Int J Biometeorol (2014) 58:1893–1903
DOI 10.1007/s00484-014-0791-y

ORIGINAL PAPER

The impact of heat, cold, and heat waves on hospital admissions in eight cities in Korea

Ji-Young Son · Michelle L. Bell · Jong-Tae Lee

Received: 31 March 2013 / Revised: 25 October 2013 / Accepted: 6 January 2014 / Published online: 21 January 2014
© ISB 2014

Abstract Although the impact of temperature on mortality is well documented, relatively fewer studies have evaluated the associations of temperature with morbidity outcomes such as hospital admissions, and most studies were conducted in North America or Europe. We evaluated weather and hospital admissions including specific causes (allergic disease, asthma, selected respiratory disease, and cardiovascular disease) in eight major cities in Korea from 2003 to 2008. We also explored potential effect modification by individual characteristics such as sex and age. We used hierarchical modeling to first estimate city-specific associations between heat, cold, or heat waves and hospitalizations, and then estimated overall effects. Stratified analyses were performed by cause of hospitalization, sex, and age (0–14, 15–64, 65–74, and ≥75 years). Cardiovascular hospitalizations were significantly associated with high temperature, whereas hospitalizations for allergic disease, asthma, and selected respiratory disease were significantly associated with low temperature. The overall heat effect for cardiovascular hospitalization was a 4.5 % (95 % confidence interval 0.7, 8.5 %) increase in risk comparing hospitalizations at 25 to 15 °C. For cold effect, the overall increase in risk of hospitalizations comparing 2 with 15 °C was 50.5 (13.7, 99.2 %), 43.6 (8.9, 89.5 %), and 53.6 % (9.8, 114.9 %) for allergic disease, asthma, and selected respiratory disease, respectively. We did not find statistically significant effects of heat waves compared with nonheat wave days. Our results suggest susceptible populations such as women and younger persons. Our findings provide suggestive evidence that both high and low ambient temperatures are associated with the risk of hospital admissions, particularly in women or younger person, in Korea.

Keywords Bayesian hierarchical model · Cold · Heat · Heat wave · Hospital admissions

Introduction

The environmental exposure of weather has received growing attention due to several extreme events with substantial public health consequences. These include the 2003 heat wave in France that increased mortality by an estimated 141 % in Paris, with higher risks for women and the elderly (Canouï-Poitrine et al. 2006; Poumadère et al. 2005). In addition, climate change is anticipated to alter weather patterns with more frequent, intense, and longer heat waves, as well as more extreme temperatures, which could have a substantial health burden (Haines et al. 2006; Peng et al. 2011). Thus, a better understanding of how heat, cold, and heat waves impact human health is needed in order to protect public health in the present day and to understand potential impacts in the future.

Although many studies have addressed the impact of temperature on mortality (e.g., Anderson and Bell 2009; Medina-Ramon et al. 2006; O'Neill et al. 2003; Son et al. 2011), relatively fewer studies have evaluated the effects of temperature on morbidity outcomes, such as hospital admissions. Evidence on health impacts other than mortality is needed to understand the full scope of weather's impacts on health. Furthermore, most of the existing studies were conducted in

Electronic supplementary material The online version of this article (doi:10.1007/s00484-014-0791-y) contains supplementary material, which is available to authorized users.

J.-Y. Son · M. L. Bell
School of Forestry and Environmental Studies, Yale University, New Haven, CT, USA

J.-T. Lee (✉)
Department of Environmental Health, College of Health Science, Korea University, San 1 Jeongreung-dong, Seongbuk-gu, Seoul, South Korea 136-703
e-mail: jtlee@korea.ac.kr

North America or Europe. The studies that have been conducted suggest a substantial increase in risk of hospitalization from cardiovascular and respiratory disease (Lin et al. 2009b; Linares and Diaz 2008; Michelozzi et al. 2009; Ren et al. 2006), including hospital admissions from cardiovascular disease such as acute myocardial infarction and stroke (Dawson et al. 2008; Ebi et al. 2004; Koken et al. 2003).

Previous mortality studies have shown that temperature's effects differ by location and population. Several studies have demonstrated variation in the temperature-mortality relationship by race, sex, age, socioeconomic status, and adaptation measures such as air conditioning (Anderson and Bell 2009; Bell et al. 2008; O'Neill et al. 2003). However, the influences of some effect modifiers still remain unclear. For example, some studies identified a higher temperature effect among women for mortality, while others observed men to be a greater risk (Bell et al. 2008; Son et al. 2011; Yu et al. 2010). On the other hand, some studies reported no effect modification by sex (Basu and Ostro 2008). Moreover, the effects of ambient temperature and what subpopulation is most vulnerable to temperature depend on the cause and type of health outcome considered as well as several factors such as population characteristics (e.g., sex, age, baseline health status, health care system, and adaptation such as air conditioning) that will vary by place.

There are large heterogeneities in population and pollutant characteristics across many Asian countries including Korea compared with North America or Europe, especially due to rapid economic development and industrialization that are taking place in Asia. In our previous paper, we compared several health, economic, and environmental indicators for Korea and several other countries and demonstrated that Korea has different characteristics of air pollution, social, and health patterns than that in other Asian or Western countries (Son et al. 2013). Thus, more local studies covering various locations are needed to investigate susceptible populations to temperature's effect on morbidity given the limitations of extrapolating results from studies conducted in other regions and the need for information on sensitive groups to aid decision makers.

To date, few studies have been conducted for Korea to assess the impacts of temperature on health (Ha et al. 2009, 2011; Hong et al. 2003; Kim et al. 2006; Lim et al. 2012; Son et al. 2011, 2012). However, most of these studies focused on mortality or single city. Studies have shown that in Korea, mortality was associated with winter temperature (Ha et al. 2009), heat (Kim et al. 2006), heat and cold (Son et al. 2011), previous-winter's mortality (Ha et al. 2011), and heat waves (Son et al. 2012). Only two studies have analyzed the effects of temperature on morbidity outcomes in Korea. One examined associations between low temperature and ischemic stroke for 3 years of data in the city of Incheon (Hong et al. 2003). Another investigated the cardiovascular and respiratory hospital admissions using 4 years of data for four metropolitan areas (Lim et al. 2012).

We conducted, to the best of our knowledge, the largest study to date of weather and hospital admissions in Korea. Our study examined how heat, cold, and heat waves affect risk of hospitalization for multiple causes (allergic disease, asthma, selected respiratory disease, and cardiovascular disease) in eight major cities in Korea from 2003 to 2008. We considered multiple lags, effects by city and overall across the cities, and potential effect modification by sex and age based on individual-level data.

