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**High Ambient Temperature and Mortality: A Review of Epidemiologic Studies
from 2001 to 2008**

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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 and case-crossover approaches.

10 While other reviews have been conducted more recently on heat and mortality, the
11 focus has been on methodological issues and approaches [2] and on climatology [3],
12 leaving a number of important epidemiologic studies excluded. Many studies of
13 ambient temperature and mortality did not account for air pollutants, and in the previous
14 review [1], it was not clear from the few studies conducted whether air pollutants acted
15 as confounders, effect modifiers, or both. It is critical to separate the independent
16 effects of both ambient temperature and air pollutants, since they may often influence
17 each other on a daily basis. Thus, the actual association between ambient temperature
18 and mortality can be observed, only after accounting for pollutants in the models with
19 ambient temperature. Furthermore, demographic characteristics, such as poverty and
20 age, can modify the severity of heat effects through various physiological and
21 behavioral pathways. Thus, certain subgroups may be particularly vulnerable to heat
22 effects, and identifying them for specific locations would be beneficial for targeting
23 public health interventions.

1
2 Here, the epidemiologic evidence from the past decade of high ambient temperature
3 and mortality is summarized, with a closer examination of studies of the potential effect
4 of air pollution on the temperature-mortality association, as well as vulnerable
5 subgroups. A general discussion of mortality displacement on the association between
6 temperature and mortality is also included. Mortality displacement (also known as
7 harvesting) refers to the phenomena suggesting that observed deaths from some
8 environmental exposure, such as ambient temperature, occur in the most frail
9 individuals whose deaths have only been brought forward by a few days.

10

11 **Methodological issues**

12

13 ***Inclusion/exclusion criteria***

14 All studies included in this review were published in peer-reviewed journals between
15 January 2001 and December 2008. Pub Med was used to search for the following
16 keywords: temperature, apparent temperature, heat, heat index, and mortality. In
17 addition, Table 2 had the keyword “air pollutants,” “ozone,” or “particulate matter”
18 added, and Table 3 had “vulnerable”, “susceptible subgroups/groups” added. The
19 search was limited to the English language and epidemiologic studies. The review
20 focused primarily on quantitative studies of ambient temperature, consisting of studies
21 using the time-series and/or case-crossover methods. The outcomes from these
22 studies generally reported a regression coefficient, relative risk (time series), odds ratio
23 (case-crossover), or percent change in mortality, along with corresponding standard

1 errors or confidence intervals. Studies that reported mortality counts or excess deaths
2 following heat waves were excluded so that the focus remained on general ambient
3 temperature exposure, rather than on short time periods. Review articles or studies
4 focusing on cold temperature effects were also excluded. Thirty-six studies published
5 in peer-reviewed journals were selected for this epidemiologic review, with 57 total
6 studies in the references that included a general discussion of temperature and
7 mortality.

8

9 ***Exposure assessment***

10

11 Temperature data are often measured near airport monitoring stations, and analyzed at
12 the city or county level. Thus, misclassification of exposure may occur, especially for
13 larger geographic areas. Also, measuring ambient temperature outside of urban areas
14 may artificially reduce the temperature measurement, since urban areas often have
15 higher temperatures than suburban or surrounding areas because of heat absorbed by
16 buildings and roadways (known as the urban heat-island effect). However, since the
17 bias should be non-differential (i.e., not different by county or other unit of analysis), the
18 bias in the estimate would be toward the null, where the results would be
19 underestimated. Misclassification of exposure may be reduced in future studies by
20 using smaller buffer zones, such as five or ten kilometers around each monitor, if
21 sufficient data are available.

22

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

15

16 ***Case selection***

17

18 Heat-related mortality is often underestimated, and since a systematic definition still
19 does not exist, it may only be indicated when heat waves occur, resulting in a signal
20 detection bias. Thus, investigators often use all-cause mortality excluding mortality due
21 to accidents, or other related outcome, such as mortality from cardiovascular or
22 respiratory diseases in epidemiologic studies of heat or elevated ambient temperature.
23 The underlying cause of death is usually used for epidemiologic studies and should be

1 sufficient for characterizing the temperature-mortality association, although associated
2 causes of death can also be used.

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. Thus,
7 gathering data on individual characteristics, as has been done in a previous study [4],
8 would be informative. In addition, medication use, time-activity patterns, and biologic
9 mechanisms could be further understood.

10

11 ***Study design***

12

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

18

19 The time-series is a widely accepted approach in both air pollution and temperature
20 studies. The time-series study generally encompasses large populations in multiple
21 geographic areas over a given time period. Mortality counts or rates are compared to
22 exposure measurements collected at regular time intervals (e.g., daily, weekly).

23 Seasonality and other confounding factors that fluctuate over time are accounted for by

1 adding the covariates to the model (i.e., day of the week, air pollutants) and using
2 smoothing functions to the model using specified degrees of freedom.

3

4 The case-crossover design has been employed more recently, gaining widespread
5 popularity for studying air pollution and temperature in the past decade. This study
6 design is similar to a matched case-control study; however, each case in the case-
7 crossover study serves as his/her own control. Thus, biases due to measured and
8 unmeasured confounders, such as genetics, health behaviors, and physiologic
9 differences, are controlled for by study design. The case-crossover study design has
10 been refined since its introduction in 1991, from the unidirectional, to the bidirectional,
11 and most recently, to the time-stratified approach. The time-stratified approach limits
12 the bias from selecting control periods only previously to the case period
13 (unidirectional), or from not selecting control periods at random from the time at which
14 the case occurred (bidirectional). Most commonly, control periods are selected within
15 the same month and the same year that the case period occurred in the time-stratified
16 approach to inherently minimize biases that may occur from time trends. Day of the
17 week is also matched for by study design by choosing control periods every seven
18 days, or may be added to the model as an indicator variable, especially if data are
19 sparse (e.g., if using particulate matter in the model, data are often collected every third
20 day, and thus, would warrant control periods to be selected every third day). In the
21 studies listed in the following tables, all case-crossover studies used the time-stratified
22 approach.

