Title: Ambient Temperature and Morbidity: A Review of Epidemiological Evidence

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Abbreviations:

ACS: acute coronary syndrome

CI: confidence interval

PM_{10}: particulate matter less than 10 μm in aerodynamic diameter

ABSTRACT

OBJECTIVE: This paper reviews the epidemiological evidence on the relationship between ambient temperature and morbidity. It assesses the methodological issues in previous studies, and proposes future research directions.

DATA SOURCES AND DATA EXTRACTION: We searched the PubMed database for epidemiological studies on ambient temperature and morbidity of non-communicable diseases published in refereed English journals prior to June 2010. 40 relevant studies were identified. Of these, 24 examined the relationship between ambient temperature and morbidity, 15 investigated the short-term effects of heatwave on morbidity, and 1 assessed both temperature and heatwave effects.

DATA SYNTHESIS: Descriptive and time-series studies were the two main research designs used to investigate the temperature–morbidity relationship. Measurements of temperature exposure and health outcomes used in these studies differed widely. The majority of studies reported a significant relationship between ambient temperature and total or cause-specific morbidities. However, there were some inconsistencies in the direction and magnitude of non-linear lag effects. The lag effect of hot temperature on morbidity was shorter (several days) compared to that of cold temperature (up to a few weeks). The temperature–morbidity relationship may be confounded and/or modified by socio-demographic factors and air pollution.

CONCLUSIONS: There is a significant short-term effect of ambient temperature on total and cause-specific morbidities. However, further research is needed to determine an appropriate temperature measure, consider a diverse range of morbidities, and to use consistent methodology to make different studies more comparable.

INTRODUCTION

It is widely accepted that climate change is occurring, and that it is mainly caused by increased emissions of anthropogenic greenhouse gases, particularly over the last a few decades (IPCC 2007a). Global mean temperature increased by 0.07 ^{o}C per decade between 1906 and 2005, compared with 0.13 ^{o}C per decade from 1956 to 2005 (IPCC 2007b). Not only has the average global surface temperature increased, but the frequency and intensity of temperature extremes have also changed (IPCC 2007a; WHO 2008). Heatwave episodes have been associated with significant health impacts, for example, in 1995 in Chicago (Semenza et al. 1999), 2003 in Europe (Cerutti et al. 2006; Johnson et al. 2005; Larrieu et al. 2008; Mastrangelo et al. 2007; Oberlin et al. 2010), 2006 in California (Knowlton et al. 2009), and 2009 in south-eastern Australia (BoM 2009). In addition, episodes of extreme cold (cold spells) are a concern in high-latitude regions (Pattenden et al. 2003), such as Russia (Revich and Shaposhnikov 2008), the Czech Republic (Kysely et al. 2009) and the Netherlands (Huynen et al. 2001).

The effect of ambient temperature on morbidity is a significant public health issue. Every year, a large number of hospitalizations are associated with exposure to extreme ambient temperatures, especially during heatwaves and cold spells (Juopperi et al. 2002; Michelozzi et al. 2009; Schwartz et al. 2004; Semenza et al. 1999). For example, during the 1995 Chicago heatwave, it was estimated that there were 1072 (11%) excess hospital admissions among all age groups, including 838 (35%) among those aged 65 years and older, with dehydration, heat stroke and heat exhaustion as the main causes (Semenza et al. 1999). Actual numbers of morbidities may be greater than reported, since heat- or cold-related conditions may be listed as secondary diagnoses, while many studies have often considered primary diagnoses only (Kilbourne 1999; Semenza et al. 1999). Both heat- and cold-related morbidities occur more frequently among the elderly, as they are more vulnerable to temperature changes (Johnson et al. 2005; Knowlton et al. 2009; Kovats et al. 2004; Panagiotakos et al. 2004). In addition, urban residents may be exposed to higher temperatures than residents of surrounding suburban and rural areas due to the "heat island effect" resulting from high thermal absorption by dark paved surfaces and buildings, heat emitted from vehicles and air conditioners, lack of vegetation and trees, and poor ventilation (Barry and Chorley 2003; Hajat and Kosatsky 2009; O'Neill and Ebi 2009). Due to the urban heat island effect, people in urban areas are usually at an increased risk of morbidity from ambient heat exposure (O'Neill and Ebi 2009). The morbidity effect of temperature is likely to become more severe as the number of elderly people increases (from 737 million over age 60 in 2009 to 2 billion by 2050 globally) and the proportion of urban residents increases (by approximately 18% of tover the next 40 years), and because climate change will continue for at least the next several decades – even under the most optimistic scenarios (IPCC 2007a; UNDESA 2010a; UNDESA 2010b).

In this paper, we assess the current epidemiological evidence concerning the effects of temperature on morbidity, identify knowledge gaps in this field, and make recommendations for future research directions.

METHODS

The PubMed electronic database was used to retrieve published studies examining the relationship between ambient temperature and morbidity of non-communicable diseases (we excluded communicable diseases such as vector-borne diseases as the research designs and analysis methods differ between communicable and non-communicable diseases). Our primary search used the following U.S. National Library of Medicine's Medical Subject Headings (MeSH terms) and keywords: "weather", "climate", "temperature", "morbidity", "hospitalization", "emergency medical services", "family practice", "primary health care", "heatwave", "heat wave", "cold surge", and "cold spell". All subterms were included, and we limited the search to original epidemiological studies published in English before June 2010.

In order to examine the relationship between ambient temperature and morbidity, all relevant studies were included in this review. Eligibility included any epidemiological studies which used original data and appropriate effect estimates (e.g., regression coefficient, relative risk, odds ratio, percentage change in morbidity, and morbidity or excess morbidity following heatwaves); where ambient temperature or a composite temperature measure was a main exposure of interest; and where the outcome measure included a non-communicable disease (e.g., cardiovascular, cerebrovascular or respiratory diseases). Titles and abstracts were screened for relevance, and full texts were then obtained for further assessment if papers met the inclusion criteria. We also inspected the reference list of each article to check if any studies were missed from the primary electronic search.

RESULTS

A total of 614 articles were identified from the PubMed database, and 76 initially met the eligibility criteria for further full text inspection after reading abstracts (Figure 1). We excluded 41 articles because 3 had no original data, 27 only assessed the effect of season or broad weather conditions, and 11 did not report appropriate effect estimates. 5 studies were added after manually inspecting the reference lists of all relevant articles. Finally, 40 articles were included in the review. Among them, 24 examined the relationship between general ambient temperature and morbidity, 15 investigated short-term effects of heatwaves on morbidity, and 1 assessed both general ambient temperature- and heatwave-related health effects.