Material and methods

Health and weather data

We obtained hospital admission data for eight major cities (Seoul, Busan, Incheon, Daegu, Daejeon, Gwangju, Ulsan, and Jeju) in Korea between January 1, 2003 and December 31, 2008 from the National Health Insurance Corporation, Republic of Korea. Supplementary Fig. 1 shows the locations of the cities. The hospital records include data on cause of hospitalization, sex, and age. We considered hospitalization causes of allergic disease (International Classification of Diseases, ICD-10; World Health Organization 2007, J30, J45, and L20), asthma (ICD-10, J45 and J46), selected respiratory disease (ICD-10, J05, J18, J20, J21, J40–J42, J44–J46, and J67), and cardiovascular disease (ICD-10, I00–I99). The data on respiratory disease hospitalizations were previously formatted to include selected diseases: croup, pneumonia, bronchiolitis, respiratory infection including bronchitis, chronic obstructive pulmonary disease (COPD), asthma, and pneumonitis. We restricted the study period to the warm season (March through August) for analysis of effects from heat and heat waves and to the cold season (September through February) for analysis of effects from the cold.

The National Meteorological Administration, Republic of Korea, provided hourly measurements of ambient temperature and relative humidity for each city during the study period. We converted weather data into 24-h values (i.e., daily) by averaging the 24 hourly values for temperature and relative humidity for each day and city.

Statistical analysis

For each city, we excluded the first day of each month from the analysis to control for the tendency of provider organizations to submit claims to the Health Insurance Review Agency on the first day of month and interaction between this tendency and year. Supplementary Fig. 2 shows the relationship between hospital admission counts for cardiovascular disease of the first day of month and the average for other days of month. This tendency for higher effects on the first day of the month is stronger in some years than others (Supplementary Fig. 2). Previous Korean studies using hospital admission data controlled for the first day of month using indicator variables (Lim et al. 2012; Yi et al. 2010).

We used a two-stage hierarchical modeling strategy to first estimate the association between heat, cold, or heat waves and hospital admissions in each city, and then in a second stage, combined city-specific estimates to generate an estimate of the overall effect. As the first stage, we estimated the increase in risk of hospital admissions using generalized linear models for each city and cause of hospitalization separately. The modeling structure allows for a nonlinear relationship between temperature and risk of hospital admission. We controlled for daily relative humidity, day of the week, and time trends to account for seasonal and long-term trends. The model structure is

$$\ln\left[E\left(Y_t^c\right)\right] = \beta_0^c + a^c\mathrm{DOWt} + ns(\mathrm{time}_t) + ns\left(\mathrm{temperature}_t^c\right) + ns\left(\mathrm{humidity}_t^c\right) \tag{1}$$

where

$E(Y_t^c)$	=expected number of hospitalizations for a specific cause, assumed to follow an overdispersed Poisson distribution, for city *c* on day *t*
β_0^c	=model intercept for city *c*
a^c	=vector of regression coefficients for day of the week for city *c*
DOW_t	=categorical variable for day of the week on day *t*
$ns(\mathrm{time}_t)$	=natural cubic spline of a variable representing time to adjust for long-term trends, with degrees of freedom (df)=3 per warm or cold season
$ns(\mathrm{temperature}_t^c)$	=natural cubic spline of temperature for city *c* on day *t*, with df=3 and equally spaced knots
$ns(\mathrm{humidity}_t^c)$	=natural cubic spline of humidity for city *c* on day *t*, with df=4.

Equation 1 provides an estimate of a nonlinear association between temperature and risk of hospital admissions for each city. In order to compare effects across cities, we estimated heat- and cold-related temperature effects for specific portions of the temperature-morbidity response curve by estimating effects of relative (comparing risk across temperature percentiles based in each city) and absolute (comparing risk at specific temperatures) temperature changes. In other words, the relative effects are calculated based on the distribution of temperature within a given city (e.g., 99th percentile) whereas the absolute effects are calculated based on comparisons of specific temperatures (e.g., 25 °C). For the heat effect, we calculated the change in morbidity risk comparing the 99th to 90th percentile (relative effect) and 25 to 15 °C (approximate 90th to 50th percentile of mean temperature across cities) (absolute effect). For the cold effect, we present results comparing morbidity risk at the 1st to 10th percentile (relative effect) and 2 to 15 °C (approximate 10th to 50th percentile of mean temperature across cities) (absolute effect). Absolute effects compare risk estimates at the same absolute temperatures across cities, whereas relative effects compare risk estimates for temperatures that are hot or cold for a given city's temperature distribution. These estimates have different interpretations as the relative effects represent health impacts for what is a hot or cold day for a given city, whereas the absolute effects compare health impacts at the same temperatures across all cities regardless of the cities' typical weather patterns. Different effect estimates across cities for absolute effects suggest that some populations have adapted to weather conditions that are harmful in other communities.

We estimated city-specific estimates of absolute and relative heat and cold effects for each city using Eq. 1. We then generated an overall effect estimate across the eight cities by combining the city-specific effects, accounting for the estimates' statistical uncertainty, using a Bayesian hierarchical model through Two-Level Normal independent sampling estimation (TLNise) (Everson 2000). Similar analytical design has been used in previous studies of weather in other regions and for other health outcomes (Anderson and Bell 2009).

Previous work showed that mortality effects from cold temperature persist for longer lag times than effects do for high temperature (Anderson and Bell 2009; Son et al. 2011). We investigated multiple lag structures of temperature, examining effects of the same day and the average of the same day and up to 35 days previous for the relative effects for heat and cold (Supplementary Fig. 3). For subsequent analysis, we chose the lag with the highest effect for heat and cold. The association of heat with hospital admissions was the highest on the same day (lag 0), and cold-related risk of hospitalizations persisted for longer time periods (lag 0–32).

Whereas the above analysis considers high temperatures, human health response may differ for prolonged periods of consecutive days of extreme heat, known as heat waves. There is no standard definition of a heat wave; however, heat waves are generally defined based on intensity (i.e., level of high heat) and duration (i.e., prolonged period of heat). We applied a definition of heat wave as ≥2 consecutive days with daily mean temperature at or above the 98th percentile warm season daily mean temperature for that city. This definition has been used in our previous research and in other work (Gasparrini and Armstrong 2011; Son et al. 2012). For the first stage, we applied generalized linear models to estimate the difference in morbidity during heat wave days compared with nonheat wave days. We controlled for daily mean temperature, day of the week, relative humidity, and time trends. We estimated a separate effect for each heat wave in a city and then estimated overall effect within each city and across the cities using a Bayesian hierarchical model, as in an earlier study (Son et al. 2012).

