit per  
14 unit change in temperature (assuming linearity), or if a regression coefficient is given,  
15 rather than selecting a threshold value for temperature. In addition, investigators should  
16 consider accounting for air pollutants and identifying vulnerable subgroups in their  
17 epidemiologic studies.

18

19 The recent epidemiologic evidence suggests that PM and O<sub>3</sub> ~~may be~~ both  
20 confounders, and some studies also found O<sub>3</sub> to be an effect modifier in the warmer  
21 months. In other words, the association between temperature and mortality is partially a  
22 result of the effect of confounding by PM and O<sub>3</sub>. However, this confounding effect is  
23 relatively small, and there is clearly an independent effect of both temperature and air

1 pollution on mortality. Others have reported that temperature has a greater effect on  
2 mortality with higher levels of O<sub>3</sub> (i.e., synergism). Some of the conflicting evidence  
3 for confounding and effect modification by air pollutants may be due to high correlations  
4 between pollutants and temperature, making it difficult to tease apart the independent  
5 effects of either exposure. Also, different sources, chemistry, size distribution of  
6 particles, compositions and patterns of exposure [41][43] of gases and particles are  
7 observed throughout the US and elsewhere. Although O<sub>3</sub> generally peaks in the  
8 summer throughout the US, for example, particulate matter peaks in the winter in  
9 California and in the summer on the East Coast. Thus, there would more likely be an  
10 impact of PM on elevated ambient temperature and health outcomes on the East Coast.  
11 Acclimatization may also play a critical role in the temperature-mortality association.  
12 People who live in areas where high ambient temperatures or heat waves are typically  
13 experienced may be less affected than people who reside in areas where high ambient  
14 temperatures are less commonly observed. Thus, even if there is effect modification  
15 between ambient temperature and a pollutant, such as O<sub>3</sub>, the influence on mortality  
16 may be minimal, but synergistic in areas where heat waves are uncommon.

17  
18  
19 Several vulnerable subgroups have been identified. Many of these outcomes and  
20 vulnerable subgroups have not been identified in previous epidemiologic studies of  
21 ambient temperature and were dependent on the location and study population. Thus,  
22 region-specific policies, especially in urban areas, are vital to the mitigation of heat-  
23 related deaths. Specifically, those dying from cardiovascular, respiratory, and some

1 specific cardiovascular diseases, such as ischemic heart disease, congestive heart  
2 failure, and myocardial infarction were at greater risk for heat-related mortality. Other  
3 vulnerable subgroups included: Black racial/ethnic group, women, those with lower  
4 socioeconomic status, and all age groups, particularly the elderly over 65 years of age  
5 as well as infants and young children.

6  
7 Infants, ~~and~~ young children, and the elderly should be specifically targeted in future  
8 studies to prevent heat-related mortality. With the elderly increasing in urban  
9 environments, an important research goal is the identification of clinical patterns of  
10 chronic diseases that increase the susceptibility to heat. Furthermore, vulnerable  
11 subgroups need to be further identified by cause-specific outcomes or demographics,  
12 such as racial/ethnic group. Furthermore, adverse birth outcomes have been found to  
13 be associated with air pollutants in previous studies, but have not been investigated,  
14 specifically for ambient temperature. Although previous studies of air pollution and birth  
15 outcomes have not accounted for temperature, some investigators have suggested  
16 seasonal associations, implying that temperature could also play a role with adverse  
17 birth outcomes and warrants further investigation.

18  
19 ~~There is less known about morbidity associated with temperature, and because few of~~  
20 ~~the outcomes examined have enough overlap across studies, it is difficult to come up~~  
21 ~~with a consensus of the results. Following the Chicago heat wave in July 1995,~~  
22 ~~Semenza et al. [47][44] found an excess risk of dehydration and heat stroke as primary~~  
23 ~~diagnoses and CVD, renal disease and diabetes as underlying causes. Hansen et al.~~

1 ~~[48][45] also found an association with renal disease and mental health [49][46] in~~  
2 ~~Australia. Other investigators also reported increased associations with other CVD~~  
3 ~~outcomes, such as acute myocardial infarction [28, 38, 50][20, 35, 47], congestive heart~~  
4 ~~failure [50][47], and coronary atherosclerosis [50][47]. Ischemic, but not hemorrhagic~~  
5 ~~[51][48] stroke, and pulmonary heart disease [50][47] were also found to have elevated~~  
6 ~~associations in Glasgow, Scotland and Denver, Colorado, respectively. Further~~  
7 ~~research of morbidity can be assessed by examining emergency room/urgent care visits~~  
8 ~~and hospitalizations.~~

9  
10 ~~Although many studies of temperature have been conducted in other disciplines such as~~  
11 ~~climatology, they have received greater attention in epidemiology in the past five years.~~

12 Several biological mechanisms have been postulated for susceptible populations to  
13 heat-related mortality, particularly the elderly [42][49]. When body temperatures rise,  
14 blood flow generally shifts from the vital organs to underneath the skin's surface in an  
15 effort to cool down. The body's ability to regulate its temperature (also known as  
16 thermoregulation) may be impeded when too much blood is diverted, putting increased  
17 stress on the heart and lungs. Increased blood viscosity, elevated cholesterol levels  
18 associated with higher temperatures, and higher sweating threshold may also trigger  
19 heat-related mortality [43][50]. The body's ability to adapt to high ambient temperature  
20 can be influenced by acclimatization. People who live in areas where high ambient  
21 temperatures are not generally experienced are more likely to be affected by a heat  
22 wave. The synergistic impact of high ambient temperature along with high levels of air  
23 pollutants, such as O<sub>3</sub> and PM, may also play a role in increasing the mortality effect.

1 Furthermore, heat waves occurring earlier in the year may have a greater impact on  
2 mortality since the population has not had the chance to adapt to hotter temperatures.