Methodological Considerations

Study Designs and Statistical Approaches

A variety of study designs were used to assess the health effects of heatwaves and/or cold spells, and to characterize the association between temperature and morbidity. Most studies employed either a descriptive or time-series study design. Statistical methods varied with study design.

Descriptive studies

Simple comparisons were applied in the analysis of health effects of isolated heatwaves in 7 studies (Cerutti et al. 2006; Ellis et al. 1980; Johnson et al. 2005; Jones et al. 1982; Knowlton et al. 2009; Rydman et al. 1999; Semenza et al. 1999), in addition to studies where risk factors and illnesses studied during heatwaves and cold spells were often characterized in details. To assess effects of heatwaves on morbidity, most of the studies estimated an excess proportion by comparing observed versus expected morbidity. Many methods were used to calculate expected morbidity, which largely depended on the chosen baseline. Usually expected hospital admissions were based on the average number of admissions during comparison days or weeks, for example, the days prior to or after a heatwave, or the same time period in previous years without heatwaves (Huynen et al. 2001; Johnson et al. 2005; Semenza et al. 1999; Yang et al. 2009). Although such comparative analyses can provide useful insights into the short-term response of the population to a heatwave or cold spell event, they may under- or over-estimate effects because of use of an inappropriate baseline, potential morbidity displacement, and lack of control for confounding factors (e.g., air pollution).

Time-series studies

Time-series studies have been widely used to examine short-term effects of temperature on morbidity (Kovats et al. 2004; Linares and Diaz 2008; Michelozzi et al. 2009; Schwartz et al. 2004). Morbidity counts or rates were usually used as the outcome measures, while temperature measurements at corresponding intervals were employed as exposure indicators. Time-series analysis using daily data was commonly applied, but weekly or monthly data were used in some studies, which may make it difficult to detect acute temperature effects on morbidity (Roger and Francesca 2008; Touloumi et al. 2004). Effects were often estimated as the percent change in morbidity per unit increase (or decrease) in temperature (e.g., one or several degrees Centigrade or interquartile range change) (Ebi et al. 2004; Green et al. 2009; Koken et al. 2003; Lin et al. 2009). In this design, confounding is limited to time-varying factors such as air pollution, influenza epidemics, season, holiday, and the day of the week (which could be taken into account in multivariable models).

In general, both hot and cold extremes of temperature have an adverse effect on health which suggests a potential nonlinearity of the temperature effect. Thus Poisson regression through generalized additive models was widely used to assess the temperature–morbidity relationship after adjustment for long-term effects, seasonality and other seasonally varying factors (Barnett et al. 2005; Ren et al. 2006; Schwartz et al. 2004). Alternatively, analyses were stratified by summer/winter or warm/cold periods to remove seasonal patterns and simplify analyses (Lin et al. 2009; Michelozzi et al. 2009; Piver et al. 1999; Wang et al. 2009; Ye et al. 2001). Appropriate temperature thresholds were selected based on model fit (Kovats et al. 2004) or selected cut-off (e.g., percentiles or absolute values of the temperature distribution) (Michelozzi et al. 2009), which facilitated the analysis of health effects of temperature extremes.

Exposure Measurements

Mean daily temperature (Kovats et al. 2004; Liang et al. 2008; Schwartz et al. 2004) was a simple and common temperature indicator. Minimum (Ebi et al. 2004; Linares and Diaz 2008) and maximum temperatures (Linares and Diaz 2008; Wang et al. 2009) were also used in many studies. Diurnal temperature range was reported to be a risk factor for patients suffering from cardiovascular and respiratory diseases (Liang et al. 2008; 2009) . Other studies used biometeorological indices such as apparent temperature (Green et al. 2009; Michelozzi et al. 2009) and Humidex (Mastrangelo et al. 2007). These perceived indices combine air temperature and humidity, and are considered to be better measures of the effect of temperature on the human body than temperature alone. However, no single temperature measure was reported to be superior to the others to predict the mortality (Barnett et al. 2010).

In examining the effect of heatwaves (and cold spells), the first thing to be considered is the definition of the exposure, which may vary with geographic location and climatic condition because the sensitivity of populations to heat stress varies geographically (Hansen et al. 2008a; Knowlton et al. 2009; Kovats et al. 2004; Revich and Shaposhnikov 2008; Robinson 2001). As heat effects in one area may not be applicable to another area, multi-city studies were recently conducted to assess general heat effects (Anderson and Bell 2009; Green et al. 2009; Michelozzi et al. 2009). Besides heatwave intensity, heatwave duration is also an important risk factor in estimating the health effect of heat episodes (Mastrangelo et al. 2007). Vulnerability to heat stress depends on many factors, such as age, pre-existing diseases, environmental humidity, and adaptative response (Bouchama and Knochel 2002; Cui et al. 2005; Parsons 2003). A long heatwave could lead to accumulated heat stress on the body when heat produced and obtained from the environment overwhelms the heat loss by thermoregulation. Over consecutive hot days without cooler nights, individuals may suffer from thermoregulatory failure, increasing the risk of illnesses (Bouchama and Knochel 2002; Parsons 2003). There is also evidence that the effect of extreme cold might increase with increasing duration as low temperature can lead to cardiovascular stress by increasing platelet counts, red cells, blood viscosity, plasma cholesterol, fibrinogen and blood pressure, and increase susceptibility to pulmonary diseases by causing bronchoconstriction (Hong et al. 2003; Huynen et al. 2001; Keatinge et al. 1984; Mercer 2003).

Outcome Measurements

Although admissions for some heat-related conditions such as heat stroke, heat exhaustion, fluid and electrolyte abnormalities, and acute renal failure were higher during heatwaves (Hansen et al. 2008b; Knowlton et al. 2009; Semenza et al. 1999), actual numbers were assumed to be underestimated as many cases were likely to be coded cardiovascular or respiratory diseases in primary diagnoses. As a result, some researchers recommend that primary and secondary discharge diagnoses be considered together to reduce misclassification of heat-related diseases (Kilbourne 1999; Semenza et al. 1999). The common causes of morbidity evaluated in previous studies included total cardiovascular and respiratory diseases (Lin et al. 2009; Linares and Diaz 2008; Michelozzi et al. 2009; Ren et al. 2006) and specific diseases such as stroke (Kyobutungi et al. 2005; Ohshige et al. 2006; Wang et al. 2009), acute myocardial infarction (Chang et al. 2004; Ebi et al. 2004; Schwartz et al. 2004; Ye et al. 2001), and acute coronary syndrome (ACS) (Liang et al. 2008; Panagiotakos et al. 2004).

