Environmental Science and Pollution Research (2020) 27:42335–42345
https://doi.org/10.1007/s11356-020-10452-5

REVIEW ARTICLE

A review of the impact of outdoor and indoor environmental factors on human health in China

Yuxia Ma[1] · Yifan Zhang[1] · Bowen Cheng[1] · Fengliu Feng[1] · Haoran Jiao[1] · Xiaoyan Zhao[2] · Bingji Ma[1] · Zhiang Yu[1]

Received: 22 June 2020 / Accepted: 9 August 2020 / Published online: 24 August 2020

Abstract
The Intergovernmental Panel on Climate Change (IPCC) reported that global climate change has led to the increased occurrence of extreme weather events. In the context of global climate change, more evidence indicates that abnormal meteorological conditions could increase the risk of epidemiological mortality and morbidity. In this study, using a systematic review, we evaluated a total of 175 studies (including 158 studies on outdoor environment and 17 studies on indoor environment) to summarize the impact of outdoor and indoor environment on human health in China using the database of PubMed, Web of Science, the Cochrane Library, and Embase. In particular, we focused on studies about cardiovascular and respiratory mortality and morbidity, the prevalence of digestive system diseases, infectious diseases, and preterm birth. Most of the studies we reviewed were conducted in three of the metropolises of China, including Beijing, Guangzhou, and Shanghai. For the outdoor environment, we summarized the effects of climate change–related phenomena on health, including ambient air temperature, diurnal temperature range (DTR), temperature extremes, and so on. Studies on the associations between temperature and human health accounted for 79.7% of the total studies reviewed. We also screened out 19 articles to explore the effect of air temperature on cardiovascular diseases in different cities in the final meta-analysis. Besides, modern lifestyle involves a large amount of time spent indoors; therefore, indoor environment also plays an important role in human health. Nevertheless, studies on the impact of indoor environment on human health are rarely reported in China. According to the limited reports, adverse indoor environment could impose a high health risk on children.

Keywords Meteorological factor · Indoor environment · Cardiovascular diseases · Respiratory diseases · Infectious diseases

Introduction

According to the World Health Organization (WHO) report in 2012, 12.6 million people (including 2.987 million people in China) died because of unhealthy living or working environments, which accounted for 23% of all deaths (WHO 2016). It has been suggested that the environmental risk factors, such as extreme meteorological conditions and air pollution, have adverse effects on human mortality and morbidity (De Sario et al. 2013; Kelly and Fussell 2015). Several epidemiological studies have reported the effects of air temperature, humidex, and apparent temperature on human health in China (Ma et al. 2018; Ban et al. 2017; Yin and Wang 2017; Ge et al. 2018; Cui et al. 2019) and other countries (Fernández-Raga et al. 2010; Medina-Ramón and Schwartz 2007; Katsouyanni et al. 1993; Zanobetti and Schwartz 2008; Revich and Shaposhnikov 2008). Strong evidence showed that extreme air temperatures have significant impact on human health (Kovats and Hajat 2008; Ma et al. 2019), especially among vulnerable groups (e.g., the elderly, children, and people with chronic diseases) (WHO 2008). In addition, seasonal changes in weather have extensive effects on the outcomes of human health, including mortality rates due to cardiovascular, respiratory, and infectious diseases (Burkart et al. 2014).

Responsible Editor: Lotfi Aleya

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11356-020-10452-5) contains supplementary material, which is available to authorized users.

✉ Yuxia Ma
mayuxia07@lzu.edu.cn

[1] College of Atmospheric Sciences, Key Laboratory of Semi-Arid Climate Change, Ministry of Education, Lanzhou University, Lanzhou 730000, China

[2] Neurology Department, General Hospital of the Chinese People's Liberation Army, Beijing 100000, China