3  
4 ~~The studies to date are often limited by information provided by the death certificate~~  
5 ~~data. For example, information on income level, poverty, or air conditioning use is not~~  
6 ~~offered on the individual level, so it is difficult to examine socioeconomic status.~~  
7 ~~Gathering data on individual characteristics, as has been done in a previous study~~  
8 ~~[4][51], would be informative. In addition, medication use, time-activity patterns, and~~  
9 ~~biologic mechanisms could be further understood. Since temperature has often been~~  
10 ~~examined on the county level in most studies, misclassification of exposure may occur,~~  
11 ~~especially for larger counties. However, since the bias should be non-differential (i.e.,~~  
12 ~~not different by county or unit of analysis), the bias in the estimate would be toward the~~  
13 ~~null, where the results would be underestimated.~~

14  
15 This review is timely as climate change receives more global attention, and more  
16 epidemiologic studies have been recently conducted. It, however, has several  
17 limitations. While it includes the most recent epidemiologic studies using time-series  
18 and case-crossover methods, it does not include studies of heat waves or studies using  
19 other approaches in an effort to focus on general ambient temperature over longer time  
20 periods. Both methods rely on ecologic exposure variables for temperature, and the  
21 time-series analysis also uses aggregated counts of mortality. Thus, an advantage of  
22 the case-crossover study is that differences by individual-level characteristics such as  
23 age, race/ethnic group, gender can be analyzed. Although the methods used across  
24 studies were similar, it was still often difficult to compare estimates between studies

1 because of the analysis type (e.g., different threshold values). There were also not a  
2 sufficient number of studies to conduct a meta-analysis of the results, or other more  
3 substantial quantification. Finally, there may be some publication bias in the studies  
4 that were chosen, but by using PubMed, the bias may be limited, as it includes most  
5 scientific journals.

6  
7 Further studies need to be conducted in more urban locations so that policies can be  
8 implemented for specific areas rather than for an entire geographic area. These studies  
9 would be helpful to the National Weather Service, -health care institutions, and  
10 governmental agencies to implement policies to prevent heat-related mortality and also  
11 create a better heat warning system based on current studies. They will also be helpful  
12 to establish policy guidelines for the U.S. Environmental Protection Agency (personal  
13 communication), and could be used for economic analyses. Although no formal  
14 evaluation of heat-health watch warning systems has been performed to date, sSome  
15 city-based heat-health watch warning systems ~~that~~ have already been implemented  
16 appear to be successful in greatly reducing mortality following heat waves [44][52].  
17 For example, the 2003 heat wave in Western Europe resulted in 35,000 deaths, but a  
18 warning system is being developed by the World Health Organization so that  
19 subsequent heat waves ~~do not in more recent years did produce not produce~~ such  
20 ~~devastating detrimental results.effects.~~ However, heat-health watch warning systems are  
21 not able to reduce heat-related mortality without a prevention plan targeting vulnerable  
22 subgroups, such as the one being developed by the World Health Organization on  
23 Health Health Action Plans (<http://www.euro.who.int/Document/E91350.pdf>).

1 ~~Since many of these deaths occurred in the elderly in urban areas, the diminished~~  
2 ~~mortality can be partially attributed to the loss of the susceptible population, but also to~~  
3 ~~better heat warning systems especially in the affected areas, such as Western Europe~~  
4 ~~[42, 55, 56][39, 53, 54].~~

5

## 6 **Conclusions**

7

8 ~~There appears to be confounding/effect modification by particulate matter and/or ozone~~  
9 ~~in some studies. Elevated temperature was associated with increased risk for those~~  
10 ~~dying from cardiovascular, respiratory, cerebrovascular, and some specific~~  
11 ~~cardiovascular diseases, such as ischemic heart disease, congestive heart failure, and~~  
12 ~~myocardial infarction. Vulnerable subgroups also included: Black racial/ethnic group,~~  
13 ~~women, those with lower socioeconomic status, and all age groups, particularly the~~  
14 ~~elderly over 65 years of age as well as infants and young children. Many of these~~  
15 ~~outcomes and vulnerable subgroups have not been identified previously and were~~  
16 ~~dependent on the location and study population. Thus, region-specific policies,~~  
17 ~~especially in urban areas, are vital to the mitigation of heat-related deaths.~~

18

19

## 1 List of abbreviations

2 CO carbon monoxide

3 NO<sub>2</sub> nitrogen dioxide

4 O<sub>3</sub> ozone

5 PM particulate matter

6 SO<sub>2</sub> sulfur dioxide

7 C Celsius

8 F Fahrenheit

9 CI confidence interval

10

11

## 12 Competing interests

13 The author declares no competing interests.

14 ~~The opinions expressed in this article are solely those of the author and do not~~  
15 ~~represent the policy or position of the State of California or the California Environmental~~  
16 ~~Protection Agency.~~

17

18

## 19 Author's contributions

20

21 **Rupa Basu** conducted the literature search for this review, specified the inclusion and  
22 exclusion criteria, constructed the tables, and drafted and revised the manuscript for  
23 consideration for publication.

24

## 25 Author's information

26

27 ~~Rupa Basu is currently a research scientist at Office of Environmental Health Hazard~~  
28 ~~Assessment's (OEHHA) Air Pollution Epidemiology section. Prior to joining OEHHA,~~  
29 ~~she worked at the US Environmental Protection Agency, after obtaining her PhD degree~~  
30 ~~in environmental and occupational epidemiology from The Johns Hopkins University~~  
31 ~~School of Public Health and her Master of Public Health degree with an emphasis in~~  
32 ~~environmental health at UCLA. Dr. Basu's research has focused on various~~  
33 ~~epidemiologic methods to examine environmental exposures, including estimating the~~  
34 ~~independent effects of air pollution and temperature on mortality, assessing the effects~~  
35 ~~of heat exposure on the elderly, and examining the effects of air pollution on birth~~  
36 ~~weight. She has also published a review on the health effects of indoor nitrogen dioxide~~  
37 ~~from exposure to gas stoves and a previous review of heat-related mortality.~~

38

39

40

41

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1  
2 The opinions expressed in this article are solely those of the author and do not  
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4 Protection Agency.

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1 **Table 1: Recent Studies of High Ambient Temperature and Daily\* Mortality**