Some direct cold injuries occur during winter, such as frostbite and hypothermia (Hassi et al. 2005; Juopperi et al. 2002). Ischemic stoke (Hong et al. 2003), coronary events (Barnett et al. 2005) and cardiovascular and respiratory diseases (Hajat et al. 2004; Hajat and Haines 2002) were reported in the studies of cold temperature morbidity. No study has investigated the morbidity after a cold spell, while only a few studies examined cardiovascular and respiratory mortality of extreme cold temperatures (Huynen et al. 2001; Kysely et al. 2009; Revich and Shaposhnikov 2008).

Major Findings

A number of studies examined the relationship between ambient temperature and morbidity. These studies identified the general risks of temperature as well as temperature extremes in multiple areas over time, using different research designs. Table 1 summarizes the findings of ambient temperature–morbidity studies, while Table 2 focuses on those from heatwave studies.

Threshold Effects of Temperature

A non-linear relationship between temperature and morbidity was evident across different studies which illustrated U-, V-, or J-shaped patterns (Kovats et al. 2004; Liang et al. 2008; Lin et al. 2009; Linares and Diaz 2008) with the minimum morbidity at a certain temperature or temperature range (threshold temperature) and increased morbidity below and above the threshold. However, few studies identified clear threshold temperatures based on model fit (Kovats et al. 2004; Lin et al. 2009).

There is some evidence that both hot and cold threshold temperature for morbidity vary by location For example, in a study in New York City, hospital admissions for respiratory diseases increased at temperatures greater than 28.9 ^{o}C (Lin et al. 2009). However, the threshold temperature of respiratory hospital admissions in London was lower (23 ^{o}C) (Kovats et al. 2004) as the cooler summers resulted in lower acclimatization to high temperature. The cold threshold temperature also differed for each region in Quebec, Canada in winter (Bayentin et al. 2010).

Different thresholds have also been identified for different diseases. A large increase in emergency hospital admissions was observed for respiratory diseases at temperatures above 23 ^{o}C in Greater London, while admissions for renal diseases increased above a lower temperature of 18 ^{o}C (Kovats et al. 2004)..

Magnitude of the Effects of Temperature and Heatwave

Consistent with expectations that the relation between temperature and morbidity will follow a V-, or J-shaped curve, a study in Taiwan reported that emergency room admissions for acute coronary syndrome (ACS) were lowest for temperatures of 27–29 °C. Compared with this baseline range, ACS admissions were 28.4% higher for average daily temperatures in the range of 17–27 °C (with a slight increase above 29 °C), and 53.9% higher for temperatures < 17 °C (Liang et al. 2008). To fully assess the shape of the association between temperature and morbidity, it is necessary to evaluate associations across the entire temperature range throughout a year. Studies focused on associations during hot or cold seasons only usually show a linear association of temperature with morbidity. For example, Lin et al. (2009) reported increased counts of cardiovascular (3.6%, 95% CI: 0.3%–6.9%) and respiratory diseases (2.7%, 95% CI: 1.3%–4.2%) with a 1 °C increase in temperature during the summer in New York City, while a study in Brisbane reported a decreased risk of emergency admissions for primary intracerebral hemorrhage with 1 °C increase in minimum temperature (RR=0.95, 95% CI: 0.91–0.98) during the winter (Wang et al. 2009). In contrast, a study of 12 European cities revealed that the association between temperature and cardiovascular and cerebrovascular hospital admissions tended to be negative linear but did not reach statistical significance during hot seasons (Michelozzi et al. 2009). However, some studies that evaluated associations over the entire year also reported evidence of linear, versus J- or V-shaped, associations (Panagiotakos et al. 2004; Schwartz et al. 2004).For example, in 12 U.S. cities, average temperature was positively related to the admissions for heart diseases in the 65+ age group (Schwartz et al. 2004). Cardiovascular, respiratory and cerebrovascular diseases are composed of many subtypes which might react to temperature in different ways (Dawson et al. 2008; Lin et al. 2009; Wang et al. 2009; Ye et al. 2001). For example, hemorrhage stroke and ischemic stroke hospital admissions, which both would be classified as cerebrovascular diseases, showed opposite relationships to temperature increases in California (Green et al. 2009) . Additionally, an interquartile range increase in maximum temperature during hot seasons in Denver was associated with a 12.5% and 28.3% decrease in risk of hospitalization for coronary atherosclerosis and pulmonary heart disease, compared to a 17.5% increase for acute myocardial infarction among the elderly (Koken et al. 2003). It suggested that patients with chronic rather than acute cardiovascular conditions might avoid outdoor exposures during unfavourable weather, resulting in a null or negative association. Moreover, if appointments for mild diseases are postponed or cancelled during extremely hot or cold periods, the effect of temperature on morbidity might be underestimated.

Despite evidence of variation among specific diseases, increased overall morbidity has been consistently associated with heatwaves. For example, during a Chicago heatwave in 1995, there were 838 (35 %) more hospital admissions of the elderly (aged 65 or older) compared to the average number of admissions during comparable weeks (Semenza et al. 1999). A total of 16,166 (3%) excess emergency department visits and 1182 (1%) excess hospitalizations occurred in California during the 2006 heatwave (Knowlton et al. 2009). In England, the 2003 heatwave caused an excess of 1% total emergency hospital admissions (Johnson et al. 2005). A study in Adelaide reported a 4% and 7% increase in total ambulance transport and hospital admissions during heatwaves, as compared with non-heatwave periods (Nitschke et al. 2007).

Lag Structure of Temperature

Some studies explored temporal patterns (lag structure) of the association between exposure to temperature over previous days and health risk on a particular day. Various lag days were reported for the association of temperature with morbidity, ranging from the same day (Green et al. 2009) to one month (Chang et al. 2004), with shorter lags during warmer seasons and longer lags during cooler seasons (Barnett et al. 2005; Hajat and Haines 2002). A study of 12 U.S. cities also reported that associations with hot temperatures were more immediate than with cold temperatures (Schwartz et al. 2004). Most recent studies have reported short-term effects of high temperature on the same day and the three days following heat exposure

(Green et al. 2009; Koken et al. 2003; Lin et al. 2009). For example, the greatest number of hospital admissions for respiratory and cardiovascular diseases were observed 0–1 days and 1–3 days following increased temperatures (Lin et al. 2009). Seven-day lag was used to evaluate the effect of temperature on hospital admissions for several specific cardiovascular diseases (Ebi et al. 2004). One-month lag has also been reported by a study that evaluated average temperatures over a monthly period across several whole years (Chang et al. 2004), but it was not clear whether the effects would have been more immediate if daily data had been evaluated. Hajat and Haines (2002) found a strong association between consultations for respiratory disease and mean temperature below 5 ^{o}C over a 10-day period (i.e. 6–15 days before the consultation) in London, which implied a later and longer lag for cold temperatures than hot ones.