Separate analyses were performed by cause of hospitalization (allergic disease, asthma, selected respiratory disease, and cardiovascular disease). We generated effect estimates for the total population, and using stratified analysis generated estimates by sex and age (0–14, 15–64, 65–74, and ≥75 years). All analyses were conducted using R 2.10.1 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Table 1 shows summary statistics of hospital admissions and meteorological variables for each city and across all cities. Average daily mean temperature was the highest in Jeju (16.2 °C) and the lowest in Incheon (12.6 °C). The mean daily hospital admission counts were lowest in Jeju (4.7 for allergic disease, 5.7 for asthma, 27.7 for selected respiratory disease, and 32.8 for cardiovascular disease) and highest in Seoul (36.1, 36.3, 224.3, and 601.8, respectively). In total, the study includes 5,051,392 hospital admissions: 229,068 for allergic disease, 233,890 for asthma, 1,413,698 for selected respiratory disease, and 3,174,736 for cardiovascular disease.

We generated city-specific temperature-morbidity response curves based on the selected temperature lag structures (lag 0 for heat effect and lag 0–32 for cold effect). Figure 1 shows some examples of these curves as the increase in risk of hospitalizations for a given temperature compared with a reference temperature. The exposure-response curves of the relationship between temperature and hospital admissions varied among cities and causes (e.g., selected respiratory vs cardiovascular disease). We used lag structures of temperature on the same day (lag 0) for heat effect and lag 0–32 for cold effect for subsequent analysis.

Table 2 shows results for the absolute heat effect based on specific temperatures for each city and overall across all cities. Table 3 provides results for the relative heat effect based on each city's temperature distribution. We found an increase in risk of hospital admissions from cardiovascular disease with increasing high temperature in most cities and overall across all cities. The overall heat effect for hospitalization from cardiovascular disease was a 4.5 % (95 % confidence interval 0.7, 8.5 %) increase in hospitalizations comparing risk at 25 to 15 °C and 3.2 % (−0.5, 7.1 %) comparing the 99th and 90th percentiles of temperatures. Although some city-specific estimates were negative, we found positive central estimates of overall effects for allergic disease, asthma, and selected respiratory disease for absolute temperature effects; however, no statistically significant associations were observed for any causes. For relative temperature effects, we found negative central estimates of overall associations for all the hospitalization causes studied except for cardiovascular disease; however, no statistically significant associations were observed (Tables 2 and 3). The absolute and relative effect estimates have different interpretations regarding acclimatization. In this study, we found that both absolute and relative heat effects showed variation across cities; however, variation of absolute effect across cities was a little larger, which implies some degree of acclimatization.

Table 4 shows results for the absolute cold effect for each city and overall across the cities. In this analysis, Jeju city is not included because the city's minimum temperature is higher than 2 °C (approximate average of 10th percentiles of mean temperature across all cities). For cold effect, the overall

Table 1 Summary statistics of hospital admissions and meteorological variables by city, 2003–2008

City	Weather (mean (SD))		Daily hospital admissions (mean (SD))			
	Temperature (°C)	Relative humidity (%)	Allergic disease	Asthma	Selected respiratory disease	Cardiovascular disease
Seoul	12.9 (10.0)	61.6 (14.9)	36.1 (16.6)	36.3 (16.6)	224.3 (98.7)	601.8 (209.1)
Busan	14.7 (7.9)	61.9 (18.2)	21.5 (12.1)	21.9 (12.2)	140.3 (70.8)	288.7 (122.6)
Incheon	12.6 (9.4)	66.8 (14.5)	14.6 (8.6)	15.0 (8.8)	71.0 (34.6)	156.6 (63.6)
Daegu	14.5 (9.2)	58.0 (16.3)	11.4 (6.6)	11.9 (6.9)	68.6 (35.3)	161.3 (57.8)
Daejeon	13.2 (9.6)	65.6 (13.8)	6.4 (3.9)	6.4 (4.0)	34.6 (18.2)	85.9 (34.5)
Gwangju	14.2 (9.2)	67.4 (13.0)	9.1 (5.7)	8.7 (5.4)	65.3 (34.3)	90.3 (38.1)
Ulsan	14.6 (8.5)	61.7 (17.6)	8.0 (5.2)	8.0 (5.3)	35.3 (22.7)	80.2 (40.0)
Jeju	16.2 (7.6)	65.4 (12.2)	4.7 (3.2)	5.7 (4.0)	27.7 (17.0)	32.8 (15.1)
Overall	14.1 (8.9)	63.6 (15.1)	108.1 (46.2)	110.3 (47.2)	669.2 (307.4)	1,497.5 (554.0)

Selected respiratory disease included croup, pneumonia, bronchiolitis, respiratory infection including bronchitis, chronic obstructive pulmonary disease (COPD), asthma, and pneumonitis (ICD-10, J05, J18, J20, J21, J40–J42, J44–J46, and J67)

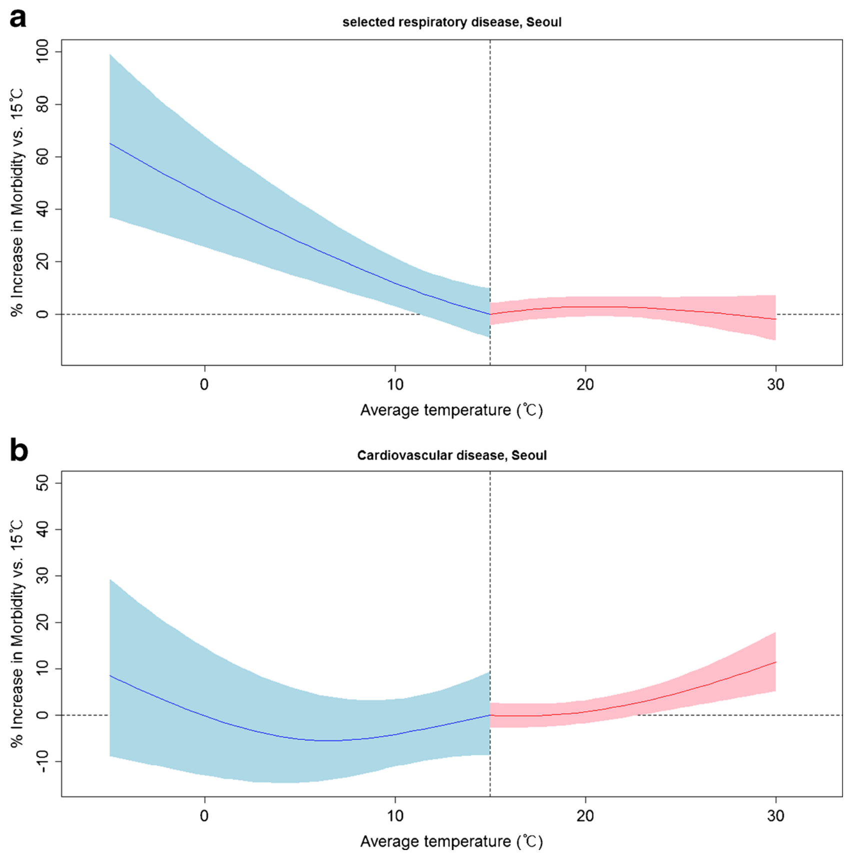

Fig. 1 Relationship between temperature and risk of hospital admissions for a given temperature compared with a reference temperature of 15 °C for Seoul. The *blue portion* of the curve shows cold effects (lag 0). The *red portion* of the curve shows heat effects (lag 0–32). The *solid line* represents the central estimate; the *shaded areas* represent 95 % posterior intervals