23

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

5

6 ***Mortality displacement***

7

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

16

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

23

1 **Summary of Studies**

2

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

14

15 ***General Ambient Temperature and Mortality***

16

17 In Table 1, the recent studies of high ambient temperature and mortality are
18 summarized. To focus on the effects of warmer temperatures, most investigators
19 limited their data above a threshold value, or have compared effect estimates from
20 temperatures above a threshold value to another lower value. The threshold value is
21 often based on some percentile of the data (i.e., 90th or 95th percentile), after visual
22 inspection of the exposure-response curves or by mathematical (i.e., through
23 derivatives) or statistical (i.e., by maximum likelihood) methods. The data are often

1 limited to the summer months or warm season to establish heat effects. Limiting the
2 data to summer months or the warm season is also employed to exclude possible
3 (negative or positive) effects from cold temperatures on mortality in the attempt to
4 estimate the actual risk from heat effects. Because of these several classifications of
5 temperature exposure, it is difficult to directly compare the values resulting from these
6 studies. However, few comparisons can be made. For example, in Europe and Korea,
7 where different levels of temperature and humidity were experienced, the mortality
8 estimates above a threshold of (23.3C to 29.7C) resulted in different effect estimates
9 [12]. With similar threshold values in the Mediterranean (29.4C) and Korea (27-29.7C),
10 a 1C increase of apparent temperature corresponded to a 3.12% increase in daily
11 mortality in Mediterranean cities, and a much higher effect in Korea (6.73%-16.3% in 6
12 cities) for a similar time period. Two recent studies conducted by Basu et al. [6, 14]
13 and Zanobetti and Schwartz [7] using identical methods suggested that the effect
14 estimates throughout California and other parts of the US are similar, even with different
15 ranges of apparent temperature. They both found approximately a 2% increase in
16 mortality associated with a 10F increase in apparent temperature.

17

18 ***Air Pollutants as Confounders/Effect Modifiers***

19

20 Table 2 includes recent studies that have evaluated air pollutants as a potential
21 confounder and/or effect modifier of the high ambient temperature and mortality
22 association. The pollutants that have been examined include ozone (O₃), particulate
23 matter less than 10 ug/m³ in aerodynamic diameter (PM₁₀), fine particulate matter

1 (PM_{2.5}), carbon monoxide (CO), sulfur dioxide (SO₂), and nitrogen dioxide (NO₂). Most
2 investigators who considered pollutants evaluated PM and O₃, since these pollutants
3 have been found to be associated with mortality and are often correlated with high
4 temperature..

5
6 Although the effect estimates changed with pollutants in the model, no significant
7 confounding [15] or effect modification by pollution on the association between
8 temperature and mortality was reported in some recent studies conducted in the US [6,
9 7]. The studies conducted by Bell et al. and Zanobetti and Schwartz considered PM₁₀
10 (as well as PM_{2.5} in the Zanobetti and Schwartz study) and O₃, while the study by Basu
11 et al. considered O₃, PM_{2.5}, PM₁₀, NO₂, CO, and SO₂. Stafoggia [16] and Rainham and
12 Smoyer-Tomic [17] also reported no confounding by O₃ in Italy and Canada,
13 respectively, and Pattenden did not find confounding by markers of PM in both Sofia
14 (total suspended in particulates) and London (black smoke). However, PM₁₀ was found
15 to be confounder in Monterrey, Mexico [18], Sydney, Australia [19], and in regions
16 throughout the United States, especially in the summer [5]. Ren and Tong [20] also
17 observed PM₁₀ to modify the association in their study conducted in Brisbane,
18 Australia. O₃ was found to be a confounder especially on hot days [18, 21], and other
19 investigators also showed O₃ to be a positive effect modifier of temperature and
20 mortality, at least in some study locations [22, 23].

21
22 The results for confounding and/or effect modification by air pollutants on the
23 temperature-mortality association remain mixed; as stated, some investigators reported

1 air pollutants as confounders or effect modifiers while others found no significant
2 confounding or effect modification in their studies.

3

4 ***Cause-specific Outcomes and Vulnerable Subgroups***

5

6 Much of the focus of epidemiologic studies has been identifying cause-specific
7 outcomes and vulnerable subgroups of mortality from high ambient temperature (Table
8 3).

9

10 Cause-specific outcomes

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

16

17 Age

18 Age has been found to modify the association between ambient temperature and
19 mortality. The elderly have been reported to be at greater risk from mortality following
20 heat waves, as well as ambient temperature. In addition to the elderly who were at
21 least 75 years [12], 70 years [31] or 65 years [5, 14, 15, 19, 24-26, 33, 34] of age,
22 children under 15 years [18, 33], children five years and younger [14], and infants one
23 year of age and under [14, 35] have been identified to be at increased risk for mortality

1 from high ambient temperature. One investigator also reported 15 to 64 years of age to
2 be at a significantly increased risk, although still lower than the elderly or young children
3 [33].