Harvesting Effects of Temperature

Evidence of a harvesting effect (e.g., mortality displacement) has been documented by studies of heat-related mortality (Braga et al. 2002; Muggeo and Hajat 2009) that showed an immediate increase in mortality followed by reduced mortality among susceptible people, consistent with a temporal advance in deaths that would have occurred later in time in the absence of exposure to heat or cold. However, the impact of harvesting on morbidity has not been fully investigated, and short-, intermediate- and long-term effects should be examined for to determine the impact of harvesting. Schwartz et al. (2004) reported evidence of a short-term advance in emergency hospital admissions for heart diseases and myocardial infarction in people aged 65+ within a few days after high temperature exposure, with a positive association on the day of admission followed by a period of lower-than-average admissions, returning to the baseline after a week. No evidence of a harvesting effect was observed for cold weather in this study (Schwartz et al. 2004). No other temperature–morbidity studies have formally investigated the harvesting issue.

Confounding and Modification of the Temperature–Morbidity Relationship

Some socio-demographic factors might confound and/or modify the temperature–morbidity relationship. Children and the elderly are usually susceptible to heat- or cold-related health risks. Although there was evidence for heat-related increases in emergency admissions for children under 5 years (Kovats et al. 2004), more studies reported the highest-risk age groups to be those over 65 (Hong et al. 2003; Knowlton et al. 2009; Semenza et al. 1999) or 75 years old (Johnson et al. 2005; Kovats et al. 2004; Lin et al. 2009). Women have been reported to have greater risks for coronary events, ACS and ischemic stroke in cold periods than men (Barnett et al. 2005; Hong et al. 2003; Panagiotakos et al. 2004). However, emergency transport cases for heat stroke, cardiac insufficiency, hypertension, myocardial infarction, asthma, chronic bronchitis, and pneumonia were greater in males than in females during the summer in Tokyo (Piver et al. 1999; Ye et al. 2001). Lin et al (2009) reported higher risks for people of Hispanic ethnicity than those of non-Hispanic ethnicity (6.1% vs. 1.7%) of being admitted to hospital for respiratory diseases during the summer in New York, while no effect modification by race/ethnicity (e.g., White, Black, Hispanic, and Asian) or gender was found in the association between mean apparent temperature and hospital admissions for cardiovascular and respiratory diseases in California (Green et al. 2009).

In many locations, concentrations of air pollutants are associated with meteorological conditions. For example, there is usually a higher ozone concentration in summer as it is a secondary pollutant caused by the reaction of volatile organic compounds, carbon monoxide and nitrogen dioxide in the presence of sunlight, while PM_{10} peaks during the winter in many places due to the combustion of coal and/or wood for heating. These pollutants are often controlled for when considering the effect of ambient temperature on morbidity (Kovats et al. 2004; Liang et al. 2008; Linares and Diaz 2008; Michelozzi et al. 2009). However, few studies have explored whether exposure to air pollution modifies associations between temperature and morbidity. Ren et al. (2006) reported that PM_{10} significantly modified the relationship between daily minimum temperature and hospital admissions for cardiovascular and respiratory diseases in Brisbane, with stronger estimated effects of temperature at higher levels of PM_{10}. In a multi-city European study, ozone did not appear to modify or confound associations between hot temperature and hospital admissions for cardiovascular, cerebrovascular, and respiratory diseases (Michelozzi et al. 2009).

CONCLUSIONS AND RECOMMENDATIONS

We identified 40 relevant studies, with most of them being conducted in America and Europe during the last decade. Some descriptive studies provided early evidence of heat-related morbidity in specific cities during a single heatwave, and recently research has expanded to address the temperature–morbidity relationship in larger and more diverse populations in multiple areas. Although the case-crossover approach has been seldom used (Green et al. 2009; Hong et al. 2003; Kyobutungi et al. 2005), it is expected to be increasingly applied due to its ability to effectively control for individual-level confounding.

A number of well-controlled studies showed that ambient temperature was significantly associated with total and cause-specific morbidities, in which most reported heat effects with only a few reporting cold effects. Several studies found U- or V-shaped exposure-response relationships with morbidity increasing at both ends of the temperature scale. The majority of studies reported detrimental effects of heat on the same day or up to following three days, and longer cold effects up to a 2–3 weeks lag with no substantial effects after more than one month.

A number of reasons may explain the heterogeneity of results across these studies. First, previous studies covered a wide range of populations in various geographical locations. Besides different demographic characteristics, some domestic and local adaptation factors could influence the direction and magnitude of the effects of ambient temperature on non-fatal health outcomes. For example, Ostro et al.(2010) estimated that the use of air conditioning could significantly reduce the effects of temperature on hospitalizations for multiple diseases, with 0.76% absolute reduction in excess risk of cardiovascular disease for every 10% increase in air conditioner ownership. Second, many different temperature indicators have been used to define exposure, including minimum, mean, maximum temperature, diurnal temperature range, apparent temperature, and Humidex. However, which temperature measure is better to predict morbidity remains to be determined. Third, studies have evaluated many different measures of morbidity, including general practitioner visits (Hajat et al. 2004; Hajat and Haines 2002), emergency department visits or admissions (Liang et al. 2009; Wang et al. 2009), and hospitalizations (Lin et al. 2009; Michelozzi et al. 2009). They are not mutually exclusive (e.g., a patient visiting an emergency department could be subsequently admitted into hospital). Emergency is typically considered to be less severe and more acute than hospitalization, which implies that it can catch the effect of temperature change at the early stage. It has been suggested that studies including emergency department visits may yield more valuable information for describing the epidemiology of temperature-related morbidity than a hospitalization-only study (Knowlton et al. 2009). Finally, there were also many methodological differences across studies, including statistical models, study population characteristics (e.g., age and gender), use of lag days (e.g., a single lag and multiple-lag), and potential confounders considered.

The IPCC has projected that global mean surface temperature will increase by 1.8–4.0 ^{o}C (best estimate) by 2100 relative to 1980–1999 (IPCC 2007a). Therefore, efforts to understand how climate change will affect health are urgently needed. Further studies are warranted to determine appropriate measures of exposure for morbidity research; to estimate non-linear delayed temperature effects; to investigate the threshold temperatures in specific locations;

and to understand the relative importance and interactive effects of air pollutants and temperature on morbidity – especially in areas with high air pollution. More multi-city studies with consistent methodology should be conducted to make it easy to compare and interpret the temperature effects on morbidity across cities. There is also a need to consider more than one type of morbidity, and track cases from one health service to another by linking medical records. Such studies will provide valuable information for designing and implementing intervention strategies to alleviate the public health impacts of climate change.