increase in risk of hospital admissions comparing the 2 with 15 °C was 50.5 (13.7, 99.2 %), 43.6 (8.9, 89.5 %), and 53.6 % (9.8, 114.9 %) for allergic disease, asthma, and selected respiratory disease, respectively. Cold effects were highest in Busan, which had the highest daily mean temperature other than Jeju (Table 4). For relative temperature effects, we found positive central estimates of associations for all the hospitalization causes studied; however, no statistically significant associations were observed for any causes or city (Table 5). Although the confidence intervals for cold effects are wide, cold effects generally appear higher than heat effects in most cities.

Table 6 shows city-specific and overall risk of hospitalizations on heat wave days compared with nonheat wave days. Overall, across the eight cities, we estimated a positive, although not statistically significant, effect of heat waves

Table 2 City-specific and overall absolute heat effects

City	Percent change in risk (95 % interval)			
	Allergic disease	Asthma	Selected respiratory disease	Cardiovascular disease
Seoul	0.4 (−6.5, 7.9)	−1.3 (−8.3, 6.2)	1.7 (−3.0, 6.6)	5.0 (1.6, 8.5)
Busan	13.2 (2.2, 25.4)	9.0 (−1.8, 20.8)	17.4 (10.3, 24.9)	4.0 (−0.5, 8.6)
Incheon	−9.3 (−20.3, 3.2)	−12.7 (−23.2, −0.8)	0.2 (−6.9, 7.8)	13.0 (6.8, 19.5)
Daegu	15.0 (3.5, 27.8)	16.6 (5.2, 29.1)	14.1 (8.2, 20.3)	0.7 (−3.2, 4.7)
Daejeon	33.7 (16.6, 53.3)	31.4 (14.9, 50.3)	−0.7 (−10.3, 9.9)	7.9 (2.7, 13.4)
Gwangju	−4.2 (−15.5, 8.6)	−0.4 (−12.5, 13.4)	−3.8 (−9.6, 2.4)	8.0 (2.4, 13.9)
Ulsan	−0.0 (−11.7, 13.2)	5.2 (−7.3, 19.3)	8.5 (−1.4, 19.5)	0.1 (−5.6, 6.1)
Jeju	−3.2 (−19.2, 16.0)	−8.3 (−22.2, 8.2)	−9.2 (−18.9, 1.6)	−3.4 (−10.9, 4.7)
Overall	5.1 (−5.1, 16.4)	4.3 (−6.0, 15.8)	3.6 (−3.6, 11.4)	4.5 (0.7, 8.5)

Lag 0 for heat effect. The values represent percent change in risk comparing the 25 and 15 °C. These temperatures approximate the average 90th and 50th percentiles of mean temperature across all cities

Table 3 City-specific and overall relative heat effects

City	Percent change in risk (95 % interval)			
	Allergic disease	Asthma	Selected respiratory disease	Cardiovascular disease
Seoul	0.0 (−12.5, 14.3)	−1.5 (−14.0, 12.9)	−2.0 (−10.3, 7.1)	3.5 (−2.5, 9.7)
Busan	2.8 (−14.9, 24.3)	1.6 (−16.2, 23.2)	6.0 (−5.6, 18.9)	1.4 (−5.9, 9.2)
Incheon	−4.2 (−22.7, 18.9)	−5.9 (−24.0, 16.6)	−0.7 (−12.2, 12.4)	8.2 (−1.3, 18.5)
Daegu	2.3 (−17.1, 26.3)	2.4 (−16.5, 25.7)	0.9 (−9.1, 12.0)	3.3 (−3.7, 10.8)
Daejeon	7.6 (−16.3, 38.3)	5.2 (−17.8, 34.7)	−3.0 (−19.6, 17.1)	2.7 (−6.0, 12.1)
Gwangju	−5.1 (−25.2, 20.5)	−3.8 (−24.9, 23.3)	−2.5 (−13.6, 10.1)	2.1 (−7.3, 12.5)
Ulsan	−7.4 (−28.0, 19.2)	−6.0 (−27.2, 21.4)	−0.2 (−17.5, 20.6)	4.0 (−6.1, 15.2)
Jeju	−4.2 (−32.1, 35.2)	−5.3 (−31.0, 30.0)	−6.0 (−23.9, 16.3)	−0.6 (−13.1, 13.8)
Overall	−0.6 (−9.5, 9.1)	−1.4 (−10.1, 8.2)	−0.4 (−6.0, 5.5)	3.2 (−0.5, 7.1)

Lag 0 for heat effect. Values represent percent change in risk comparing the 99th and 90th percentile of mean temperature for each city

compared with nonheat wave days on hospital admissions from allergic disease (7.2 %, 95 % confidence interval (CI) −21.3, 46.0 %), asthma (9.1 %, 95 % CI −18.7, 46.3 %) and selected respiratory disease (13.2 %, 95 % CI −5.4, 35.5 %), respectively, but not for cardiovascular disease (−4.3 %, 95 % CI −14.4, 7.1 %).

For hospitalization causes that demonstrated associations for heat and cold (i.e., heat effect for cardiovascular disease; cold effect for allergic disease, asthma, and selected respiratory disease), we investigated whether some subpopulations are more sensitive than others. Figure 2 and Supplementary Table 1 show overall absolute heat and cold effects stratified by sex and age. We found higher central estimates for heat and cold effects among women compared with men in all analyses, although the 95 % intervals of estimates for men and women overlapped. Heat effects for cardiovascular disease were higher for younger age groups (0–14 and 15–64 years) than older age groups (65–74 and ≥75 years). Higher and statistically significant cold effects also were found in younger persons (0–14 years) for risk of hospital admissions from allergic disease, asthma, and selected respiratory disease, although 95 % intervals among all age groups overlapped.

Discussion

Our study found that both high and low temperatures were associated with the risk of hospitalization in Korea. For absolute temperature changes, hospital admissions due to cardiovascular disease were significantly associated with higher ambient temperature, whereas hospital admissions due to allergic disease, asthma, and selected respiratory disease were significantly associated with low ambient temperature. We did not find a statistically significant effect of heat waves compared with nonheat wave days for any hospitalization causes. Our findings suggest potential susceptible populations such as women and younger persons for heat- and cold-related risk of hospitalization.