4

5 Gender

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

10

11 Race/ethnic group

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

16

17 Socioeconomic factors

18 Other factors that provoked greater risk included indicators for lower socioeconomic
19 status, including the less educated, persons living in lower income areas [16] and dying
20 out of the hospital [14, 27, 38]. Also, increased poverty [39], and lack of air conditioner
21 [11, 37, 39] were observed risk factors. However, lower socioeconomic status [33] and
22 education level were not found to be a risk factor in all studies [14].

23

Latitude Variations

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

12

13 **Conclusions**

14

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

1 consider accounting for air pollutants and identifying vulnerable subgroups in their
2 epidemiologic studies.

3

4 The recent epidemiologic evidence suggests that PM and O₃ may be confounders, and
5 some studies also found O₃ to be an effect modifier in the warmer months. In other
6 words, the association between temperature and mortality is partially a result of the
7 effect of PM and O₃. However, this confounding effect is relatively small, and there is
8 clearly an independent effect of both temperature and air pollution on mortality. Others
9 have reported that temperature has a greater effect on mortality with higher levels of O₃
10 (i.e., synergism). Some of the conflicting evidence for confounding and effect
11 modification by air pollutants may be due to high correlations between pollutants and
12 temperature, making it difficult to tease apart the independent effects of either exposure.
13 Also, different sources, chemistry, size distribution of particles, compositions and
14 patterns of exposure [41] of gases and particles are observed throughout the US and
15 elsewhere. Although O₃ generally peaks in the summer throughout the US, for
16 example, particulate matter peaks in the winter in California and in the summer on the
17 East Coast. Thus, there would more likely be an impact of PM on elevated ambient
18 temperature and health outcomes on the East Coast. Acclimatization may also play a
19 critical role in the temperature-mortality association. People who live in areas where
20 high ambient temperatures or heat waves are typically experienced may be less
21 affected than people who reside in areas where high ambient temperatures are less
22 commonly observed. Thus, even if there is effect modification between ambient

1 temperature and a pollutant, such as O₃, the influence on mortality may be minimal, but
2 synergistic in areas where heat waves are uncommon.

3
4 Several vulnerable subgroups have been identified. Many of these outcomes and
5 vulnerable subgroups have not been identified in previous epidemiologic studies of
6 ambient temperature and were dependent on the location and study population. Thus,
7 region-specific policies, especially in urban areas, are vital to the mitigation of heat-
8 related deaths. Specifically, those dying from cardiovascular, respiratory, and some
9 specific cardiovascular diseases, such as ischemic heart disease, congestive heart
10 failure, and myocardial infarction were at greater risk for heat-related mortality. Other
11 vulnerable subgroups included: Black racial/ethnic group, women, those with lower
12 socioeconomic status, and all age groups, particularly the elderly over 65 years of age
13 as well as infants and young children.

14
15 Infants, young children, and the elderly should be specifically targeted in future studies
16 to prevent heat-related mortality. With the elderly increasing in urban environments, an
17 important research goal is the identification of clinical patterns of chronic diseases that
18 increase the susceptibility to heat. Furthermore, vulnerable subgroups need to be
19 further identified by cause-specific outcomes or demographics, such as racial/ethnic
20 group. Furthermore, adverse birth outcomes have been found to be associated with air
21 pollutants in previous studies, but have not been investigated, specifically for ambient
22 temperature. Although previous studies of air pollution and birth outcomes have not
23 accounted for temperature, some investigators have suggested seasonal associations,

1 implying that temperature could also play a role with adverse birth outcomes and
2 warrants further investigation.

3

4 Several biological mechanisms have been postulated for susceptible populations to
5 heat-related mortality, particularly the elderly [42]. When body temperatures rise, blood
6 flow generally shifts from the vital organs to underneath the skin's surface in an effort to
7 cool down. The body's ability to regulate its temperature (also known as
8 thermoregulation) may be impeded when too much blood is diverted, putting increased
9 stress on the heart and lungs. Increased blood viscosity, elevated cholesterol levels
10 associated with higher temperatures, and higher sweating threshold may also trigger
11 heat-related mortality [43]. The body's ability to adapt to high ambient temperature can
12 be influenced by acclimatization. People who live in areas where high ambient
13 temperatures are not generally experienced are more likely to be affected by a heat
14 wave. The synergistic impact of high ambient temperature along with high levels of air
15 pollutants, such as O₃ and PM, may also play a role in increasing the mortality effect.
16 Furthermore, heat waves occurring earlier in the year may have a greater impact on
17 mortality since the population has not had the chance to adapt to hotter temperatures.

18

19 This review is timely as climate change receives more global attention, and more
20 epidemiologic studies have been recently conducted. It, however, has several
21 limitations. While it includes the most recent epidemiologic studies using time-series
22 and case-crossover methods, it does not include studies of heat waves or studies using
23 other approaches in an effort to focus on general ambient temperature over longer time

1 periods. Both methods rely on ecologic exposure variables for temperature, and the
2 time-series analysis also uses aggregated counts of mortality. Thus, an advantage of
3 the case-crossover study is that differences by individual-level characteristics such as
4 age, race/ethnic group, gender can be analyzed. Although the methods used across
5 studies were similar, it was still often difficult to compare estimates between studies
6 because of the analysis type (e.g., different threshold values). There were also not a
7 sufficient number of studies to conduct a meta-analysis of the results, or other more
8 substantial quantification. Finally, there may be some publication bias in the studies
9 that were chosen, but by using PubMed, the bias may be limited, as it includes most
10 scientific journals.