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Table 1. Characteristics of the ambient temperature– morbidity studies (n=25).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Studies of both hot and cold exposure:						
Ebi et al. 2004	Three California regions, USA, 1983–1997 nand January–June 1998	Minimum and maximum temperature	Hospitalizations for AMI, angina pectoris, CHF, stroke	Time-series; Poisson regression, GEE	Temperature changes (a 3°C increase in maximum temperature, or a 3 °C decrease in minimum temperature) increased hospitalizations for residents 70+ years of age by 6%–13% in San Francisco and 6%–18% in Sacramento, small changes in Los Angeles Association varied by region, age and gender Lag: 7 days	Normal weather periods and El Nino events were analysed separately and combined; no air pollution was controlled for.
Schwartz et al. 2004	12 Cities, USA, 1986–1994	Daily mean temperature	Urgent hospital admissions for heart disease and MI, aged ≥ 65 years	Time-series; Poisson regression, distributed lag models	Positive linear relation for all heart diseases RR=1.15 (0.96–1.37) increased risk of 80 °F (compared with 0 °F) Harvesting effect (within 10 days) in hot temperatures but not in cold weather Similar but smaller effects of temperature for MI admissions Lag: 0, 1 day	Systematically examined temperature and morbidity in several U.S. cities with various climates; air pollution was not controlled for as confounder.

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Bayentin et al. 2010	Quebec, Canada, April 1, 1989–March 31, 2006	Mean temperature	Hospitalization for IHD	Time-series; GAM	V or U-shaped curves threshold different for each region and for both genders Lag duration dependent on the region High admissions observed earlier in 65+ age group; high excess risks associated with high smoking prevalence and high deprivation indexes (material or social)	No air pollution was controlled for; only description of deprivation indexes presented, rather cooperated it into model
Ohshige et al. 2006	Yokohama, Japan, 1992–2003	Mean temperature	Stroke incidence of emergency transport events, aged ≥50 years	Time-series; Poisson regression, ordinary least squares regression	Significant negative effect of mean temperature on the stoke incidence of the emergency transport events	Ranges rather than actual values of temperature, humidity and barometric pressure were used; no air pollution was controlled for
Liang et al. 2008	Taichung, Taiwan, January 1, 2000–March 31, 2003	Mean temperature, DTR	Emergency room admissions for ACS	Time-series; Poisson regression	28.4% increase risk for 17–27 °C and 53.9% for lower than 17 °C (reference 27–29 °C of mean temperature) 34.4% increase risk for above 9.6 °C (reference <5.8 °C of DTR)	Only one hospital was included

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Liang et al. 2009	Taichung, Taiwan, 2001–2002	Mean temperature, DTR	Emergency room admissions for COPD	Time-series; Poisson regression	RR=1.2 for 22.95–26.58 ^{o}C and RR=1.5 for lower than 22.95 ^{o}C (reference 29.42 ^{o}C of mean temperature) RR=1.14 for above 9.6 ^{o}C (reference <6.6 ^{o}C of DTR)	Only one hospital was included
Ren et al 2006	Brisbane, Australia, 1996–2001	Minimum temperature	Hospital admissions and emergency visits for CVD and RD	Time-series; Poisson GAM, nonparametric bivariate response model, non-/stratification model	PM_{10} modified the effects of temperature on respiratory and cardiovascular hospital admissions with enhanced adverse effects at high level, but no clear evidence for emergency visits Lag: 0–2 days	First to examine the PM_{10} modification of the association between temperature and health outcomes
Wang et al. 2009	Brisbane, Australia, summer and winter, 1996–2005	Minimum and maximum temperature	Emergency admissions for PIH and IS	Time-series; GEE	Different response of PIH and IS to temperature variation by season 1 ^{o}C increase in minimum and maximum temperature 15% (5%–26%) and 12% (2%–22%) for PIH in <65 years in summer; 1 ^{o}C decrease in minimum and maximum temperature 6% (2%–10%) and 7% (4%–11%) for PIH in ≥65 years in winter	First to examine the impact of temperature variation on different types of stroke morbidity in a sub-tropical city

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Rothwell et al.1996	Oxfordshire, UK, 1980s	Mean temperature	First ever in a lifetime stroke	Chi-square	There was no significant seasonal variation. The incidence of primary intracerebral haemorrhage was increased at low temperature, but not for ischaemic stroke or subarachnoid haemorrahage.	Community- rather than hospital-based study was conducted to avoid selection bias; the incidence of first ever in a lifetime stroke was collected; no confounders were controlled for
Panagiotakos et al.2004	Athens, Greece, January 2001–August 2002	Daily mean/ minimum/maximum temperature, T.H.I.	Non-fatal ACS in the emergency units	Time-series; GAM	Negative correlation between hospital admissions for ACS and daily temperature Per 1 ^{o}C decrease in mean temperature 5.0% (4.6%–5.4%) increase hospital admissions for ACS, similar results for minimum, maximum temperatures and T.H.I. Stronger association in females and the elderly	No air pollution was controlled for
Kyobutungi et al. 2005	Heidelberg, Germany, August 1998–January 2000	Maximum temperature and 24-hour difference in maximum temperature	Ischemic stroke incidence	Case-crossover; Conditional logistic regression	No risk associated with ambient maximum temperature and its 24-hour difference	Use both absolute temperature and temperature difference in one day; no air pollution was controlled for

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Dawson et al. 2008	Scotland, May 1, 1990–June 22, 2005	Mean/minimum/ maximum temperature, mean temperature change over the preceding 24 and 48h	Acute stroke hospital admissions	Time-series; Negative binomial regression, Poisson regression	1 ^{o}C increase in mean temperature during the preceding 24h 2.1% (0.7%–3.5%) increase in ischaemic stroke admissions	No air pollution was controlled for
Chang et al. 2004	Seventeen countries, February 1989–January 1995	Monthly mean temperature	Monthly number of newly diagnosed cases of VTE, stroke or AMI, women aged 15–49 years	Time-series; Negative binomial regression	Significant negative associations with temperature for stroke and AMI, but not for VET 5 ^{o}C increase in mean temperature IRR=0.93 (0.89–0.97) for stroke and IRR=0.88 (0.80–0.97) for AMI Lag: within one month No modification of age and high blood pressure	Monthly mean values were used; no air pollution was controlled for