Table 4 City-specific and overall absolute cold effects

City	Percent change in risk (95 % interval)			
	Allergic disease	Asthma	Selected respiratory disease	Cardiovascular disease
Seoul	−2.4 (−20.4, 19.7)	−4.5 (−22.1, 17.1)	38.0 (21.0, 57.3)	−2.8 (−14.2, 10.2)
Busan	117.1 (61.6, 191.8)	110.9 (57.6, 182.3)	124.9 (88.0, 169.0)	−7.6 (−21.8, 9.1)
Incheon	47.6 (8.2, 101.4)	38.5 (1.8, 88.3)	91.8 (59.1, 131.2)	−11.7 (−26.0, 5.4)
Daegu	20.0 (−14.3, 68.1)	15.2 (−17.2, 60.4)	−17.4 (−31.3, −0.8)	−7.4 (−20.7, 8.2)
Daejeon	70.7 (12.2, 159.7)	79.8 (17.5, 175.1)	49.5 (12.1, 99.2)	−10.0 (−24.5, 7.3)
Gwangju	85.0 (28.5, 166.3)	53.8 (5.9, 123.4)	120.9 (80.9, 169.6)	−12.1 (−27.7, 6.9)
Ulsan	66.4 (8.3, 155.7)	62.4 (4.5, 152.4)	21.6 (−11.9, 67.9)	5.7 (−15.1, 31.6)
Overall	50.5 (13.7, 99.2)	43.6 (8.9, 89.5)	53.6 (9.8, 114.9)	−6.8 (−14.3, 1.4)

Lag 0–32 for cold effect. The values represent percent change in risk comparing the 2 and 15 °C. These temperatures approximate the average 10th and 50th percentiles of mean temperature across all cities. Jeju city is not included in this analysis

Table 5 City-specific and overall relative cold effects

City	Percent change in risk (95 % interval)			
	Allergic disease	Asthma	Selected respiratory disease	Cardiovascular disease
Seoul	1.9 (−26.9, 42.1)	1.7 (−27.1, 41.7)	5.5 (−15.1, 31.0)	3.6 (−15.5, 27.1)
Busan	9.2 (−26.5, 62.4)	8.3 (−26.8, 60.1)	10.2 (−13.3, 40.1)	2.4 (−18.2, 28.2)
Incheon	11.9 (−32.9, 86.7)	10.0 (−33.7, 82.3)	8.1 (−20.4, 47.0)	4.1 (−21.8, 38.6)
Daegu	1.9 (−37.7, 66.6)	2.3 (−37.0, 66.0)	−1.1 (−24.5, 29.6)	2.5 (−18.4, 28.8)
Daejeon	0.2 (−48.2, 93.6)	0.2 (−48.6, 95.5)	3.2 (−34.3, 62.2)	2.9 (−21.7, 35.2)
Gwangju	7.6 (−37.1, 84.0)	3.7 (−40.2, 80.0)	8.8 (−19.0, 46.0)	2.5 (−23.0, 36.5)
Ulsan	7.0 (−40.0, 91.0)	6.5 (−41.2, 93.0)	−0.0 (−35.3, 54.5)	3.5 (−23.1, 39.2)
Overall	5.6 (−15.8, 32.3)	4.7 (−16.5, 31.2)	5.5 (−8.4, 21.5)	3.1 (−8.4, 15.9)

Lag 0–32 for cold effect. The values represent percent change in risk comparing the 1st and 10th percentile of mean temperature for each city. Jeju city is not included in this analysis

In this study, we used mean temperature, although in a previous study of heat waves and mortality in Korea, we performed several sensitivity analyses using multiple temperature metrics such as minimum and maximum temperature. That study found that all metrics were highly correlated and the effect estimates were similar (Son et al. 2012). Previous studies of weather and mortality have used various temperature metrics such as minimum, maximum, apparent temperature, and mean daily temperature and found that all metrics produced nearly identical results, with the highest effect for mean daily temperature (Hajat et al. 2006; Anderson and Bell 2009). Thus, we used mean temperature, which can be interpreted more easily.

We considered two approaches to compare temperature effect across cities including estimates based on a given city's temperature distribution (relative effects), allowing comparison of region with various temperature range and the effect of an absolute temperature change from a moderate to hot or cold. These two estimates have different interpretations regarding acclimatization. If a high degree of acclimatization occurs, absolute effects would differ across cities, meaning that populations respond differently to the same temperature levels. The relative effects, estimating health effects in what is a hot or cold day for that city, taking into account the temperature distribution for that city. Differences in absolute and relative effects may be related to acclimatization factors such as biological adaptation, behavior modification (e.g., in case of extreme temperature, increased use of air conditioning, and staying indoors), and public recognition. Our findings across cities on acclimatization are important for climate change studies and public policy maker.

Previous findings on associations between temperature and hospitalizations vary across studies. A US study found that extreme high temperature appears to increase hospital admissions for cardiovascular and respiratory disorders in New York City (Lin et al. 2009b). In a study of 12 US cities, Schwartz et al. (2004) reported an effect of high temperature on hospital admissions for cardiovascular disease. Knowlton et al. (2009)

Table 6 City-specific and overall risk of hospitalizations on heat wave days compared with nonheat wave days

City	Percent change in risk (95 % interval)			
	Allergic disease	Asthma	Selected respiratory disease	Cardiovascular disease
Seoul	33.0 (2.4, 72.8)	27.9 (−4.7, 71.7)	18.5 (−1.5, 42.7)	−3.3 (−13.9, 8.6)
Busan	−5.9 (−73.7, 237.4)	8.5 (−63.5, 221.8)	9.1 (−44.5, 114.2)	−12.2 (−46.1, 43.0)
Incheon	−21.7 (−55.0, 36.1)	−8.0 (−45.0, 53.7)	2.2 (−24.0, 37.6)	0.2 (−17.1, 21.2)
Daegu	25.9 (−34.4, 141.5)	27.0 (−32.1, 137.7)	37.9 (0.7, 88.9)	−15.8 (−38.9, 16.0)
Daejeon	−14.2 (−59.4, 81.3)	−9.3 (−59.1, 101.3)	−12.7 (−50.0, 52.5)	−4.8 (−22.3, 16.6)
Gwangju	16.9 (−39.7, 126.5)	−0.4 (−50.8, 101.6)	13.7 (−19.7, 61.0)	−9.8 (−36.0, 27.0)
Ulsan	8.4 (−53.1, 150.6)	11.6 (−54.8, 175.3)	3.0 (−46.6, 98.9)	3.6 (−31.7, 57.2)
Jeju	−16.1 (−62.2, 86.4)	−11.4 (−64.3, 120.1)	11.0 (−35.3, 90.4)	0.3 (−25.3, 34.7)
Overall	7.2 (−21.3, 46.0)	9.1 (−18.7, 46.3)	13.2 (−5.4, 35.5)	−4.3 (−14.4, 7.1)