11
12 Further studies need to be conducted in more urban locations so that policies can be
13 implemented for specific areas rather than for an entire geographic area. These studies
14 would be helpful to the National Weather Service, health care institutions, and
15 governmental agencies to implement policies to prevent heat-related mortality and also
16 create a better heat warning system based on current studies. They will also be helpful
17 to establish policy guidelines for the U.S. Environmental Protection Agency (personal
18 communication), and could be used for economic analyses. Although no formal
19 evaluation of heat-health watch warning systems has been performed to date, some
20 city-based heat-health watch warning systems have already been implemented appear
21 to be successful in greatly reducing mortality following heat waves [44]. For example,
22 the 2003 heat wave in Western Europe resulted in 35,000 deaths, but the World Health
23 Organization's project, EuroHEAT, collected information about existing warning systems

1 and defined guidelines for prevention so that subsequent heat waves do not produce
2 such devastating results (<http://www.euro.who.int/document/e91347.pdf>).

3

1 **List of abbreviations**

2 CO carbon monoxide

3 NO₂ nitrogen dioxide

4 O₃ ozone

5 PM particulate matter

6 SO₂ sulfur dioxide

7 C Celsius

8 F Fahrenheit

9 CI confidence interval

10

11 **Competing interests**

12 The author declares no competing interests.

13 **Author's contributions**

14

15 RB conducted the literature search for this review, specified the inclusion and exclusion
16 criteria, constructed the tables, and drafted and revised the manuscript for consideration
17 for publication.

18

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20

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22 represent the policy or position of the State of California or the California Environmental
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REFERENCES

- 1
- 2
- 3 1. Basu R, Samet JM: **Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence.** *Epidemiol Rev* 2002, **24**:190-202.
- 4
- 5
- 6 2. Kinney P, O'Neill M. S., Bell M. L., Schwartz J.: **Approaches for estimating effects of climate change on heat-related deaths: challenges and opportunities.** *Environmental Science & Policy* 2008, **11**:87-96.
- 7
- 8
- 9 3. Gosling SN, McGregor GR, Paldy A: **Climate change and heat-related mortality in six cities part 1: model construction and validation.** *Int J Biometeorol* 2007, **51**:525-540.
- 10
- 11
- 12 4. Basu R, Samet JM: **An exposure assessment study of ambient heat exposure in an elderly population in Baltimore, Maryland.** *Environ Health Perspect* 2002, **110**:1219-1224.
- 13
- 14
- 15 5. Basu R, Dominici F, Samet JM: **Temperature and mortality among the elderly in the United States: a comparison of epidemiologic methods.** *Epidemiology* 2005, **16**:58-66.
- 16
- 17
- 18 6. Basu R, Feng WY, Ostro BD: **Characterizing Temperature and Mortality in Nine California Counties.** *Epidemiology* 2008, **19**:138-145.
- 19
- 20 7. Zanobetti A, Schwartz J: **Temperature and mortality in nine US cities.** *Epidemiology* 2008, **19**:563-570.
- 21
- 22 8. Braga AL, Zanobetti A, Schwartz J: **The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities.** *Environ Health Perspect* 2002, **110**:859-863.
- 23
- 24
- 25 9. Zeger SL, Dominici F, Samet J: **Harvesting-resistant estimates of air pollution effects on mortality.** *Epidemiology* 1999, **10**:171-175.
- 26
- 27 10. Schwartz J: **Harvesting and long term exposure effects in the relation between air pollution and mortality.** *Am J Epidemiol* 2000, **151**:440-448.
- 28
- 29 11. Braga AL, Zanobetti A, Schwartz J: **The time course of weather-related deaths.** *Epidemiology* 2001, **12**:662-667.
- 30
- 31 12. Baccini M, Biggeri A, Accetta G, Kosatsky T, Katsouyanni K, Analitis A, Anderson HR, Bisanti L, D'Ippoliti D, Danova J, et al: **Heat effects on mortality in 15 European cities.** *Epidemiology* 2008, **19**:711-719.
- 32
- 33
- 34 13. Hajat S, Kovats RS, Atkinson RW, Haines A: **Impact of hot temperatures on death in London: a time series approach.** *J Epidemiol Community Health* 2002, **56**:367-372.
- 35
- 36
- 37 14. Basu R, Ostro BD: **A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California.** *Am J Epidemiol* 2008, **168**:632-637.
- 38
- 39
- 40 15. Bell ML, O'Neill MS, Ranjit N, Borja-Aburto VH, Cifuentes LA, Gouveia NC: **Vulnerability to heat-related mortality in Latin America: a case-crossover study in Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico.** *Int J Epidemiol* 2008, **37**:796-804.
- 41
- 42
- 43
- 44 16. Stafoggia M, Forastiere F, Agostini D, Biggeri A, Bisanti L, Cadum E, Caranci N, de' Donato F, De Lisio S, De Maria M, et al: **Vulnerability to heat-related**
- 45