In recent years, ambient air temperature has become an adverse health factor. Some epidemiological studies have reported that ambient air temperature is significantly associated with morbidity and mortality. The relationships between daily or monthly mean, maximum, or minimum air temperatures and mortality often showed U-, V-, or J-shaped curves, suggesting that both high and low temperatures would increase health risks (Analitis et al. 2008; Gasparrini et al. 2015; Carmona et al. 2016). For example, Ma et al. (2014) pooled the effect estimates in 17 Chinese cities, indicating that a 1 °C decrease (increase) from the 25th to 1st (the 75th to 99th) percentiles of temperature was associated with increases of 1.69% (2.83%), 2.49% (3.02%), and 1.60% (4.64%) in total, cardiovascular and respiratory mortality, respectively. Zhang et al. (2014) examined the association between temperature and emergency department (ED) visits in Shanghai and found that per 1 °C decrease (increase) in temperature was associated with an overall 2.76% (1.78%) increase in ED visits. Similar results have been confirmed in studies conducted in other parts of China (Ban et al. 2017; Li et al. 2017; Zhou et al. 2014; Jie et al. 2014; Liu et al. 2014; Guo et al. 2012); exposure to high or low temperatures not only affects the respiratory and circulatory systems but can also increase deaths caused by diabetes (Yang et al. 2016), renal colic incidence (Yang et al. 2016); preterm birth rate (He et al. 2015; Guo et al. 2018), and onset of mental disorders (Peng et al. 2017). In addition, ambient air temperatures were also closely related to the incidence of infectious diseases like scarlet fever (Zhang et al. 2018; Duan et al. 2017); chickenpox (Chen et al. 2017); infectious diarrhea (Wang et al. 2015a; Zhou et al. 2013; Yang et al. 2016; Li et al. 2016; Ma et al. 2010); bacillary dysentery (Cheng et al. 2017); varicella infections (Yang et al. 2016); scrub typhus cases (Li et al. 2014a); measles (Ma et al. 2017; Yang et al. 2014); hand, foot, and mouth disease (HFMD) (Li et al. 2014b; Zhao et al. 2016; Yang et al. 2016); and dengue fever (Fan et al. 2014), especially when the temperature rises. In Beijing, Duan et al. (2017) reported that the monthly mean temperature showed a positive effect (RR = 1.196, 95% CI: 1.022, 1.399) on scarlet fever. In Guangzhou, Li et al. (2014a) found that each 1 °C rise in temperature corresponded to an increase of 9.47% (95% CI: 9.36–9.58%) and 14.98% (95% CI: 13.65 to 16.33%) in the weekly number of HFMD cases and scrub typhus cases. In Shanghai, Zhou et al. (2013) also provided a clear evidence of high temperature on increasing the incidence of diarrhea: 1 °C elevation of temperature was associated with 2.68% (95% CI: 1.83–3.52%) increase in diarrhea visits.

Epidemiological studies have pointed out that diurnal temperature range (DTR) and temperature change between the neighboring days (TCN) both showed adverse effects on human health. DTR (defined as the difference between daily maximum and minimum air temperatures) is a meteorological indicator for climate change and urbanization effects. Previous studies reported that DTR is related to mortality (Zhou et al. 2014; Luo et al. 2013; Yang et al. 2012) and the incidence of respiratory and cardiovascular diseases (Ma et al. 2018; Ge et al. 2013; Wang et al. 2013a; Xu et al. 2013). TCN was suggested to be associated with mortality in China (Lin et al. 2013; Cheng et al. 2014), Australia (Guo et al. 2011), and the United States (Zhan et al. 2017). In Brisbane, Australia, mortality of cardiovascular diseases would increase by 35.3% (95% CI: 3.3–77.2%) for per 3 °C increase in TCN (Guo et al. 2011). In Hefei (the capital and largest city of Anhui Province), China, non-accidental mortality would increase by 3% (with the range of 0–5%) with per 3 °C increase in the maximum TCN (Cheng et al. 2014). In the United States, there was a relatively high risk of mortality among people aged ≥ 75 years on the days with positive changes in TCN (Zhan et al. 2017).