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Hot exposure only:						
Koken et al. 2003	Denver,USA, July–August, 1993–1997	Maximum temperature	Hospital admissions for CVD, aged >65 years	Time-series; Poisson regression, GLM, GEE	1 °C increase 17.5% (2.9%–34.3%), 13.2% (2.9%–24.4%), -12.5%(-18.9%–-5.5%), and -28.3% (-38.4%–-16.5%) for AMI, CHF, coronary atherosclerosis and pulmonary heart disease, respectively Lag: 0, 1 day Male had higher numbers of hospital admissions than female	Only July and August were included
Green et al. 2009	Nine California counties, USA, May–September, 1999–2005	Mean apparent temperature	Hospital admissions for CVD, RD, diabetes, dehydration, heat stroke, intestinal infectious diseases, and ARF	Case-crossover; Conditional logistic regression, meta-analysis	Per 10 °F increase apparent temperature, 2.0% (0.7%–3.2%) excess risk in RD, 3.7% pneumonia, 3.1% diabetes, 10.8% dehydration, 7.4% ARF, 404.0% heat stroke, and -10.4% in hemorrhagic stroke Lag: 0 Effect differed by age, little evidence of effect modification of gender, ethnicity, $PM_{2.5}$ and ozone, and non-linearity	GIS methods were used to improve exposure assessment

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Lin et al. 2009	New York, USA, summer, 1991–2004	Mean temperature, mean apparent temperature, 3-day moving average of apparent temperature	Hospital admissions for CVD and RD	Time-series; GAM, linear-threshold model	1 ^{o}C increase above mean temperature threshold 2.7% (1.25%–4.16%) for RD on the same day and 3.6% (0.32%–6.94%) for CD on lag-3 day 1 ^{o}C increase above mean apparent temperature threshold 2.1% (1.1%–3.1%) and 1.4% (0.4%–2.4%) for RD on the same day and 1 day later; 2.5%, 2.1%, and 3.6% at 1, 2, and 3days later for CD Lag: 0–3 days Positive interaction between high temperature (above 29.4 ^{o}C) and humidity Greater increases of CVD and RD admissions in Hispanic persons, the elderly and low-income persons; gender and disease type interacted with temperature	One city was included; first to examine the independent and joint effects of temperature and humidity; conducted stratified analyses based on family income
Piver et al. 1999	Tokyo, Japan, July and August 1980–1995	Daily maximum temperature	Emergency transport cases for heat stroke	Time-series; GLM, GEE	Daily maximum temperature associated with heat stroke Greater number of heat stroke emergency transport cases in male than in female; smallest risk in female aged 0–14 years and the greatest in male >65 years	Only July and August were included

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Ye et al. 2001	Tokyo, Japan, July and August 1980–1995	Daily maximum temperature	Hospital emergency transports for CVD and RD aged > 65 years	Time-series; GLM, GEE	Except hypertension and pneumonia, daily maximum temperature not associated with hospital emergency transport 1 ^{o}C increase 3.8% (2.0%–5.0%) increase in pneumonia and 1.4% (0.4%–2.0%) decrease in hypertension Lag: 0	Only July and August were included. Several specific diseases were considered
Kovats et al. 2004	Greater London, UK, April 1, 1994– March 31, 2000	3-day moving average temperature	Emergency hospital admissions for CVD, RD, CD, renal disease, ARF, calculus of the kidney and ureter	Time-series; Autoregressive Poisson regression, hockey stick model	No relation between total emergency hospital admissions and high temperature; 1 ^{o}C above threshold 5.44% (1.92%–9.09%) for RD, 1.30% (0.27%–2.35%) for renal disease, 0.24% (0.02%–0.46%) in children under 5, and 10.86% (4.44%–17.67%) for RD in 75+ age group	Contrasting patterns of mortality and hospital admissions during hot weather

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Linares and Diaz 2008	Madrid, Spain, May–September, 1995–2000	Maximum and minimum temperatures	Emergency hospital admissions for all causes, RD and CVD	Time-series; ARIMA	V-shaped relationship 1 ^{o}C increase above maximum temperature threshold 36 ^{o}C 4.6% (0.9%–8.4%) for all causes in the all age group (lag 0), 17.9% (9.5%–26.0%) for all causes in the 75+ age group (lag 1) and 27.5% (13.3%–41.4%) for RD in the 75+ age group (lag 0); no relationship between heat (above 36 ^{o}C) and admissions for CVD in all the age groups Lag: 0,1	One hospital data was used
Michelozzi et al. 2009	Twelve European cities, April–September, each city ≥3 years during1990–2001	Maximum apparent temperature	Hospital admission for CVD, CD and RD	Time-series; GEE, random effect meta-analysis	No or tendentious negative relationship between temperature and CVD and CD; 1 ^{o}C increase above threshold 14.5% (1.9%–7.3%) in Mediterranean and 13.1% (0.8%–5.5%) in North-Continental region in the 75+ age group for RD, almost twice that of all ages Lag: 0–3 days	First attempt to evaluate the effect of temperature on several morbidity outcomes using a standardized methodology in a multi-centre European study

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Cold exposure only:						
Hong et al. 2003	Incheon, Korea, 1998–2000	Daily average temperature, 3-hour average temperature	IS onset	Case-crossover; Conditional logistic regression	IS onset was associated with decrease in temperature. One interquartile range decrease in temperature (17.4 °C) OR=2.9 (1.5–5.3) for IS on lag 1 Lag: 1 day, 24–54 h Stronger effects for women, >65 years, non-obese persons and those with hypertension or hypercholesterolemia , and in winter	Used bi-directional control selection scheme; assessed lag structure in hours
Hajat and Haines 2002	London, UK, January 1992–September 1995	Mean temperature	GP consultation for RD and CVD, aged ≥65 years	Time-series; GAM	1 °C decrease below 5 °C, 10.5% (7.6%–13.4%) increase in RD and 12.4% (0.7%–25.4%) in asthma; no relationship between cold temperature and GP for CVD Lag: 6–15 days	Primary care data could be influenced by patient behaviours and service availability

Table 1. Characteristics of the ambient temperature– morbidity studies (n=25) (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Hajat et al. 2004	UK, 1992–2001	Mean temperature	GP consultations for RD, aged ≥65 years	Time-series; GLM	Linear association between low temperature and an increase in RD in all 16 locations 1 ^{o}C decrease below 5 ^{o}C, biggest effect 19.0% (13.6%–24.7%) increase in Norwich for lower respiratory tract infections; weaker relationships for upper respiratory tract infections consulation Lag: 0–20 days Larger effects in the north than the south	Primary care data was used
Barnett et al. 2005	Twenty-four populations, 1980–1995	Mean temperature	Daily records of coronary events, aged 35–64 years	Time-series; Distributed lag model, hierarchical meta-regression; logistic model, Bayesian hierarchical model	Daily rates of coronary events negative correlated with the average temperature Lag: 0–3 days Coronary event rates increased more in populations living in warm climates than cold climates Greater increase in women than in men with the odds 1.07 (1.03–1.11)	Air pollutants and respiratory infections were not controlled for

[a]These studies are ordered by the place investigated (America, Asia, Australia, Europe, and the worldwide), and then the date of publication and the first author.