- 1 **mortality: a multicity, population-based, case-crossover analysis.**
2 *Epidemiology* 2006, **17**:315-323.
- 3 17. Rainham DG, Smoyer-Tomic KE: **The role of air pollution in the relationship**
4 **between a heat stress index and human mortality in Toronto.** *Environ Res*
5 2003, **93**:9-19.
- 6 18. O'Neill MS, Hajat S, Zanobetti A, Ramirez-Aguilar M, Schwartz J: **Impact of**
7 **control for air pollution and respiratory epidemics on the estimated**
8 **associations of temperature and daily mortality.** *Int J Biometeorol* 2005,
9 **50**:121-129.
- 10 19. Vaneckova P, Beggs PJ, de Dear RJ, McCracken KW: **Effect of temperature on**
11 **mortality during the six warmer months in Sydney, Australia, between 1993**
12 **and 2004.** *Environ Res* 2008a, **108**:361-369.
- 13 20. Ren C, Tong S: **Temperature modifies the health effects of particulate**
14 **matter in Brisbane, Australia.** *Int J Biometeorol* 2006, **51**:87-96.
- 15 21. Medina-Ramon M, Schwartz J: **Temperature, Temperature Extremes, and**
16 **Mortality: A Study of Acclimatization and Effect Modification in 50 United**
17 **States Cities.** *Occup Environ Med* 2007.
- 18 22. Ren C, Williams GM, Morawska L, Mengersen K, Tong S: **Ozone modifies**
19 **associations between temperature and cardiovascular mortality: analysis**
20 **of the NMMAPS data.** *Occup Environ Med* 2008, **65**:255-260.
- 21 23. Filleul L, Cassadou S, Medina S, Fabres P, Lefranc A, Eilstein D, Le Tertre A,
22 Pascal L, Chardon B, Blanchard M, et al: **The relation between temperature,**
23 **ozone, and mortality in nine French cities during the heat wave of 2003.**
24 *Environ Health Perspect* 2006, **114**:1344-1347.
- 25 24. Ishigami A, Hajat S, Kovats RS, Bisanti L, Rognoni M, Russo A, Paldy A: **An**
26 **ecological time-series study of heat-related mortality in three European**
27 **cities.** *Environ Health* 2008, **7**:5.
- 28 25. Hajat S, Kovats RS, Lachowycz K: **Heat-related and cold-related deaths in**
29 **England and Wales: who is at risk?** *Occup Environ Med* 2007, **64**:93-100.
- 30 26. Goodman PG, Dockery DW, Clancy L: **Cause-specific mortality and the**
31 **extended effects of particulate pollution and temperature exposure.** *Environ*
32 *Health Perspect* 2004, **112**:179-185.
- 33 27. Medina-Ramón M, Zanobetti A, Cavanagh DP, Schwartz J: **Extreme**
34 **Temperatures and Mortality: Assessing Effect Modification by Personal**
35 **Characteristics and Specific Cause of Death in a Multi-City Case-Only**
36 **Analysis.** *Environ Health Perspect* 2006, **114**:1331.
- 37 28. Schwartz J: **Who is sensitive to extremes of temperature?: A case-only**
38 **analysis.** *Epidemiology* 2005, **16**:67-72.
- 39 29. Stafoggia M, Schwartz J, Forastiere F, Perucci CA: **Does Temperature Modify**
40 **the Association between Air Pollution and Mortality? A Multicity Case-**
41 **Crossover Analysis in Italy.** *Am J Epidemiol* 2008, **167**.
- 42 30. Stafoggia M, Forastiere F, Agostini D, Caranci N, de'Donato F, Demaria M,
43 Michelozzi P, Miglio R, Rognoni M, Russo A, Perucci CA: **Factors affecting in-**
44 **hospital heat-related mortality: a multi-city case-crossover analysis.** *J*
45 *Epidemiol Community Health* 2008, **62**:209-215.

- 1 31. Dilaveris P, Synetos A, Giannopoulos G, Gialafos E, Pantazis A, Stefanadis C:
2 **CLimate Impacts on Myocardial infarction deaths in the Athens Territory:**
3 **the CLIMATE study.** *Heart* 2006, **92**:1747-1751.
- 4 32. Kolb S, Radon K, Valois MF, Heguy L, Goldberg MS: **The short-term influence**
5 **of weather on daily mortality in congestive heart failure.** *Arch Environ Occup*
6 *Health* 2007, **62**:169-176.
- 7 33. Gouveia N, Hajat S, Armstrong B: **Socioeconomic differentials in the**
8 **temperature-mortality relationship in Sao Paulo, Brazil.** *Int J Epidemiol* 2003,
9 **32**:390-397.
- 10 34. El-Zein A, Tewtel-Salem M, Nehme G: **A time-series analysis of mortality and**
11 **air temperature in Greater Beirut.** *Sci Total Environ* 2004, **330**:71-80.
- 12 35. Diaz J, Linares C, Tobias A: **Impact of extreme temperatures on daily**
13 **mortality in Madrid (Spain) among the 45-64 age-group.** *Int J Biometeorol*
14 2006, **50**:342-348.
- 15 36. Hajat S, Armstrong B, Baccini M, Biggeri A, Bisanti L, Russo A, Paldy A, Menne
16 B, Kosatsky T: **Impact of High Temperatures on Mortality: Is There an Added**
17 **Heat Wave Effect?** *Epidemiology* 2006, **17**:632-638.
- 18 37. O'Neill MS, Zanobetti A, Schwartz J: **Disparities by race in heat-related**
19 **mortality in four US cities: the role of air conditioning prevalence.** *J Urban*
20 *Health* 2005, **82**:191-197.
- 21 38. O'Neill MS, Zanobetti A, Schwartz J: **Modifiers of the temperature and**
22 **mortality association in seven US cities.** *Am J Epidemiol* 2003, **157**:1074-
23 1082.
- 24 39. Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA: **Temperature**
25 **and mortality in 11 cities of the eastern United States.** *Am J Epidemiol* 2002,
26 **155**:80-87.
- 27 40. Kim H, Ha JS, Park J: **High temperature, heat index, and mortality in 6 major**
28 **cities in South Korea.** *Arch Environ Occup Health* 2006, **61**:265-270.
- 29 41. Blanchard C: **Spatial and Temporal Characterization of Particulate Matter.** In
30 *Particulate Matter Science for Policy Makers: A NARSTO Assessment.* Edited
31 by McMurry PH, Shepherd MF, Vickery JS. Cambridge: Cambridge University
32 Press; 2003: Chapter 6
- 33 42. Bouchama A, Knochel JP: **Heat stroke.** *N Engl J Med* 2002, **346**:1978-1988.
- 34 43. Astrand P-O, Rodahl K, Dahl HA, Stromme SB: *Textbook of Work Physiology:*
35 *Physiological Bases of Exercise.* 4th edn. Canada: McGraw-Hill; 2003.
- 36 44. Smoyer KE, Rainham DG, Hewko JN: **Heat-stress-related mortality in five**
37 **cities in Southern Ontario: 1980-1996.** *Int J Biometeorol* 2000, **44**:190-197.
- 38 45. McMichael AJ, Wilkinson P, Kovats RS, Pattenden S, Hajat S, Armstrong B,
39 Vajanapoom N, Niciu EM, Mahomed H, Kingkeow C, et al: **International study**
40 **of temperature, heat and urban mortality: the 'ISOTHURM' project.** *Int J*
41 *Epidemiol* 2008, **37**:1121-1131.
- 42 46. Vaneckova P, Hart MA, Beggs PJ, de Dear RJ: **Synoptic analysis of heat-**
43 **related mortality in Sydney, Australia, 1993-2001.** *Int J Biometeorol* 2008b,
44 **52**:439-451.
- 45 47. Barnett AG: **Temperature and cardiovascular deaths in the US elderly:**
46 **changes over time.** *Epidemiology* 2007, **18**:369-372.