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Reference	Study <u>location</u> <u>population</u>	Method	Exposure	Result: <u>effect estimate (95% CI)</u>
Baccini 2008 [12][7]	15 European cities, <u>June</u> <del>April</del> - <u>August</u> <u>September</u> 1990- 2000 (5-11 years depending on data availability for city)	Time-series; <u>% change</u>	Maximum apparent temperature (threshold 29.4C Mediterranean cities and 23.3C north- continental cities)	1C increase above threshold 3.12% (0.60- 5.72%) in Mediterranean and 1.84% (0.06- 3.64%) in north-continental region  <u>Lag: 3 days prior</u>
Basu 2008 [6][5]	9 California counties, May to September 1999-2003	Time-series and case-crossover; <u>% change</u>	Daily apparent temperature (minimum, mean, maximum); daily mean <del>O<sub>3</sub></del> <u>O<sub>3</sub></u> , PM <sub>2.5</sub> , PM <sub>10</sub> , NO <sub>2</sub> , CO, SO <sub>2</sub>	<u>Per 10 F increase mean temperature, 2.3</u> <u>(1.0-3.6), similar results for minimum and</u> <u>maximum temperatures</u>  <u>Lag: 0</u>
<u>Bell 2008</u> <u>[15]</u>	<u>Sao Paulo, Brazil,</u> <u>Santiago, Chile and</u> <u>Mexico City, Mexico,</u> <u>1998-2002</u>	<u>Case-crossover; %</u> <u>change</u>	<u>All-cause daily mortality</u>	<u>2.69 (-2.06, 7.88) for Santiago, 6.51% (3.57,</u> <u>9.52) for Sao Paulo and 3.22% (0.93, 5.57)</u> <u>for Mexico City</u>  <u>Lag: 0</u>
McMichael 2008 [45][55]	Delhi, Monterrey, Mexico City, Chiang Mai, Bangkok, Salvador, Sao Paulo, Santiago, Cape Town, Ljubljana, Bucharest, Sofia, 2 to 5-year series (1991-1999)	Time-series; <u>%</u> <u>change</u> ( <del>Poisson</del> <del>models with season,</del> <del>humidity, pollution,</del> <del>day of the week and</del> <del>holidays)</del>	Daily maximum, <del>minimum</del> <del>temperature, threshold (16C-</del> <del>31C) temperature,</del> relative humidity, precipitation data, PM <sub>10</sub> , BS, or TSP	<u>1C increase above threshold</u> <u>increased</u> <del>increasing</del> death rates with increasing heat in all cities: <u>(ranging from</u> <u>0.77-18.8)</u> except Chiang Mai <u>2.39 (-0.49-</u> <u>5.35)</u> and Cape Town <u>0.47 (-0.31-1.24)</u>  <u>Lag: 2-day average ; threshold 16C-31C,</u> <u>generally higher in cities with warmer climates</u> <u>(also cold effects, unrelated to climate)</u>
<u>Vaneckova</u> <u>2008a [46]</u>	<u>Sydney, Australia,</u> <u>October to March</u> <u>1993-2001</u>	Time-series; <u>ratio of</u> <u>highest 10% mortality</u> <u>days within air mass</u> <u>and % frequency of</u> <u>air mass occurrence</u>	<u>Temporal Synoptic Index (TSI)</u>	<u>1.64 and 2.64 (both significant) for warmest</u> <u>TSIs, no CI provided</u>
Zanobetti and Schwartz 2008 [7][6]	9 U.S. counties, May to September 1999- 2002	Time-series and case-crossover; <u>% change</u>	Daily apparent temperature (minimum, mean, maximum); daily mean O <sub>3</sub> , PM <sub>2.5</sub> , PM <sub>10</sub>	<u>Per 10F increase mean temperature, 1.8</u> <u>(1.09-2.5) case-crossover and 2.7 (2.0-3.5)</u> <u>time-series; similar results for minimum and</u> <u>maximum temperatures</u>

				<u>Lag: 0</u>
<u>Barnett 2007 [47]</u>	<u>107 U.S cities using data from the National Morbidity and Mortality Study, 1987-2000</u>	<u>Case-crossover; % change</u>	<u>Daily temperature</u>	<u>Per 10 F, summer 1987 average increase in cardiovascular deaths was 4.7 (3.0-6.5). By summer 2000, the risk with higher temperature had disappeared (-0.4, -3.2-2.5)</u>  <u>Lag: 04</u>
<u>Medina-Ramon 2007 [21]</u>	<u>50 US cities in cold (November to March) and warm (May to September) seasons</u>	<u>Case-crossover; % change</u>	<u>Binary variable as extreme heat (range 22-32C) and continuous; O<sub>3</sub></u>	<u>5.74 (3.38-8.15) for extreme heat</u>  <u>Lag: 2-day average</u>
<u>Kolb 2007 [32]</u>	<u>Montreal, Canada 1984-1993</u>	<u>Case-crossover; odds ratio</u>	<u>Mean daily and maximum temperature, barometric pressure, relative humidity, adjusted for O<sub>3</sub> and both NO<sub>2</sub> and O<sub>3</sub></u>	<u>1.20 (1.14-1.38) for 25-30C maximum temperature; strong nonlinear association with a threshold at 25C</u>  <u>Lag: average 02; no association after 3 days</u>
<u>Carson 2006 [52]</u>	<u>London, England, 4 time periods, winter: December-March; non-winter: April-November</u>	<u>Time-series; ratio of winter to non-winter deaths</u>	<u>Daily mean temperature</u>	<u>1.24 (1.16-1.34) from 1900-10, ; 1.54 (1.42, 1.68) from 1927-37, 1.48 (1.35,-1.64) from 1954-64, 1.22 (1.13-1.31) from 1986-96; heat deaths diminished overall in the century</u>
<u>Kim 2006 [40][42]</u>	<u>6 cities in South Korea, summer 1994-2006</u>	<u>Time-series; % change</u>	<u>Daily mean temperature thresholds (27-29.7C)</u>	<u>1 C above threshold 16.3% (14.2, 18.4), 9.10% (5.12, 13.2), 7.01% (4.42, 9.66), 6.73% (2.47, 11.2) for Seoul, Daegu, Incheon and Gwangju, respectively, for daily mean temperature 1C above threshold</u>
<u>Le Tertre 2006 [42][39]</u>	<u>9 French cities, August 2003 heat wave</u>	<u>Time-series</u>	<u>Temperature terms with added heat wave term</u>	<u>3,096 excess deaths; RR for excess deaths ranged from 1.16 to 5.00</u>
<u>Michelozzi 2006 [48][56]</u>	<u>4 Italian cities, June to September 2003 &amp; 2004 and reference period (Roma, Torino, Milano: 1995-2002 and Bologna: 1996-2002)</u>	<u>Time-series; % change</u>	<u>Daily maximum apparent temperature thresholds (28-32C)</u>	<u>Greatest variation in mortality in 2003 for all cities; increase also at 26-28C for Torino and Roma 1 C above threshold 3.2 (1.9-4.6), 5.0 (3.8-6.1), 5.4 (4.3-6.5), 3.8 (2.5-5.0) for Bologna, Milano, Roma, and Torino, respectively</u>
<u>Conti 2005 [56][54]</u>	<u>21 capitals of Italian regions, June to August 2003</u>	<u>Comparison of mortality counts to 2002</u>	<u>Humidex</u>	<u>3,134 excess deaths; greatest increase among elderly and NW cities</u>