A few studies reported the joint effects of air temperature and rainfall on respiratory morbidity (Su et al. 2014; Zhang et al. 2015c), cardiovascular mortality (Jie et al. 2014; Li et al. 2015; Li et al. 2011), hemorrhagic fever with renal syndrome (HFRS) (Liu et al. 2013b), HFMD (Wu et al. 2016; Chen et al. 2015a), bacillary dysentery (Li et al. 2015), and chickenpox (Chen et al. 2017). Some studies reported that air temperature could modify the effect of ambient air pollution on human health risks, such as cardiovascular and respiratory mortality (Li et al. 2011; Qian et al. 2008), COPD morbidity (Qiu et al. 2018), and outpatient visits for eczema (Li et al. 2016).

In this study, we reviewed a total of 175 recent studies on the effects of environmental conditions (158 for outdoor environment and 17 for indoor environment) on human health in China. For the outdoor environment, we summarized the effects of climate change–related phenomena on health, such as temperature, DTR, TCN, or other factors. The reviewed studies covered all areas of China (Fig. 1). The majority of the studies were about big cities, including 36 for Guangzhou, 35 for Beijing, 31 for Shanghai, and 22 for Wuhan. Besides that, 11–20 studies were for Harbin, Shenyang, Tianjin, Ji’nan,

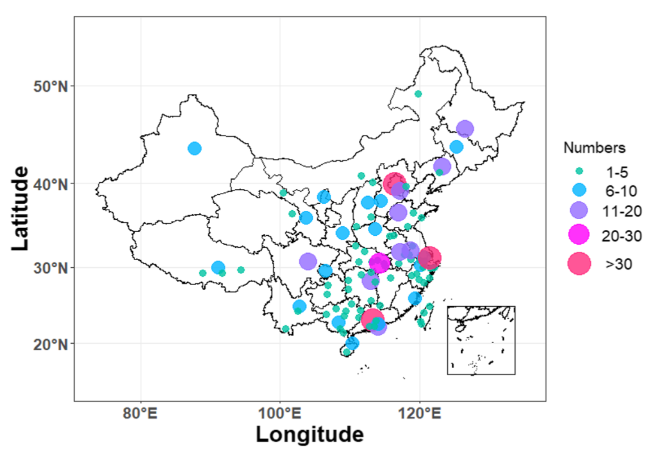

Fig. 1 Number of reviewed studies that were conducted in different locales of China

Hefei, Nanjing, Chengdu, Changsha, and Hong Kong, and the rest of the studies were for other cities.

Methods

Data extraction

Two investigators (Yifan Zhang and Haoran Jiao) searched PubMed, Web of Science, the Cochrane Library, and Embase for studies from January 2010 to January 2020, and the following terms were used as search strategy: ("meteorological" or "weather" or "climate" or "temperature" or "hot" or "cold" or "heat wave" or "DTR" or "air pressure" or "humidity" or "wind" or "rainfall" or "precipitation" or "sunshine duration") and ("circulation" or "circulatory" or "cardiovascular" or "cerebrovascular" or "respiratory" or "communicable" or "infectious" or "digestive" or "metabolic" or "endocrine" or "premature birth" or "preterm birth") and ("mortality" or "morbidity" or "hospital visit" or "hospital emergency" or "hospital admission").

A total of 4,367 articles were retrieved; then two investigators screened the titles and abstracts and excluded clearly irrelevant and unusable references independently; any differences were resolved by Bowen Cheng.

We finally selected 272 articles on the impact of environmental factors on human health and added 135 articles we selected from other data platforms. After removing duplicates in Endnote software, we screened out 175 articles with clear classifications of urban and environmental factors in China for regional statistical analysis.

Meta-analysis

The following eligibility criteria were included in the final meta-analysis: (a) focused on the effects of ambient temperature on cardiovascular diseases; (b) reference temperature or threshold was indicated; (c) RR and 95% CI was indicated; (d) no seasonality; (e) not extreme weather events; and (f) not projected temperature-related outcomes.

In the 175 articles, we selected 19 articles to explore the effect of air temperature on cardiovascular diseases in different cities. The characteristics of selected studies (including the first author, publication year, studied area and period, statistical methods, effect estimate of temperature, outcome variable, relative risks with 95% CI) were shown in the appendix (Yang et al. 2013). We divided the effects of temperature into two groups: cold effect and hot effect. In each group, we calculated the combined effect value according to the city. RRs from the individual studies were pooled with the random effects method because of the large degree of variation in the overall effect estimates between studies. The detailed screening process was shown in Fig. 2.