- 1 48. Michelozzi P, De Sario M, Accetta G, de'Donato F, Kirchmayer U, D'Ovidio M,
2 Perucci CA: **Temperature and summer mortality: geographical and temporal**
3 **variations in four Italian cities.** *J Epidemiol Community Health* 2006, **60**:417-
4 423.
- 5 49. Pattenden S: **Mortality and temperature in Sofia and London.** 2003.
- 6 50. Ren C, Williams GM, Tong S: **Does particulate matter modify the association**
7 **between temperature and cardiorespiratory diseases?** *Environ Health*
8 *Perspect* 2006, **114**:1690-1696.
- 9 51. Yip FY, Flanders WD, Wolkin A, Engelthaler D, Humble W, Neri A, Lewis L,
10 Backer L, Rubin C: **The impact of excess heat events in Maricopa County,**
11 **Arizona: 2000-2005.** *Int J Biometeorol* 2008, **52**:765-772.
- 12 52. Hajat SA, Ben G.; Gouveia, Nelson; Wilkinson, Paul: **Mortality Displacement of**
13 **Heat-Related Deaths: A Comparison of Delhi, Sao Paulo, and London.**
14 *Epidemiology* 2005, **16**:613.
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16

1 **Table 1: Recent Studies of High Ambient Temperature and All-Cause Daily Mortality***

2

| Reference | Study population | Method | Exposure | Result: effect estimate (95% CI) |
|---------------------------------|---|---|---|--|
| Baccini 2008 [12] | 15 European cities, April-September 1990-2000 (5-11 years depending on data availability for city) | Time-series; % change | 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 Lag: 3 days prior |
| Basu 2008 [6] | 9 California counties, May to September 1999-2003 | Time-series and case-crossover; % change | Daily apparent temperature (minimum, mean, maximum); daily mean O ₃ , PM _{2.5} , PM ₁₀ , NO ₂ , CO, SO ₂ | Per 10 F increase mean temperature, 2.3 (1.0-3.6), similar results for minimum and maximum temperatures Lag: 0 |
| Bell 2008 [15] | Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-2002 | Case-crossover; % change | Same day apparent temperature compared with days at 75 th percentile, O ₃ , PM ₁₀ | 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 Lag: 0 |
| McMichael 2008 [45] | 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; % change | Daily maximum threshold (16C-31C) temperature, relative humidity, precipitation data, PM ₁₀ , BS, or TSP | 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) Lag: 2-day average |
| Vaneckova 2008a [46] | Sydney, Australia, October to March 1993-2001 | Time-series; ratio of highest 10% mortality days within air mass and % frequency of air mass occurrence | Temporal Synoptic Index (TSI) | 1.64 and 2.64 (both significant) for warmest TSIs, no CI provided |
| Zanobetti and Schwartz 2008 [7] | 9 U.S. counties, May to September 1999-2002 | Time-series and case-crossover; % change | Daily apparent temperature (minimum, mean, maximum); daily mean O ₃ , PM _{2.5} , PM ₁₀ | Per 10F increase mean temperature, 1.8 (1.09-2.5) case-crossover and 2.7 (2.0-3.5) time-series; similar results for minimum and maximum temperatures Lag: 0 |
| Barnett 2007 [47] | 107 U.S cities using data from the National Morbidity and Mortality | Case-crossover; % change | Daily temperature | 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 |