<a href="#">Grize 2005 [55][53]</a>	<a href="#">Switzerland, January 1990-December 2003</a>	<a href="#">Excess mortality from 2003 heat wave</a>	<a href="#">Daily mean, minimum, maximum temperature, mean/maximum PM10, O3, NO2</a>	<a href="#">7% increase June to August 2003; mostly in region north of Alps with combination of day temperature above 35C and night temperature above 20C</a>	
<a href="#">Davis 2003 [61][57]</a>	<a href="#">28 US metropolitan areas, 1964-1998</a>	<a href="#">Annual excess mortality</a>	<a href="#">Threshold for apparent temperature</a>	<a href="#">41.0 (SE 4.8) per million in the 1960s and 70s, 17.3 (2.7) in the 80s and 10.5 (2.0) in the 90s in combined analysis</a>	
<a href="#">Stafoggia 2006 [16]</a>	<a href="#">Bologna, Milan, Rome, Turin, 1997-2003</a>	<a href="#">Case-crossover; odds ratio</a>	<a href="#">30C mean apparent temperature relative to 20C; odds ratio</a>	<a href="#">1.34 (1.27, 1.42)</a> <a href="#">Lag: 01</a>	
<a href="#">Basu 2005 [5]</a>	<a href="#">20 US metropolitan areas, seasonal analysis 1992</a>	<a href="#">Time series (relative risk) and case-crossover (odds ratio)</a>	<a href="#">Mean daily temperature per 10F adjusted for dew point temperature; daily O3</a>	<a href="#">Per 10F, 1.15 (1.07-1.24), 1.10 (0.96-1.27), 1.08 (0.92-1.26), 1.08 (1.02-1.15), and 1.01 (0.92-1.11) in the Southwest, Southeast, Northwest, Northeast, and Midwest, respectively, in the summer from the time-stratified case-crossover</a> <a href="#">Lag: 0,1</a>	
<a href="#">El-Zein 2004 [34]</a>	<a href="#">Greater Beirut, Lebanon, 1997-1999</a>	<a href="#">Time-series; % change</a>	<a href="#">Mean daily temperature, mean daily humidity, minimum mortality temperature (TMM)=27.5C</a>	<a href="#">1 C above TMM 12.3 (5.7, 19.4%) increase in annual mortality</a> <a href="#">Lag: 0</a>	
<a href="#">Goodman 2004 [26]</a>	<a href="#">Dublin, Ireland, April 1980 to December 1996</a>	<a href="#">Time-series; % change</a>	<a href="#">Daily minimum temperature, daily mean relative humidity</a>	<a href="#">1 C increase 0.4 (0.3-0.6) increase</a> <a href="#">Lag: 0</a>	
<a href="#">Pattenden 2003 [49]</a>	<a href="#">Sofia, Bulgaria (1996-1999) and London, England (1993-1996)</a>	<a href="#">Time-series; % change</a>	<a href="#">Daily mean temperature, relative humidity and PM (black smoke for London and total suspended particulates for Sofia)</a>	<a href="#">1 C increase above 90th % 1.9 (1.4 to 2.4) in London, and 3.5 (2.2 to 4.8) in Sofia</a> <a href="#">Lag: 2 day average</a>	
<a href="#">Curriero 2002 [39][58]</a>	<a href="#">11 Eastern US cities, 1973-1994</a>	<a href="#">Time-series; % change</a>	<a href="#">Daily mean <del>Models using</del> temperature, dew point temperature; minimum mortality temperature (MMT) range: 65.2-90.3</a>	<a href="#">1 C above MMT range 1.4-6.7J-shaped curve,</a> <a href="#">Lag: 0lag01 most predictive, variations by latitude, SES factors</a>	
<a href="#">Braga 2001 [11][59]</a>	<a href="#">12 US cities. 1986-1993</a>	<a href="#">Time-series; % increase</a>	<a href="#">Mean daily <del>t</del>Temperature, relative humidity (% increase relative to 30C)</a>	<a href="#">4% increase (no CI given);</a> <a href="#">Lag: 0 or 1</a> <a href="#">Harvesting effect for hHot temperatures-effect primarily harvesting effect; neither hot or cold</a>	

				<del>temperatures had much effect in hot cities</del>
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2 ~~\* exceptions: El-Zein 2004 (annual). Carson 2006 (weekly). Table 2: Recent Studies of High Ambient Temperature and Mortality Examining Air~~  
3 ~~Pollution~~  
4 ~~as a Potential Confounder and/or Effect Modifier~~  
5

1 **Table 2: Recent Studies of High Ambient Temperature and Mortality Examining Air Pollutants as Potential Confounders and/or Effect Modifiers**  
2

Reference	Study location	Method	Exposure	Outcome	Result
<a href="#">Basu 2008 [6]</a>	<a href="#">9 California counties, May to September 1999-2003</a>	<a href="#">Time-series and case-crossover</a>	<a href="#">Same day mean apparent temperature; daily mean O<sub>3</sub>, also PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, CO, SO<sub>2</sub>, lag 0 for PM, lag01 for gases</a>	<a href="#">All-cause mortality</a>	<a href="#">Confounders: none found</a> <a href="#">Effect modifiers: none found</a>
<a href="#">Bell 2008 [15][16]</a>	<a href="#">Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-2002</a>	<a href="#">Case-crossover</a>	<a href="#">Same day apparent temperature compared with days at 75<sup>th</sup> percentile, same day lag O<sub>3</sub> same-day lag PM<sub>10</sub> except Santiago lag 1 PM<sub>10</sub></a>	<a href="#">All-cause daily mortality</a>	<a href="#">Confounders: O<sub>3</sub>, PM<sub>10</sub></a> <a href="#">Effect modifiers: not studied</a> <a href="#">Among those 65+ years, 2.69% (-2.06, 7.88) for Santiago, 6.51% (3.57, 9.52) for Sao Paulo and 3.22% (0.93, 5.57) for Mexico City; estimates lowered although still positive after adjusting for ozone</a>
<a href="#">McMichael 2008 [45]</a> <a href="#">McMichael 2008 [42]</a>	<a href="#">Delhi, Monterrey, Mexico City, Chiang Mai, Bangkok, Salvador, Sao Paulo, Santiago, Cape Town, Ljubljana, Bucharest, Sofia, 2 to 5-year series (1991-1999)</a>	<a href="#">Time-series; % increase</a>	<a href="#">Daily maximum threshold (16C-31C) temperature, relative humidity, precipitation data, PM<sub>10</sub>, BS, or TSP</a>	<a href="#">All-cause mortality</a> <a href="#">1C increase above threshold increased death rates with increasing heat in all cities: (ranging from 0.77-18.8) except Chiang Mai 2.39 (-0.49-5.35) and Cape Town 0.47 (-0.31-1.24) for 2-day lag; similar effects for 15-64 years and 65+ years</a>	<a href="#">Confounders: none found</a> <a href="#">Effect modifiers: not studied</a>
<a href="#">Ren 2008 [22]</a>	<a href="#">US 95 NMMAPS counties, June to September 1987-2000</a>	<a href="#">Time-series</a>	<a href="#">Daily maximum temperature (same-day, lag 1), maximum hourly O<sub>3</sub></a>	<a href="#">CVD mortality</a>	<a href="#">Confounders: not studied</a> <a href="#">Effect modifier: O<sub>3</sub></a>
<a href="#">Vaneckova 2008a</a>	<a href="#">Sydney, Australia, October to March 1993-</a>	<a href="#">Time-series</a>	<a href="#">Temporal Synoptic Index (TSI) on the highest 10% mortality</a>	<a href="#">All-cause, circulatory,</a>	<a href="#">Confounders: O<sub>3</sub> on warm, humid days and PM<sub>10</sub> on hot, dry days</a>