Heat waves defined as ≥2 days with mean temperature above the 98th percentile of temperature for that city

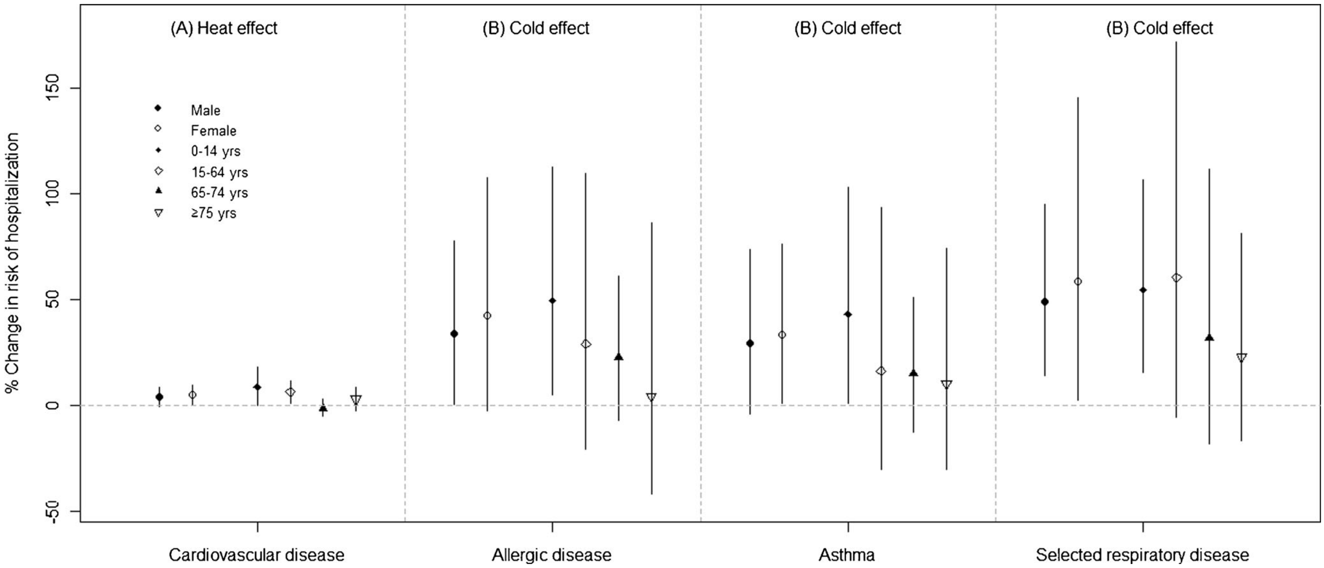

Fig. 2 Percentage increase in hospital admissions risk for the absolute heat (comparison of risks at 25 and 15 °C) and cold (comparison of risks at 2 and 15 °C) effects by sex and age, overall across eight cities. The *point* represents the central estimate; the *vertical lines* represent 95 % posterior intervals

observed significantly elevated risks for hospitalizations for heat-related illnesses, acute renal failure, electrolyte imbalance, and nephritis during the 2006 CA heat wave compared with nonheat wave periods. On the other hand, a European study found that high temperatures are associated with respiratory admissions but not cardiovascular admissions (Michelozzi et al. 2009). Only two previous studies of weather and hospital admissions in Korea have been performed. Lim et al. (2012) investigated the risk of hospital admissions for cardiovascular- and respiratory-related diseases attributable to diurnal temperature range (DTR) in four metropolitan areas in Korea during 2003–2006 and reported that cardiac failure and asthma admissions were significantly associated with higher DTR. Another Korean study reported that decreased ambient temperature was associated with risk of acute ischemic stroke for 3 years (1998 to 2000) of data in Incheon (Hong et al. 2003). Previous studies on weather and hospital admissions in Asia found that temperature was associated with intestinal infectious disease in Thailand (Pudpong and Hajat 2011), pneumonia admissions in Taiwan (Lin et al. 2009a), and emergency room admissions for COPD (Liang et al. 2009) and acute coronary syndrome (Liang et al. 2008) in Taiwan. Differences in findings across studies may relate to several reasons including variation in population characteristics, adaptation factors such as housing characteristics and activity patterns, local climate, and methodological differences.

Several mechanisms may explain our findings on the association between heat and cardiovascular disease, including increased platelet, red and white cell counts, blood viscosity, and plasma cholesterol during heat (Keatinge et al. 1986). Previous studies suggest that extreme cold might increase cardiovascular stress such as by increasing blood viscosity, red and white cell counts, and blood pressure and susceptibility to pulmonary diseases by causing bronchoconstriction (Hong et al. 2003; Mercer 2003; Wichmann et al. 2011).

Our study found that cold effects on hospital admissions appear higher than heat effects in most cities, although the effect estimates are based on the temperatures we compared. A study in China reported that both heat waves and cold spells were associated with increased risk of total, cardiovascular, and respiratory hospital admissions and cold spells had a larger impact than heat waves (Ma et al. 2011). This may relate to mitigation factors such as air conditioning. Ostro et al. (2010) found that ownership and use of air conditioners significantly reduced the effects of temperature on hospitalizations for a study in CA. Although several studies of ambient temperature and mortality have investigated modification by air conditioning (Anderson and Bell 2009; O'Neill et al. 2005), more studies to examine mitigation of temperature effects on morbidity outcomes are needed, including research in other regions where housing characteristics may differ.