Abbreviations: ACS, acute coronary syndrome; (A)MI, (acute) myocardial infarction; ARF, acute renal failure; ARIMA, Autoregressive Integrated Moving Average model; CD, cerebrovascular diseases; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular diseases; DTR, diurnal temperature range; GAM, Generalized additive models; GEE, generalized estimating equations; GIS, geographic information system; GLM, Generalised linear models; GP, general practitioner; IHD, ischemic heart disease; (I)RR, (incidence) rate ratio; IS, ischemic stroke; OR, odds ratio; PIH, primary intracerebral hemorrhage; RD, respiratory diseases; T.H.I., thermo-hydrological index; VTE, venous thromboembolism.

Table 2. Characteristics of the heatwave–morbidity studies (n=16).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Ellis et al. 1980	Birmingham, UK, June24–July 8, 1976	Heatwave fortnight with the reference period (two-week periods before and after the heat wave, same days in 1974 and 1975)	Mortality and morbidity	Descriptive study	Daily deaths increased significantly during heatwave. No increase of new claims for sickness benefit in working people. More hospital admissions during heatwave than for the same period in 1975 or 1974. Modest increase in the episodes of sickness in two large general practices.	One single heatwave was studied. Four different types of morbidity were used.
Applegate et 1981	Memphis, USA, June 25–July 20,1980	heatwave	Heat-related emergency room visits, hospital admissions and deaths	Descriptive study	Heat-related emergency room visits, hospital admissions and deaths rose markedly during heatwave. The most severe effects were seen in elderly, poor, black inner-city residents.	A survey of elderly persons receiving home health care was conducted during the heatwave.
Jones et al. 1982	St Louis and Kansas, USA, June and July, 1980	Heatwave with the same periods in 1979 and 1978	Total hospital admissions, emergency room visits and deaths from all causes	Descriptive study	Deaths, hospital admissions, and emergency room visits from all causes increased during heatwave in 1980 compared with 1979 and 1978 in St Louis and Kansas. Higher heat stroke rates were found in the elderly, the poor, and non-whites.	Used hospital records, medical examiners' records and death certificated to identify cases.
Faunt et al. 1995	Adelaide, Australia, February 1993	Ten-day heatwave	Emergency department presentations	Retrospective survey; Descriptive analysis	94 patients had heat-related illness of whom78% had heat exhaustion. 85% were aged ≥ 60 years; 20% came from institutional care; 48% lived alone; 30% had poor mobility. Severity was related to pre-existing conditions.	One single heatwave was studied. Only four hospitals were included.

Table 2. Characteristics of the heatwave–morbidity studies (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Rydman et al. 1999	Chicago, USA, July 6–19, 1995	Heatwave with the same period in 1994	Emergency departments visits	Descriptive study; Chi-square, t-test, linear regression	There were 2446 excess morbidity cases. Heat morbidity increased 5 days prior to the first heat-related death. The most frequent heat-related diagnoses were hyperthermia, heat exhaustion and heat stroke. Different morbidity was found in age groups, comorbid primary diseases, and disposition.	One single heatwave was studied.
Semenza et al. 1999	Chicago, USA, July 13–19, 1995	Heatwave week with 4 non-heatwave comparison weeks	Excess hospital admissions	Descriptive study	1072 (11%) more hospitalizations and 838 (35%) exceeded in the patients aged ≥ 65 years. The majority of the excess were dehydration, heat stroke, heat exhaustion and acute renal failure. There was significant excess of underlying cardiovascular diseases, diabetes, renal diseases and nervous system disorders.	Different spectrum of illnesses between primary and all discharge diagnoses during the heatwave.
Kovats et al. 2004	Greater London, UK, July 29–August 3, 1995	Heatwave	Excess emergency hospital admissions	Time-series; Autoregressive Poisson regression, hockey stick model	Hospital admissions showed a small non-significant increase of 2.6% (95% CI: -2.2–7.6), while daily mortality rose by 10.8% (95% CI: 2.8–19.3).	Contract between hospital admissions and mortality.
Johnson et al. 2005	England, August 4–13, 2003	Ten-day heatwave period compared with the same time in 1998–2002	Excess mortality and emergency hospital admissions	Descriptive study	There ware 2091 excess deaths (17%). People aged ≥ 75 years were at the greatest risk. An excess of only 1% in total emergency hospital admissions was found.	The increases of emergency hospital admissions were not comparable to mortality.

Table 2. Characteristics of the heatwave–morbidity studies (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Cerutti et al. 2006	Ticino, Switzerland, 2003	Three heatwaves compared with previous years (2000–2002)	Excess mortality and emergency ambulances service intervention	Descriptive study	The 2003 mortality in the population was not significantly different from the previous years except for the first heatwave. The number of ambulance service interventions was larger than during the previous years.	Daily rates rather than raw numbers of deaths or intervention were used.
Mastrangelo et al. 2006	Veneto Region, Italy, June 1–August 31, 2002–2003	Five consecutive heatwaves	Daily count of hospital admission by cause in people aged 74+ years	Ecologic study; Generalized estimating equations	Heatwave duration, not intensity, increased the risk of hospital admissions for heat diseases and respiratory diseases by, respectively, 16 % ($p < 0.0001$) and 5 % ($p < 0.0001$) with each additional day of heatwave duration. At least 4 consecutive hot humid days were required to observe a major increase in hospital admissions. Hospital admissions peaked equally at the first and last heatwave in 2003.	Heatwave duration, intensity and timing were considered.
Nitschke et al. 2007	Adelaide, Australia, July 1993–June 2006	31 heatwaves compared with non-heatwave periods during spring and summer	Daily ambulance transports, hospital admissions and mortality	Case-series study; Poisson regression, negative binomial regression	Total ambulance transport and total hospital admissions increased by 4% (95% CI: 1%–7%) and 7% (95% CI: -1%–16%), respectively. Admissions for mental health, renal diseases and ischaemic heart disease among people aged 65–74 years increased by 7% (95% CI: 1%–13%), 13% (95% CI: 3%–25%) and 8% (95% CI: 1%–15%), respectively. Mortality did not increase.	Three kinds of health endpoints were used.

Table 2. Characteristics of the heatwave–morbidity studies (continued).