<a href="#">[46][58]</a>	2001		days, <u>O<sub>3</sub>, PM<sub>10</sub></u>	<u>cerebrovascular</u> <u>Hot, dry (rare) and</u> <u>warm, humid</u> <u>(more frequent)</u> <u>TSl's highest</u> <u>rates; elderly,</u> <u>women more</u> <u>vulnerable; O<sub>3</sub> on</u> <u>warm, humid</u> <u>days and PM<sub>10</sub></u> <u>on hot, dry days</u> <u>found at high</u> <u>concentrations,</u> <u>but impact</u> <u>unclear</u>	<u>Effect modifiers: not studied</u>	
<a href="#">Vaneckova 2008b [19]</a>	<u>Sydney, Australia,</u> <u>October to March 1993-</u> <u>2004</u>	<u>Time-</u> <u>series</u>	<u>Daily maximum temperature,</u> <u>maximum O<sub>3</sub></u>	<u>Underlying and</u> <u>associated</u> <u>causes of death</u>	<u>Confounders: O<sub>3</sub>, PM<sub>10</sub></u>  <u>Effect modifiers: not studied</u>	
<a href="#">Zanobetti and Schwartz 2008 [7]</a>	<u>9 U.S. counties, May to</u> <u>September 1999-2002</u>	<u>Time series</u> <u>and case-</u> <u>crossover</u>	<u>Daily apparent temperature</u> <u>(minimum, mean, maximum);</u> <u>daily mean O<sub>3</sub>, PM<sub>2.5</sub></u>	<u>All-cause</u> <u>mortality</u>	<u>Confounders: none found</u>  <u>Effect modifiers: none found</u>	
<a href="#">Kolb 2007 [32]</a>	<u>Montreal, Canada 1984-</u> <u>1993</u>	<u>Case-</u> <u>crossover</u>	<u>Mean daily and maximum</u> <u>temperature, barometric</u> <u>pressure, relative humidity,</u> <u>adjusted for O<sub>3</sub> and both NO<sub>2</sub></u> <u>and O<sub>3</sub></u>	<u>Daily mortality</u>	<u>Confounders: none found</u>  <u>Effect modifiers: not studied</u>	
<a href="#">Medina-Ramon 2007 [21][22]</a>	50 US cities in cold (November to March) and warm (May to September) seasons	<u>Binary</u> <u>variable as</u> <u>extreme</u> <u>temperatur</u> <u>e and</u> <u>continuous;</u> <u>O<sub>3</sub>Case-</u> <u>crossover</u>	<u>Binary variable as extreme</u> <u>temperature and continuous; O<sub>3</sub></u>	All-cause and CVD mortality	<u>Confounder: O<sub>3</sub></u>  <u>Effect modifiers: not studied</u> <u>Adjustment</u> <u>for ozone reduced effect of extreme</u> <u>heat and linear hot temperature by 15%</u> <u>and 16%, respectively</u>	
<a href="#">Filleul 2006 [23]</a>	<u>9 French cities, all year</u> <u>and heat wave August</u> <u>2003</u>	<u>Time-</u> <u>series</u>	<u>Minimum and maximum</u> <u>temperature, 8-hour maximum</u> <u>O<sub>3</sub></u>	<u>Daily mortality</u>	<u>Confounders: not studied</u>  <u>Effect modifier: O<sub>3</sub> for some cities</u>	
<a href="#">Ren 2006</a>	<u>Brisbane, Australia (all</u>	<u>Time-</u>	<u>Minimum temperature, daily</u>	<u>Cardiorespiratory</u>	<u>Confounders: not studied</u>	

[50]	<u>year January 1996 to December 2001)</u>	<u>series</u>	<u>PM<sub>10</sub> as modifier</u>	<u>mortality</u>	<u>Effect modifier: PM<sub>10</sub></u>
Stafoggia 2006 [16][17]	Bologna, Milan, Rome, Turin, 1997-2003	<u>Case-crossover</u>	30C mean apparent temperature (lag01) relative to 20C, O <sub>3</sub>	All-cause mortality <u>and</u> previous hospitalization	<u>Confounder:s none found</u> <u>Effect modifiers: not studied</u> <u>Overall OR=1.34 (1.27, 1.42); city-specific summer O<sub>3</sub> not confounder</u>
Basu 2005 [5]	<u>20 US metropolitan areas, seasonal analysis 1992</u>	<u>Time series (and case-crossover)</u>	<u>Mean daily temperature per 10F adjusted for dew point temperature; daily O<sub>3</sub></u>	<u>Individual and daily cardiorespiratory mortality</u>	<u>Confounders: PM<sub>10</sub> in summer</u> <u>Effect modifiers: not studied</u>
O'Neill 2005 [18]	<u>Mexico City (1996-98) and Monterrey (1996-99)</u>	<u>Time series; % change</u>	<u>Heat (35-36C for Monterrey), mean temperature (25C Monterrey, 15C Mexico City), daily O<sub>3</sub></u>	<u>Daily mortality</u>	<u>Confounders: O<sub>3</sub> and PM<sub>10</sub> on hot days</u> <u>Effect modifiers: not studied</u>
Rainham and Smoyer-Tomic 2003 [17]	<u>Toronto, May 1 to September 30, 1980-1996</u>	<u>Time-series; relative risk (RR)</u>	<u>Humidex, O<sub>3</sub>, also CO, NO<sub>2</sub>, SO<sub>2</sub></u>	<u>Daily mortality</u>	<u>Confounders: none found</u> <u>Effect modifiers: not studied</u>
Pattenden 2003 [49]	<u>Sofia, Bulgaria (1996-1999) and London, England (1993-1996)</u>	<u>Time-series; % change</u>	<u>Daily weather (2-day mean) and PM (black smoke for London and total suspended particulates for Sofia)</u>	<u>Daily mortality</u>	<u>Confounders: none found</u> <u>Effect modifiers: not studied</u>