| | | | | |
|------------------------|---|---|---|---|
| | Study, 1987-2000 | | | had disappeared (-0.4, -3.2-2.5) Lag: 04 |
| Medina-Ramon 2007 [21] | 50 US cities in cold (November to March) and warm (May to September) seasons | Case-crossover; % change | Binary variable as extreme heat (range 22-32C) and continuous; O ₃ | 5.74 (3.38-8.15) for extreme heat Lag: 2-day average |
| Kolb 2007 [32] | Montreal, Canada 1984-1993 | Case-crossover; odds ratio | Mean daily and maximum temperature, barometric pressure, relative humidity, adjusted for O ₃ and both NO ₂ and O ₃ | 1.20 (1.14-1.38) for 25-30C maximum temperature; strong nonlinear association with a threshold at 25C Lag: average 02; no association after 3 days |
| Carson 2006 [52] | London, England, 4 time periods, winter: December-March; non-winter: April-November | Time-series; ratio of winter to non-winter deaths | Daily mean temperature | 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 |
| Kim 2006 [40] | 6 cities in South Korea, summer 1994-2006 | Time-series; % change | Daily mean temperature thresholds (27-29.7C) | 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 |
| Michelozzi 2006 [48] | 4 Italian cities, June to September 2003 & 2004 and reference period (Roma, Torino, Milano: 1995-2002 and Bologna: 1996-2002) | Time-series; % change | Daily maximum apparent temperature thresholds (28-32C) | 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 |
| Stafoggia 2006 [16] | Bologna, Milan, Rome, Turin, 1997-2003 | Case-crossover; odds ratio | 30C mean apparent temperature relative to 20C; odds ratio | 1.34 (1.27, 1.42) Lag: 01 |
| Basu 2005 [5] | 20 US metropolitan areas, seasonal analysis 1992 | Time series (relative risk) and case-crossover (odds ratio) | Mean daily temperature per 10F adjusted for dew point temperature; daily O ₃ | 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 Lag: 0,1 |
| El-Zein 2004 [34] | Greater Beirut, Lebanon, 1997-1999 | Time-series; % change | Mean daily temperature, mean daily humidity, minimum mortality temperature (TMM)=27.5C | 1 C above TMM 12.3 (5.7, 19.4%) increase in annual mortality |

| | | | | |
|---------------------|---|-------------------------|--|---|
| | | | | Lag: 0 |
| Goodman 2004 [26] | Dublin, Ireland, April 1980 to December 1996 | Time-series; % change | Daily minimum temperature, daily mean relative humidity | 1 C increase 0.4 (0.3-0.6) increase Lag: 0 |
| Pattenden 2003 [49] | Sofia, Bulgaria (1996-1999) and London, England (1993-1996) | Time-series; % change | Daily mean temperature, relative humidity and PM (black smoke for London and total suspended particulates for Sofia) | 1 C increase above 90th % 1.9 (1.4 to 2.4) in London, and 3.5 (2.2 to 4.8) in Sofia Lag: 2 day average |
| Curriero 2002 [39] | 11 Eastern US cities, 1973-1994 | Time-series; % change | Daily mean temperature, dew point temperature; minimum mortality temperature (MMT) range: 65.2-90.3 | Per 10F above MMT range 1.4-6.7 Lag: 0 |
| Braga 2001 [11] | 12 US cities. 1986-1993 | Time-series; % increase | Mean daily temperature, relative humidity | 4% increase (no CI given); Lag: 0 or 1 Harvesting effect for hot temperatures |

1 * Exceptions: El-Zein 2004 and Carson 2006 reported annual and weekly deaths, respectively.
2

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 | Causes of death | Result |
|---------------------------------|---|--------------------------------|---|---|--|
| Basu 2008 [6] | 9 California counties, May to September 1999-2003 | Time-series and case-crossover | Same day mean apparent temperature; daily mean O ₃ , also PM _{2.5} , PM ₁₀ , NO ₂ , CO, SO ₂ , lag 0 for PM, lag01 for gases | All-cause mortality | Confounders: none found Effect modifiers: none found |
| Bell 2008 [15] | Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-2002 | Case-crossover | Same day apparent temperature compared with days at 75 th percentile, same day lag O ₃ , same-day lag PM ₁₀ except Santiago lag 1 PM ₁₀ | All-cause daily mortality | Confounders: O ₃ , PM ₁₀ Effect modifiers: not studied |
| McMichael 2008 [45] | 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 | Daily maximum threshold (16C-31C) temperature, relative humidity, precipitation data, PM ₁₀ , BS, or TSP | All-cause mortality | Confounders: none found Effect modifiers: not studied |
| Ren 2008 [22] | US 95 NMMAPS counties, June to September 1987-2000 | Time-series | Daily maximum temperature (same-day, lag 1), maximum hourly O ₃ | CVD mortality | Confounders: not studied Effect modifier: O ₃ |
| Vaneckova 2008a [46] | Sydney, Australia, October to March 1993-2001 | Time-series | Temporal Synoptic Index (TSI) on the highest 10% mortality days, O ₃ , PM ₁₀ | All-cause, circulatory, cerebrovascular | Confounders: O ₃ on warm, humid days and PM ₁₀ on hot, dry days Effect modifiers: not studied |
| Vaneckova 2008b [19] | Sydney, Australia, October to March 1993-2004 | Time-series | Daily maximum temperature, maximum O ₃ | Underlying and associated causes of death | Confounders: O ₃ , PM ₁₀ Effect modifiers: not studied |
| Zanobetti and Schwartz 2008 [7] | 9 U.S. counties, May to September 1999-2002 | Time series and case-crossover | Daily apparent temperature (minimum, mean, maximum); daily mean O ₃ , PM _{2.5} | All-cause mortality | Confounders: none found Effect modifiers: none found |
| Kolb 2007 [32] | Montreal, Canada 1984-1993 | Case-crossover | Mean daily and maximum temperature, barometric pressure, relative humidity, adjusted for O ₃ and both NO ₂ and O ₃ | Daily all-cause mortality | Confounders: none found Effect modifiers: not studied |