Outdoor environment and human health in China

Among the 158 studies of outdoor environment on human health, 54% focused on the associations of temperatures with cardiovascular diseases, including 12% on DTR, 21% on air temperature, and 67% on extreme air temperatures (Fig. 3).

Environmental factors and cardiovascular diseases

Epidemiological studies have pointed out that increases in cardiovascular disease morbidity (Ban et al. 2017; Ge et al. 2018; Cui et al. 2019) and mortality (Ma et al. 2014; Li et al. 2017; Chen et al. 2013) were associated with changes in the ambient air temperature. Previous studies have shown that every 1 °C temperature increase/decrease beyond certain reference points can lead to increased health risks of cardiovascular diseases (Zhang et al. 2016a; Gao et al. 2017; Huang et al. 2014). Some studies selected higher and lower reference temperatures as thresholds to explore the health effects of extreme hot and cold temperatures (Zhang et al. 2015b; Ding et al. 2016; Yang et al. 2012; Tian et al. 2012). In addition, the impact of DTR was also announced in many studies. Yang et al. (2018) found that the relationship between DTR and stroke mortality was more significant in Southern China (with a relative risk of 1.02%, 95% CI: 0.62–1.43%) than in Northern China (with a relative risk of 0.10%, 95% CI: −0.27–0.47%). In Beijing, the extra risk of cardiovascular admissions would increase by 0.76% (95% CI: 0.07–1.46%) for per 1 °C increase in the 3-day moving average of DTR (Wang et al. 2013a).

Since studies related to temperature exposure and cardiovascular diseases accounted for a large proportion of the total studies, we selected appropriate literatures further to assess the health risk of low and high temperatures. After separating the hot and cold exposure, meta-analyses were fitted using a random effect model to pool the estimates of RRs from all the included cities. As presented in Fig. 4, the effect of temperature varies between different cities. The overall effects of all studies for hot and cold temperatures were 1.089 (95% CI: 1.062–1.116) and 1.171 (95% CI: 1.125–1.218), respectively. For the hot effect, the RRs ranged from 1.001 (95% CI: 0.996–1.006) to 1.820 (95% CI: 1.532–2.162), while the RRs of the cold effect ranged from 1.030 (95% CI: 0.656–1.618) to 1.800 (95% CI: 1.384–2.340).

Other meteorological elements such as atmospheric pressure, relative humidity, and precipitation also have important influences. In Changchun, the number of admissions suffering from