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Reference	Study location	Method	Exposure	Outcome	Result
Basu 2008 [6][5]	9 California counties, May to September 1999-2003	Time-series and case-crossover	Mean daily apparent temperature; daily mean O <sub>3</sub> , PM <sub>2.5</sub> , PM <sub>10</sub> , NO <sub>2</sub> , CO, SO <sub>2</sub>	All-cause mortality	No pollutant examined confounder or effect modifier
Bell 2008 [15][9]	Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-	Case-crossover	Same-day apparent temperature	All-cause daily mortality	Among those 65+ years, 2.69% (-2.06, 7.88) for Santiago, 6.51% (3.57, 9.52) for

	2002				Sao Paulo and 3.22% (0.93, 5.57) for Mexico City; estimates lowered although still positive after adjusting for ozone or PM10
Ren 2008 [23][15]	US 95 NMMAPS counties, June to September 1987-2000	Time-series	Daily maximum temperature (same-day, lag 1), maximum hourly ozone	CVD mortality	Ozone positive effect modifier in some cities; 10C increase in same-day temperature 1.17% and 8.31% increase in mortality for lowest and highest quartile ozone
Zanobetti and Schwartz 2008 [7][6]	9 U.S. counties, May to September 1999-2002	Time-series and case-crossover	Daily apparent temperature (minimum, mean, maximum); daily mean O <sub>3</sub> , PM <sub>2.5</sub> , PM <sub>10</sub>	All-cause mortality	No pollutant examined confounder or effect modifier; lag 0 best fit and strongest effect estimates
Medina-Ramon 2007 [21][12]	50 US cities in cold (November to March) and warm (May to September) seasons	Case-crossover	Binary variable as extreme temperature and continuous; ozone	All-cause and CVD mortality	Adjustment for ozone reduced effect of extreme heat and linear hot temperature by 15% and 16%, respectively
Filleul 2006 [22][14]	9 French cities, all year and heat wave	Time-series	Minimum and maximum temperature,	Daily mortality	Ozone different impact with temperature by

	August 2003		8-hour maximum ozone		city
Ren-2006-[66][60]	Brisbane, Australia (all year January 1996 to December 2001)	Time-series	Minimum temperature, daily PM10 as modifier	Cardiorespiratory morbidity and mortality	PM10 significantly modified temperature and all-cause mortality and CVD mortality
Stafoggia-2006 [16][13]	Bologna, Milan, Rome, Turin, 1997-2003	Case-crossover	30C-mean apparent temperature (lag01) relative to 20C	All-cause mortality and previous hospitalization	Overall-OR=1.34 (1.27, 1.42); city-specific summer ozone not confounder
Basu-2005-[5][4]	20 US metropolitan areas; seasonal analysis 1992	Case-crossover and time-series	Mean daily temperature per 10F adjusted for dew-point temperature; also PM10 and ozone	Individual and daily cardiorespiratory mortality	Strongest associations for summer in SW, SE, NW, NE; both methods similar results; PM10 confounder in summer, not ozone
Dear-2005-[24][16]	12 French cities, June 25-August 23, 2003	Polynomial distributed lag model	Maximum, minimum daily temperature, peak ozone level, humidity, rainfall, wind speed	Mortality	Minimum, maximum temperature and ozone all associated, also had significant interactions
O'Neill-2005 [18][10]	Mexico City (1996-98) and Monterrey (1996-99)	Time-series	% change for heat (35-36C for Monterrey); mean temperature	Daily mortality	Monterrey: adjusted heat effect=18.7% (11.7, 26.1); elevated risk persisted even

			(25C Monterrey, 15C-Mexico City), daily ozone and PM10		with PM10 and ozone; on hot days, ozone and PM10 negative confounders, with larger PM10 effect
Rainham and Smoyer-Tomic 2003-[17][29]	Toronto, May 1 to September 30, 1980-1996	Time-series	Humidex, CO, O3, NO2, SO2	Daily mortality	Total RR=1.061 (1.045, 1.077) for 50-95% and 1.004 (significant) per 1C; pollution not confounder

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Pattenden 2003	Sofia, Bulgaria (1996-1999) and London, England (1993-1996)	Daily weather (2-day mean) and PM (black smoke for London and total suspended particulates for Sofia)			
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1 **Table 33: Recent Studies Identifying Vulnerable Subgroups of Mortality from High Ambient Temperature**