| | | | | | |
|------------------------------------|--|----------------------------------|---|--|---|
| Medina-Ramon 2007 [21] | 50 US cities in cold (November to March) and warm (May to September) seasons | Case-crossover | Binary variable as extreme temperature and continuous; O ₃ | All-cause and CVD mortality | Confounder: O ₃ Effect modifiers: not studied |
| Filleul 2006 [23] | 9 French cities, all year and heat wave August 2003 | Time-series | Minimum and maximum temperature, 8-hour maximum O ₃ | Daily all-cause mortality | Confounders: not studied Effect modifier: O ₃ for some cities |
| Ren 2006 [50] | Brisbane, Australia (all year January 1996 to December 2001) | Time-series | Minimum temperature, daily PM ₁₀ as modifier | Cardiorespiratory mortality | Confounders: not studied Effect modifier: PM ₁₀ |
| Stafoggia 2006 [16] | Bologna, Milan, Rome, Turin, 1997-2003 | Case-crossover | 30C mean apparent temperature (lag01) relative to 20C, O ₃ | All-cause mortality | Confounders: none found Effect modifiers: not studied |
| Basu 2005 [5] | 20 US metropolitan areas, seasonal analysis 1992 | Time series (and case-crossover) | Mean daily temperature per 10F adjusted for dew point temperature; daily O ₃ | Individual and daily cardiorespiratory mortality | Confounders: PM ₁₀ in summer Effect modifiers: not studied |
| O'Neill 2005 [18] | Mexico City (1996-98) and Monterrey (1996-99) | Time series; % change | Heat (35-36C for Monterrey), mean temperature (25C Monterrey, 15C Mexico City), daily O ₃ | Daily all-cause mortality | Confounders: O ₃ and PM ₁₀ on hot days Effect modifiers: not studied |
| Rainham and Smoyer-Tomic 2003 [17] | Toronto, May 1 to September 30, 1980-1996 | Time-series; relative risk (RR) | Humidex, O ₃ , also CO, NO ₂ , SO ₂ | Daily all-cause mortality | Confounders: none found Effect modifiers: not studied |
| Pattenden 2003 [49] | Sofia, Bulgaria (1996-1999) and London, England (1993-1996) | Time-series; % change | Daily weather (2-day mean) and PM (black smoke for London and total suspended particulates for Sofia) | Daily all-cause mortality | Confounders: none found Effect modifiers: not studied |

1 **Table 3: Recent Studies Identifying Vulnerable Subgroups of Mortality from High Ambient Temperature**

2

| Reference | Study location | Study design | Exposure | Causes of death | Result |
|--------------------------|--|----------------|---|---|--|
| Baccini 2008 [12] | 15 European cities, April-September 1990-2000 (5-11 years depending on data availability for city) | Time-series | Maximum apparent temperature (threshold 29.4C Mediterranean cities and 23.3C north-continental cities) | Daily all-cause mortality | Respiratory diseases among 75+ years |
| Basu and Ostro 2008 [14] | 9 California counties, May to September 1999-2003 | Case-crossover | Mean daily apparent temperature | Cause-specific mortality; all-cause mortality by age, race/ethnicity, gender, education level | Cardiovascular, higher specifically for ischemic heart disease, myocardial infarction and congestive heart failure, ≤ 1 year, ≤ 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 |
| Bell 2008 [15] | Sao Paulo, Brazil, Santiago, Chile and Mexico City, Mexico, 1998-2002 | Case-crossover | Same day apparent temperature | Daily all-cause mortality | 65+ years, women in Mexico City, but men in Santiago and Sao Paulo, less educated in Sao Paulo |
| Ishigami 2008 [24] | Budapest, London and Milan, 2003 | Time-series | Mean daily temperature (lag0 and lag1), PM ₁₀ (TSP in Budapest), ozone | Daily all-cause mortality | Increased age, females 65+ years greater in London and Milan and non-elderly adults in Milan; mortality from external causes, respiratory and cardiovascular diseases |
| Stafoggia 2008 [30] | 4 Italian cities, 1997-2004 | Case-crossover | Apparent temperature 30C compared to 20C | Deaths in hospitals for those with 2+ days in hospital | Increased age, single general medicine compared to high and intensive care units; history of psychiatric disorders, cerebrovascular diseases, heart failure, stroke, chronic pulmonary diseases |
| Vaneckova 2008a [46] | Sydney, Australia, October to March 1993-2001 | Time-series | Temporal Synoptic Index (TSI); ratio of highest 10% mortality days within air mass and % frequency of air mass occurrence | Daily all-cause mortality | 65+ years, women |
| Yip 2008 [51] | Maricopa County, Arizona, June to September 2000-2005 | Time-series | Heat index | Heat-related deaths | Young and old outdoors, but greater risk for elderly indoors |
| Hajat 2007 [25] | England and Wales, 1993-2003 | Time-series | Heat (>95 th %) and cold (<5 th %) thresholds | All-cause mortality | Elderly, those in nursing care homes; respiratory and external causes, women; modified by deprivation in London |

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