Study[a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Hansen et al. 2008a	Adelaide, Australia, July 1, 1993–June 30, 2006	Heatwaves, daily maximum temperature	Daily counts of admissions and MBDs	Time-series; Poisson regression, hockey stick regression	Hospital admissions increased by 7.3% during heatwaves. Above a threshold of 26.7 °C, there was a positive association between ambient temperature and hospital admissions for MBDs. MBDs mortalities increased during heatwaves in the elderly.	First to characterize specific disorders that contributed to increased psychiatric morbidity and mortality during heatwaves.
Hansen et al. 2008b	Adelaide, Australia, 1995–2006	Heatwaves	Daily hospital admissions for renal disease, ARF and renal dialysis	Time-series; Poisson regression	Admissions for renal disease and ARF increased during heatwaves with IRR=1.10 (95% CI: 1.00–1.21) and IRR=1.26 (95% CI: 1.04–1.52), respectively. Hospitalizations for dialysis showed no increase. Pre-existing diabetes did not increase the risk of renal admission.	First investigated the association between high temperature and renal morbidity in a temperate Australian region.
Larrieu et al. 2008	France, 2003	2003 heatwave	Felt morbidity, objective morbidity of elderly people	Cross-sectional study; Chi-square, t-test, logistic regression	During the heatwave, 8.8% of the subjects felt a deterioration of heath, and 7.8% declared an objective morbid outcome. Many factors were associated with morbidity.	It is an exploratory study by using a questionnaire to collect data from subjects.

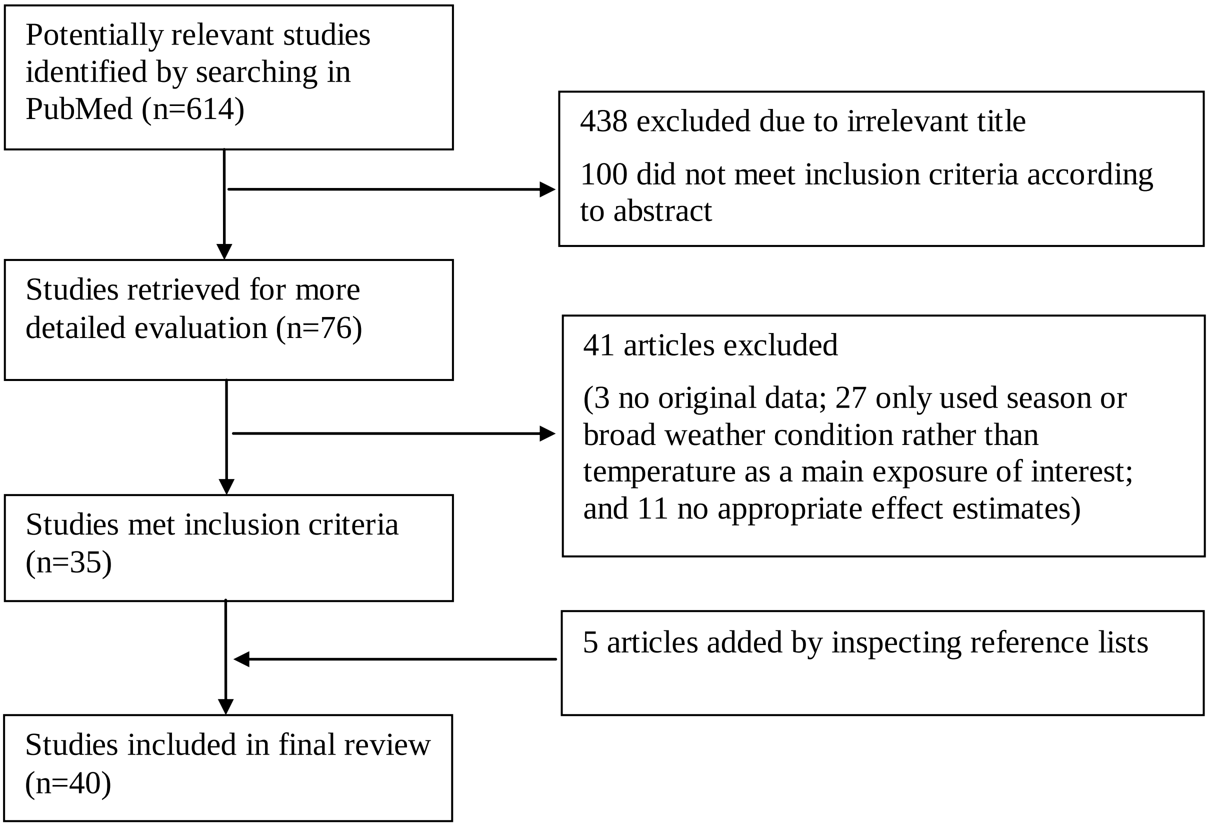
Table 2. Characteristics of the heatwave–morbidity studies (continued).

Study [a]	Location and time	Main temperature exposure variable(s)	Outcome(s)	Research design and statistical analysis	Key findings	Comments
Knowlton et al. 2009	California, USA, July 15–August 1, 2006	Heatwave with the reference period (July 8–14, August 12–22, 2006)	Excess hospitalizations and emergency department visits	Descriptive study	16,166 excess emergency department visits and 1,182 excess hospitalizations. Emergency department visits (RR = 6.30, 95% CI: 5.67–7.01) and hospitalizations (RR = 10.15, 95% CI: 7.79–13.43) for heat-related causes increased. There were significant increases for ARF, cardiovascular diseases, diabetes, electrolyte imbalance, and nephritis. The heat wave impact on morbidity varied across regions, race/ethnicity, and age groups. Children (0–4 years) and the elderly (≥ 65 years) were at greatest risk.	Principal and the first 9 secondary diagnoses were included. Using both ED visits and hospitalization.
Oberlin et al. 2010	Toulouse, France, August 1–31, 2003	heatwave	Emergency department admissions of patients aged >65 years	Retrospective study; Descriptive analysis	42 (5.5%) patients had heat-related illness. They were more likely to live in institutional care rather than at home and had longer length of stay and higher death rate than non-heat-related illness.	Double check medical record to ascertain heat-related illness.

[a]These studies are ordered by the date of publication and the first author.

Abbreviations: ARF, acute renal failure; CI, confidence interval; IRR, incidence rate ratio; MBDs, mental and behavioural disorders

Figure 1. Flow chart of literature search strategy


Potentially relevant studies identified by searching in PubMed (n=614)
438 excluded due to irrelevant title
100 did not meet inclusion criteria according to abstract
Studies retrieved for more detailed evaluation (n=76)
41 articles excluded
(3 no original data; 27 only used season or broad weather condition rather than temperature as a main exposure of interest; and 11 no appropriate effect estimates)
Studies met inclusion criteria (n=35)
5 articles added by inspecting reference lists
Studies included in final review (n=40)