Reference	Study location	Study design	Exposure	Outcome	Result
<a href="#">Baccini 2008 [12]</a>	<a href="#">15 European cities, April-September 1990-2000 (5-11 years depending on data availability for city)</a>	<a href="#">Time-series</a>	<a href="#">Maximum apparent temperature (threshold 29.4C Mediterranean cities and 23.3C north-continental cities)</a>	<a href="#">Daily mortality</a>	<a href="#">Respiratory diseases among 75+ years</a>
<a href="#">Basu and Ostro 2008 [14]</a>	<a href="#">9 California counties, May to September 1999-2003</a>	<a href="#">Case-crossover</a>	<a href="#">Mean daily apparent temperature</a>	<a href="#">Cause-specific mortality; all-cause mortality by age, race/ethnicity, gender, education level</a>	<a href="#">Cardiovascular, higher specifically for ischemic heart disease, myocardial infarction and congestive heart failure, &lt;1 year, &lt;65 years, elderly, Black race, out of hospital death; no elevated risks for cerebrovascular diseases, diabetes, respiratory; no difference by gender or high school graduation</a>
<a href="#">Bell 2008 [15]</a>	<a href="#">Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-2002</a>	<a href="#">Case-crossover</a>	<a href="#">Same day apparent temperature</a>	<a href="#">All-cause daily mortality</a>	<a href="#">65+ years, women in Mexico City, but not in Santiago and Sao Paulo, less educated in Sao Paulo</a>
<a href="#">Ishigami 2008 [24]</a>	<a href="#">Budapest, London and Milan, 2003</a>	<a href="#">Time-series</a>	<a href="#">Mean daily temperature (lag0 and lag1), PM<sub>10</sub> (TSP in Budapest), ozone</a>	<a href="#">Daily mortality</a>	<a href="#">Increased age, females 65+ years greater in London and Milan and non-elderly adults in Milan; mortality from external causes, respiratory and cardiovascular diseases</a>
<a href="#">Stafoggia 2008 [30]</a>	<a href="#">4 Italian cities, 1997-2004</a>	<a href="#">Case-crossover</a>	<a href="#">Apparent temperature 30C compared to 20C</a>	<a href="#">Deaths in hospitals for those with 2+ days in hospital</a>	<a href="#">Increased age, single general medicine compared to high and intensive care units; history of psychiatric disorders, cerebrovascular diseases, heart failure, stroke, chronic pulmonary diseases</a>
<a href="#">Vaneckova 2008a [46]</a>	<a href="#">Sydney, Australia, October to March 1993-2001</a>	<a href="#">Time-series</a>	<a href="#">Temporal Synoptic Index (TSI); ratio of highest 10% mortality days within air mass and % frequency of air mass occurrence</a>	<a href="#">Daily mortality</a>	<a href="#">65+ years, women</a>
<a href="#">Yip 2008 [51]</a>	<a href="#">Maricopa County, Arizona, June to September 2000-2005</a>	<a href="#">Time-series</a>	<a href="#">Heat index</a>	<a href="#">Heat-related deaths</a>	<a href="#">Young and old outdoors, but greater risk elderly indoors</a>
<a href="#">Hajat 2007 [25]</a>	<a href="#">England and Wales, 1993-2003</a>	<a href="#">Time-series</a>	<a href="#">Heat (&gt;95<sup>th</sup> %) and cold (&lt;5<sup>th</sup> %) thresholds</a>	<a href="#">Mortality</a>	<a href="#">Elderly, those in nursing care homes respiratory and external causes, women modified by deprivation in London</a>

<a href="#">Medina-Ramon 2007 [21]</a>	<a href="#">50 US cities in cold (November to March) and warm (May to September) seasons</a>	<a href="#">Case-crossover</a>	<a href="#">Binary variable as extreme temperature and continuous: ozone</a>	<a href="#">All-cause and CVD mortality</a>	<a href="#">Cities with milder summers, less air conditioning and higher population density</a>
<a href="#">Diaz 2006 [35]</a>	<a href="#">Madrid, January 1986-December 1997</a>	<a href="#">Time-series</a>	<a href="#">T(hwave)=Tmax-36.5C if Tmax&gt;36.5C; 5<sup>th</sup> % to 95<sup>th</sup> % temperature, NO<sub>2</sub></a>	<a href="#">AR=(RR-1)/RR for daily mortality</a>	<a href="#">Circulatory causes, males 45-64 years</a>
<a href="#">Stafoggia 2006 [16]</a>	<a href="#">Bologna, Milan, Rome, Turin, 1997-2003</a>	<a href="#">Case-crossover</a>	<a href="#">30C mean apparent temperature (lag01) relative to 20C; odds ratio</a>	<a href="#">All-cause mortality and previous hospitalization</a>	<a href="#">Increased age and greater for women, widowers, psychiatric disorders, depression, heart and circulatory disorders</a>
<a href="#">Hajat 2005 [52]</a>	<a href="#">Delhi, Sao Paulo, London, January 1991-December 1994</a>	<a href="#">Time-series</a>	<a href="#">Daily temperature (lag 0,1) greater than 20C</a>	<a href="#">Daily mortality</a>	<a href="#">Respiratory deaths in Sao Paulo and London children in Delhi</a>
<a href="#">O'Neill, Zanobetti and Schwartz 2005 [37]</a>	<a href="#">Chicago, Detroit, Minneapolis, Pittsburgh, 1988-1993 for Chicago and 1986-1993 for other cities</a>	<a href="#">Time-series</a>	<a href="#">Percent change daily mean temperature 29C relative to 15C (lag0), barometric pressure, day of the week, PM<sub>10</sub></a>	<a href="#">Mortality, prevalence of air conditioner (AC)</a>	<a href="#">Black race, lack of air conditioner</a>
<a href="#">Gouveia 2003 [33]</a>	<a href="#">Sao Paulo, Brazil, 1991-1994</a>	<a href="#">Time-series</a>	<a href="#">Daily mean temperature (lag01), SO<sub>2</sub>, PM<sub>10</sub>, CO, O<sub>3</sub>, NO<sub>2</sub>, day of the week, season, humidity</a>	<a href="#">Daily mortality, excluding violent deaths</a>	<a href="#">Greatest for 65+ years and &lt;15 years, a increased for 15-64 years, elderly cardiovascular, respiratory for adults and elderly; no modification by socioeconomic status</a>
<a href="#">O'Neill 2003 [38]</a>	<a href="#">7 US cities, 1986-1993</a>	<a href="#">Time-series</a>	<a href="#">Mean daily apparent temperature (% change 29C and -5C), PM<sub>10</sub></a>	<a href="#">Daily mortality, looking at effect modification by demographics &amp; other variables</a>	<a href="#">Black race, less educated, and outside hospital</a>
<a href="#">Rainham and Smoyer-Tomic 2003 [42]</a>	<a href="#">Toronto, May 1 to September 30, 1980-1996</a>	<a href="#">Time-series</a>	<a href="#">Humidex, CO, O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub></a>	<a href="#">Daily mortality</a>	<a href="#">Females</a>
<a href="#">Curriero 2002 [39]</a>	<a href="#">11 Eastern US cities, 1973-1994</a>	<a href="#">Time-series</a>	<a href="#">Daily mean temperature, dew point temperature; minimum mortality temperature (MMT) range: 65.2-90.3</a>	<a href="#">Daily mortality</a>	<a href="#">Higher latitude, more poverty, less air conditioning or heating</a>