In most cities, increased cold effects on hospital admissions for allergic disease, asthma, and selected respiratory disease were observed except for Daegu city with a negative effect for hospital admissions from selected respiratory disease. This result warrants additional study and further demonstrates the need for local studies. The magnitude and direction of the effects of temperature on health outcomes may be related to differences in the levels of exposure, susceptibility of subpopulations, public health interventions, health and social care services, and physical acclimatization (Anderson and Bell 2011; Michelozzi et al. 2006). A study in Europe observed geographical variability in the impact of heat on respiratory admissions among 12 European cities, and these findings may be explained by differences in the intensity of the exposure and health care systems (Michelozzi et al. 2009). Substantial variation in heat and cold effects on mortality has been observed in several studies. Researchers suggested that some heterogeneity in risk between populations can be explained by socioeconomic factors, urbanicity, population density, GDP, and the age distribution (Anderson and Bell 2009; Anderson and Bell 2011; Curriero et al. 2002; Hajat et al. 2005; Hajat and Kosatky 2010)

Previous studies exploring the lag structure of the association between temperature and mortality reported shorter lags for the associations between heat and mortality, with longer lags more relevant to cold effects on mortality (Anderson and Bell 2009; Son et al. 2011). For example, in a US study, Braga et al. (2001) reported that the effect of high temperatures was restricted to the day of death (lag 0) or the following day (lag 1), whereas the effect of cold temperatures persisted for days. On the other hand, findings on lag structure for the associations between temperature and morbidity outcomes have been rarely examined. In this study, we found that the heat effect on risk of hospitalization occurred on the current day (lag 0), whereas cold effects persisted for longer time periods, which is consistent with the limited previous findings. Although some studies exploring lag structure for the associations of temperature with hospital admissions reported shorter lags during warm seasons and longer lags during cold seasons (Green et al. 2010; Hajat and Haines 2002; Schwartz et al. 2004), further study is needed to determine the temporal patterns for a range of causes of hospitalizations and locations.

We found suggestive evidence of some susceptible populations such as women and younger age groups. For both heat and cold effects, women and younger persons tended to have higher risk for weather-related hospital admissions, although results were not statistically different between groups. The nature of susceptibility in weather-health relationships may be related to several factors such as population demographics, socioeconomic status, and exposure patterns. For example, women in Korea were older and less educated than men (Son et al. 2012). Some studies suggest that higher effects of temperature in children may be related to more outdoor activities than adults (Green et al. 2010).

Several temperature-related mortality studies have reported that some factors such as age or socioeconomic status might modify the temperature-mortality relationship. O'Neill et al. (2003) found that persons with lower educational attainment have a greater susceptibility to temperature-related mortality in Latin America. Our previous mortality studies found that women or the elderly have a higher risk for heat- and cold-related mortality risk in Seoul than men or younger persons (Son et al. 2011). However, relatively few studies have identified susceptible populations for temperature-related morbidity, and findings vary by location and type of health outcome. Some studies reported a higher risk of heat on respiratory hospital admissions among people ≥65 years of age compared with younger persons (Lin et al. 2009a, b), whereas others found a higher effect in children compared with adults (Green et al. 2010; Kovats et al. 2004). Previous findings reported a higher effect for cold on ischemic stroke or coronary events among women (Barnett et al. 2005; Hong et al. 2003), while others observed men to have a greater risk (Ye et al. 2001). On the other hand, some studies have reported no effect modification by sex in the association between temperature and hospital admissions. As vulnerability to temperature may differ by location, type of morbidity outcome, and other factors such as population characteristics and socioeconomic status, more studies are needed, including work in a range of locations.

Although this study did not consider the potential confounding by air pollutants, some studies suggest possible interaction, and findings from previous studies for confounding and/or effect modification by air pollutants vary by study. In many studies, temperature-morbidity associations were robust after adjustment for air pollutants (Basu et al. 2012; Wichmann et al. 2011, 2012). However, one study reported that PM_{10} significantly modified the effects of temperature on respiratory and cardiovascular hospital admissions (Ren et al. 2006). Another study suggested a causal intermediate role of ambient ozone in studies of temperature and mortality (Reid et al. 2012). Further study is needed to evaluate the role of air pollution in assessing the association between temperature and health outcomes.

In conclusion, our findings provide suggestive evidence that both high and low ambient temperatures are associated with risk of hospital admissions in Korea. This multicity study supports the hypothesis of increased susceptibility among women or younger persons for heat- and cold-related risk of hospitalization. These findings can benefit decision makers who design and implement plans to protect public health from extreme weather and can inform future studies of weather and health as well as research on the human health consequences of climate change.

Acknowledgments The authors thank Korea Centers for Disease Control and Prevention, National Health Insurance Corporation for providing health insurance data.

Conflict of Interest The authors declare that they have no conflicts of interest.

References

Anderson BG, Bell ML (2009) Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidemiology 20:205–213

Anderson BG, Bell ML (2011) Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristic in 43 U.S. communities. Environ Health Perspect 119(2):210–218

Barnett AG, Dobson AJ, McElduff P, Salomaa V, Kuulasmaa K, Sans S (2005) Cold periods and coronary events: an analysis of populations worldwide. J Epidemiol Community Health 59:551–557

Basu R, Ostro BD (2008) A multicounty analysis identifying the populations vulnerable to mortality associated with high ambient temperature in California. Am J Epidemiol 168(6):632–637

Basu R, Pearson D, Malig B, Broadwin R, Green R (2012) The effect of high ambient temperature on emergency room visits. Epidemiology 23(6):813–820

Bell ML, O'Neill MS, Ranjit N, Borja-Aburto VH, Cifuentes LA, Gouveia NC (2008) 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 37:796–804

Braga AL, Zanobetti A, Schwartz J (2001) The time course of weather-related deaths. Epidemiology 12(6):662–667

Canouï-Poitrine F, Cadot E, Spira A, Groupe régional Canicule (2003) Excess deaths during the August 2003 heat wave in Paris France. Rev Epidemiol Sante Publique 54:127–133

Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA (2002) Temperature and mortality in 11 cities of the Eastern United States. Am J Epidemiol 155:80–87

Dawson J, Weir C, Wright F, Bryden C, Aslanyan S, Lees K et al (2008) Associations between meteorological variables and acute stroke hospital admissions in the west of Scotland. Acta Neurol Scand 117:85–89

Ebi KL, Exuzides KA, Lau E, Kelsh M, Barnston A (2004) Weather changes associated with hospitalizations for cardiovascular disease and stroke in California, 1983–1998. Int J Biometeorol 49:48–58

Everson P (2000) Two-level normal independent sampling estimation (TLNise). Swarthmore College, Swarthmore

Gasparrini A, Armstrong B (2011) The impact of heat waves on mortality. Epidemiology 22:68–73

Green RS, Basu R, Malig B, Broadwin R, Kim JJ, Ostro B (2010) The effect of temperature on hospital admissions in nine California counties. Int J Public Health 55:113–121

Ha J, Yoon J, Kim H (2009) Relationship between winter temperature and mortality in Seoul, South Korea, from 1994 to 2006. Sci Total Environ 407:2158–2164

Ha J, Kim H, Hajat S (2011) Effect of previous-winter mortality on the association between summer temperature and mortality in South Korea. Environ Health Perspect 119:542–546

Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C (2006) Climate change and human health: impacts, vulnerability, and mitigation. Lancet 367:2101–2109

Hajat S, Haines A (2002) Associations of cold temperatures with GP consultations for respiratory and cardiovascular disease among the elderly in London. Int J Epidemiol 31:826–830