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Reference	Study location	Exposure	Outcome	Result
Basu and Ostro 2008 [8]	9 California counties, May to September 1999-2003	Daily apparent temperature	Cause-specific mortality; all-cause mortality by age, race/ethnicity, gender, education level	Increased risk for: CVD, IHD, MI, and CHF, $\leq$ elderly, Black race, out of hospital death; no effect for cerebrovascular, diabetes, respiratory; no effect by gender or high school graduation
Bell 2008 [9]	Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-2002	Same day apparent temperature	All-cause daily mortality	Among those 65+ years, 2.69% (-2.06, 7.88) for Sao Paulo and 3.22% (0.61, 5.83) for Mexico City; higher risk for women in Mexico City and higher for men in Santiago and Sao Paulo, less effect in Mexico City; greater risk in Sao Paulo
Ishigami 2008 [17]	Budapest, London and Milan, 2003	Mean daily temperature (lag0 and lag1), PM10 (TSP in Budapest), ozone	Daily mortality	Increased risk with age, females 65+ years greater in London and Milan and non-elderly adults in Milan; mortality from external causes and respiratory disease at higher temperatures
Stafoggia 2008 [22]	4 Italian cities, 1997-2004	Apparent temperature 30C compared to 20C	Deaths in hospitals for those with 2+ days in hospital	Overall OR=1.32 (1.25, 1.39); age, marital status, hospital ward risk indicators; greater risk for geriatric medicine than high and intensive care units, for history of psychiatric disorders and cerebrovascular diseases, and heart failure, stroke, chronic pulmonary diseases
Yip 2008 [61]	Maricopa County, Arizona, June to September 2000-2005	Heat index	Heat related deaths	182% increase in 2005 compared to 2000-2004; demographics (mean 56 years, young and old equally affected; more elderly found indoors)
Hajat 2007 [18]	England and Wales, 1993-2003	Heat ( $>95^{\text{th}}$ %) and cold ( $\leq 5^{\text{th}}$ %) thresholds	Mortality	Elderly, those in nursing care homes most vulnerable; risk for heat related mortality for respiratory and cardiovascular causes, women and in London, not modified by season

Kolb-2007 [25]	Montreal, Canada 1984-1993		Mean-daily and maximum temperature; barometric pressure; relative humidity; adjusted for ozone and both NO <sub>2</sub> and ozone	Daily mortality from congestive heart failure among 65+ years	Strong nonlinear association with the warmer months, with a threshold at 25C; none after lag 3 days	
Medina-Ramon-2007 [12]	50 US cities in cold (November to March) and warm (May to September) seasons		Binary variable as extreme temperature and continuous; ozone	All-cause and CVD mortality	Extreme heat (5.74%, 95% CI: 3.38, 8.15); large cities with milder summers, less air conditioning, population density	
Diaz-2006 [27]	Madrid, January 1986-December 1997		$T(h_{wave}) = T_{max} - 36.5C$ if $T_{max} > 36.5C$ ; 5 <sup>th</sup> to 95 <sup>th</sup> % temperature, NO <sub>2</sub>	AR=(RR-1)/RR for daily mortality	AR=13.3% for circulatory causes for males 45	
Dilaveris-2006 [23]	Athens, 2001		7-day average temperature; barometric pressure; relative humidity	Daily and monthly acute myocardial infarction mortality	More winter deaths, more pronounced in over-age; humidity indicator of monthly deaths	
Medina-Ramon-2006 [19]	50 US cities, 1989-2000		$\geq 99^{th}$ % for heat (May to September) and $\leq 1^{st}$ % for cold (November to March)	Daily all-cause and CVD mortality	Older age, diabetics, dying outside hospital increase for heat mortality	
Stafoggia-2006 [13]	Bologna, Milan, Rome, Turin, 1997-2003		30C mean apparent temperature (lag01) relative to 20C	All-cause mortality and previous hospitalization	Overall OR=1.34 (1.27, 1.42); increased with age greater for women, widows and widowers, psychiatric disorders, depression, heart and circulatory diseases	
Hajat-2005 [38]	Delhi, Sao Paulo,	Time-series	Daily temperature	Daily mortality	Delhi: 3-weeks after exposure;	

	London, January 1991– December 1994		(lag 0,1) greater than 20C		London: 2 days after exposure; Sao Paulo: intermediate; up to 4 weeks for respiratory deaths in SP and London and children in Delhi
O'Neill, Zanobetti and Schwartz 2005 [30]	Chicago, Detroit, Minneapolis, Pittsburgh, 1988–1993 for Chicago and 1986– 1993 for other cities	Time- series	Percent change daily mean temperature 29C relative to 15C (lag0), barometric pressure, day of the week, PM10	Mortality, prevalence of air conditioner (AC)	Deaths among Blacks (9%; 5.3, 12.8) greater than Whites (3.7%; 1.9, 5.4); AC prevalence among Blacks less than half that among Whites in combined estimate
O'Neill 2005 [10]	Mexico City (1996–1998) and Monterrey (1996–1999)	Time- series	% change for heat (35–36C for Monterrey); mean temperature (25C Monterrey, 15C Mexico City)	Daily mortality	Monterrey: adjusted heat effect=18.7% (11.7, 26.1); lower effect among children

Schwartz 2005 [20]	Medicare patients with previous hospital admission for heart or lung disease, Michigan	Case-only	99 <sup>th</sup> % hot days (also analyzed cold days as 1%)	Mortality	Diabetics (1.17; 1.04, 1.32) higher risk on hot days. Nonwhites greater risks on both hot (1.22; 1.09-1.37) and cold (1.25; 1.12-1.40) days
Gouveia 2003 [26]	Sao Paulo, Brazil, 1991-1994	Time-series	Daily mean temperature (lag01), SO <sub>2</sub> , PM <sub>10</sub> , CO, O <sub>3</sub> , NO <sub>2</sub> , day of the week, season, humidity	Daily mortality, excluding violent deaths	For each 1C above 20C, 2.5% (2.1, 2.8) for 65+ years; 2.6% (1.6, 3.6) for <15 years; 1.5% (1.1, 1.8) 15-64 years for all-cause; similar CVD effect for elderly and respiratory effect for adults and elderly; no modification by SES
O'Neill 2003 [31]	7 US cities, 1986-1993	Time-series	Mean daily apparent temperature (% change 29C and -5C);	Daily mortality, looking at effect modification	More deaths among Blacks compared to Whites, less educated, and

			PM10	by demographics & other variables	outside-hospital more strongly associated with hot and cold temperatures
Rainham and Smoyer-Tomic 2003 [29, 52]	Toronto, May 1 to September 30, 1980-1996	Time-series	Humidex, CO, O3, NO2, SO2	Daily mortality	Total RR=1.061 (1.045, 1.077) for 50-95% and 1.004 (significant) per 1C; more pronounced in females