Hajat S, Kosatky T (2010) Heat-related mortality: a review and exploration of heterogeneity. J Epidemiol Community Health 64:753–760

Hajat S, Armstrong BG, Gouveia N, Wilkinson P (2005) Mortality displacement of heat-related deaths. Epidemiology 16:613–620

Hajat S, Armstrong B, Baccini M, Biggeri A, Bisanti L, Russo A, Paldy A, Menne B, Kosatsky T (2006) Impact of high temperatures on mortality: is there an added heat wave effect? Epidemiology 17:632–638

Hong YC, Rha JH, Lee JT, Ha EH, Kwon HJ, Kim H (2003) Ischemic stroke associated with decrease in temperature. Epidemiology 14: 473–478

Keatinge WR, Coleshaw S, Easton J, Cotter F, Mattock M, Chelliah R (1986) Increased platelet and red cell counts, blood viscosity, and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis. Am J Med 81:795–800

Kim H, Ha J, Park J (2006) High temperature, heat index, and mortality in 6 major cities in South Korea. Arch Environ Occup Health 61:265–270

Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G et al (2009) The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect 117(1):61–67

Koken PJ, Piver WT, Ye F, Elixhauser A, Olsen LM, Portier CJ (2003) Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver. Environ Health Perspect 111:1312–1317

Kovats RS, Hajat S, Wilkinson P (2004) Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK. Occup Environ Med 61:893–898

Liang WM, Liu WP, Chou SY, Kuo HW (2008) Ambient temperature and emergency room admissions for acute coronary syndrome in Taiwan. Int J Biometeorol 52(3):223–229

Liang WM, Liu WP, Kuo HW (2009) Diurnal temperature range and emergency room admissions for chronic obstructive pulmonary disease in Taiwan. Int J Biometeorol 53(1):17–23

Lim YH, Hong YC, Kim H (2012) Effects of diurnal temperature range on cardiovascular and respiratory hospital admissions in Korea. Sci Total Environ 417–418:55–60

Lin HC, Lin CC, Chen CS, Lin HC (2009a) Seasonality of pneumonia admissions and its association with climate: an eight-year nationwide population-based study. Chronobiol Int 26(8):1647–1659

Lin S, Luo M, Walker RJ, Liu X, Hwang SA, Chinery R (2009b) Extreme high temperatures and hospital admissions for respiratory and cardiovascular disease. Epidemiology 20:738–746

Linares C, Diaz J (2008) Impact of high temperatures on hospital admissions: comparative analysis with previous studies about mortality (Madrid). Eur J Public Health 18:317–322

Ma W, Xu X, Peng L, Kan H (2011) Impact of extreme temperature on hospital admission in Shanghai, China. Sci Total Environ 409:3634–3637

Medina-Ramon M, Zanobetti A, Cavanagh DP, Schwartz J (2006) Extreme temperatures and mortality: assessing effect modification by personal characteristics and specific cause of death in a multi-city case-only analysis. Environ Health Perspect 114:1331–1336

Mercer JB (2003) Cold-an underrated risk factor for health. Environ Res 92:8–13

Michelozzi P, De Sario M, Accetta G, de'Donato F, Kirchmayer U, D'Ovidio M, Perucci CA, HHWWS Collaborative Group (2006) Temperature and summer mortality: geographical and temporal variations in four Italian cities. J Epidemiol Community Health 60: 417–423

Michelozzi P, Accetta G, De Sario M, D'lppoliti D, Marino C, Baccini M et al (2009) High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. Am J Respir Crit Care Med 179:383–389

O'Neill MS, Zanobetti A, Schwartz J (2003) Modifiers of the temperature and mortality association in seven US cities. Am J Epidemiol 157: 1074–1082

O'Neill MS, Zanobetti A, Schwartz J (2005) Disparities by race in heat-related mortality in four US cities: the role of air conditioning prevalence. J Urban Health 82(2):191–197

Ostro B, Rauch S, Green R, Malig B, Basu R (2010) The effects of temperature and use of air conditioning on hospitalizations. Am J Epidemiol 72:1053–1061

Peng RD, Bobb JF, Tebaldi C, McDaniel L, Bell ML, Dominici F (2011) Toward a quantitative estimate of future heat wave mortality under global climate change. Environ Health Perspect 119:701–706

Poumadère M, Mayes C, Le Mer S, Blong R (2005) The 2003 heat wave in France: dangerous climate change here and now. Risk Anal 25: 1483–1494

Pudpong N, Hajat S (2011) High temperature effects on out-patient visits and hospital admissions in Chiang Mai, Thailand. Sci Total Environ 409(24):5260–5267

Reid CE, Snowden JM, Kontgis C, Tager IB (2012) The role of ambient ozone in epidemiologic studies of heat-related mortality. Environ Health Perspect 120:1627–1630

Ren C, Williams GM, Tong S (2006) Does particulate matter modify the association between temperature and cardiorespiratory diseases? Environ Health Perspect 114:1690–1696

Schwartz J, Samet JM, Patz JA (2004) Hospital admissions for heart disease: the effects of temperature and humidity. Epidemiology 15: 755–761

Son JY, Lee JT, Anderson GB, Bell ML (2011) Vulnerability to temperature-related mortality in Seoul, Korea. Environ Res Lett 6: 034027

Son JY, Lee JT, Anderson GB, Bell ML (2012) The impact of heat waves on mortality in seven major cities in Korea. Environ Health Perspect 120:566–571

Son JY, Lee JT, Park YH, Bell ML (2013) Short-term effects of air pollution on hospital admissions in 8 cities in Korea, 2003-2008. Epidemiology 24(4):545–554

Wichmann J, Andersen Z, Ketzel M, Ellermann T, Loft S (2011) Apparent temperature and cause-specific emergency hospital admissions in Greater Copenhagen, Denmark. PLoS ONE 6(7): e22904. doi:10.1371/journal.pone.0022904

Wichmann J, Ketzel M, Ellermann T, Loft S (2012) Apparent temperature and acute myocardial infarction hospital admissions in Copenhagen, Denmark: a case-crossover study. Environ Health 11:19

Ye F, Piver WT, Ando M, Portier CJ (2001) Effects of temperature and air pollutants on cardiovascular and respiratory diseases for males and females older than 65 years of age in Tokyo, July and August 1980–1995. Environ Health Perspect 109:355–359

Yi O, Hong YC, Kim H (2010) Seasonal effect of PM10 concentrations on mortality and morbidity in Seoul, Korea: a temperature-matched case-crossover analysis. Environ Res 110:89–95

Yu W, Vaneckova P, Mengersen K, Pan X, Tong S (2010) Is the association between temperature and mortality modified by age, gender, and socio-economic status? Sci Total Environ 408:3513–3518