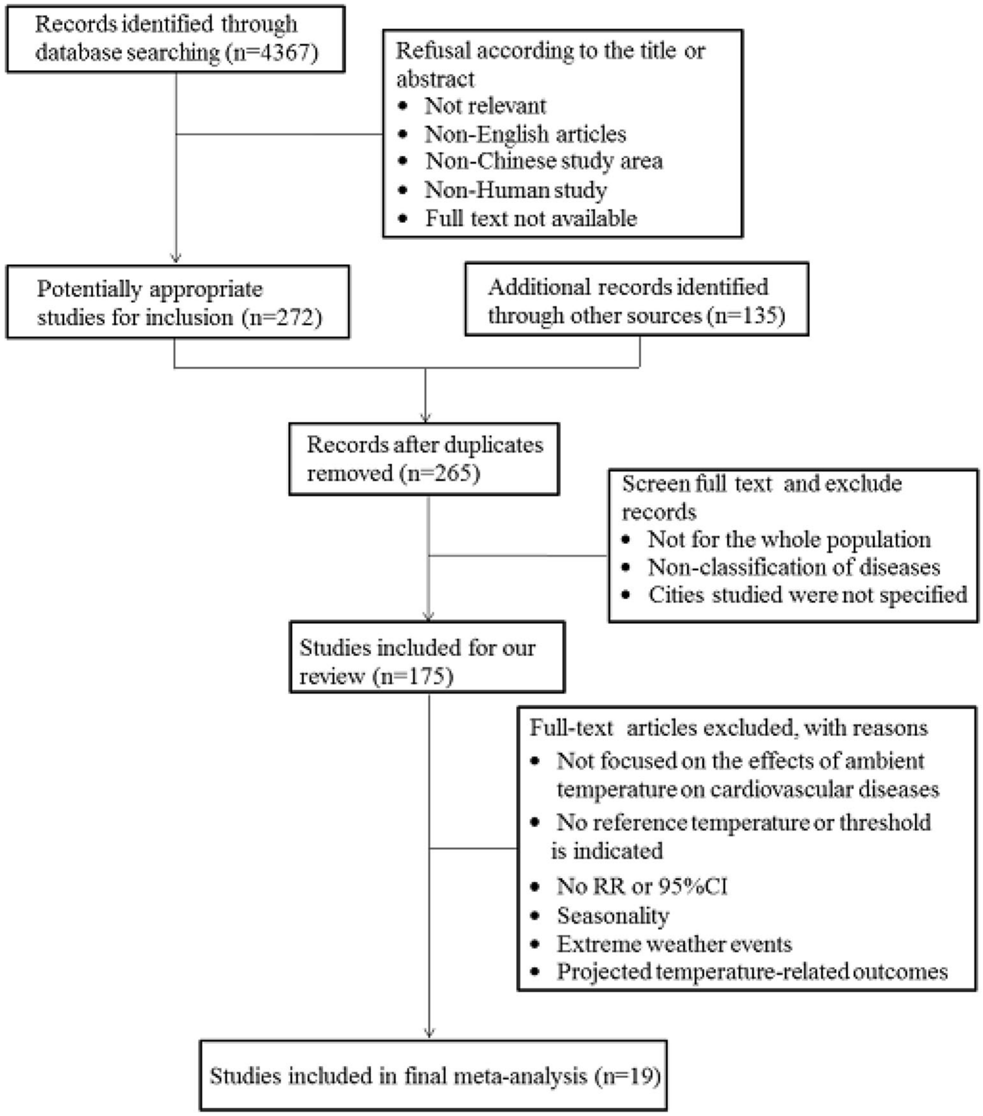

Fig. 2 Flow diagram of literatures' selection process

cerebral infarction was highly correlated with relative humidity and precipitation (Wang et al. 2013a). In Hong Kong, the positive linear association of air pressure with cardiovascular diseases was illustrated by Fong and Ma (2013). In Guangzhou, cardiovascular mortality was also found significantly affected by atmospheric pressure and relative humidity.

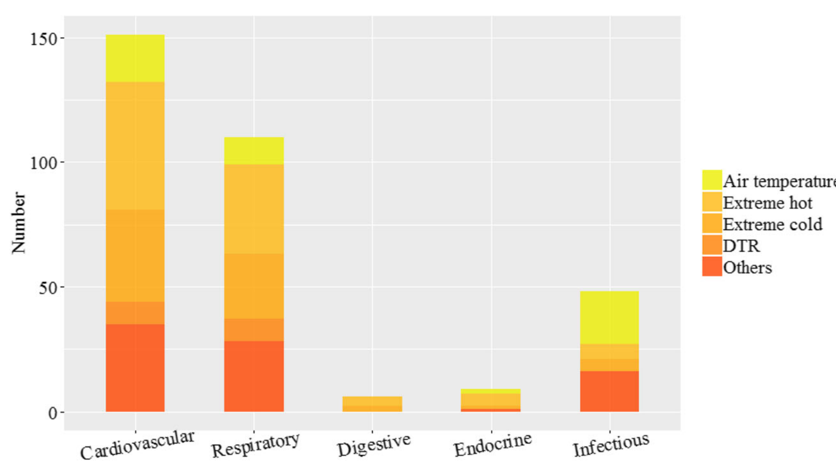

Fig. 3 Number of studies on the effects of the different meteorological factors (including DTR, extreme cold, extreme heat, air temperature, and others) on the different types of human diseases (including cardiovascular, respiratory, digestive, endocrine, and infectious diseases) in China.

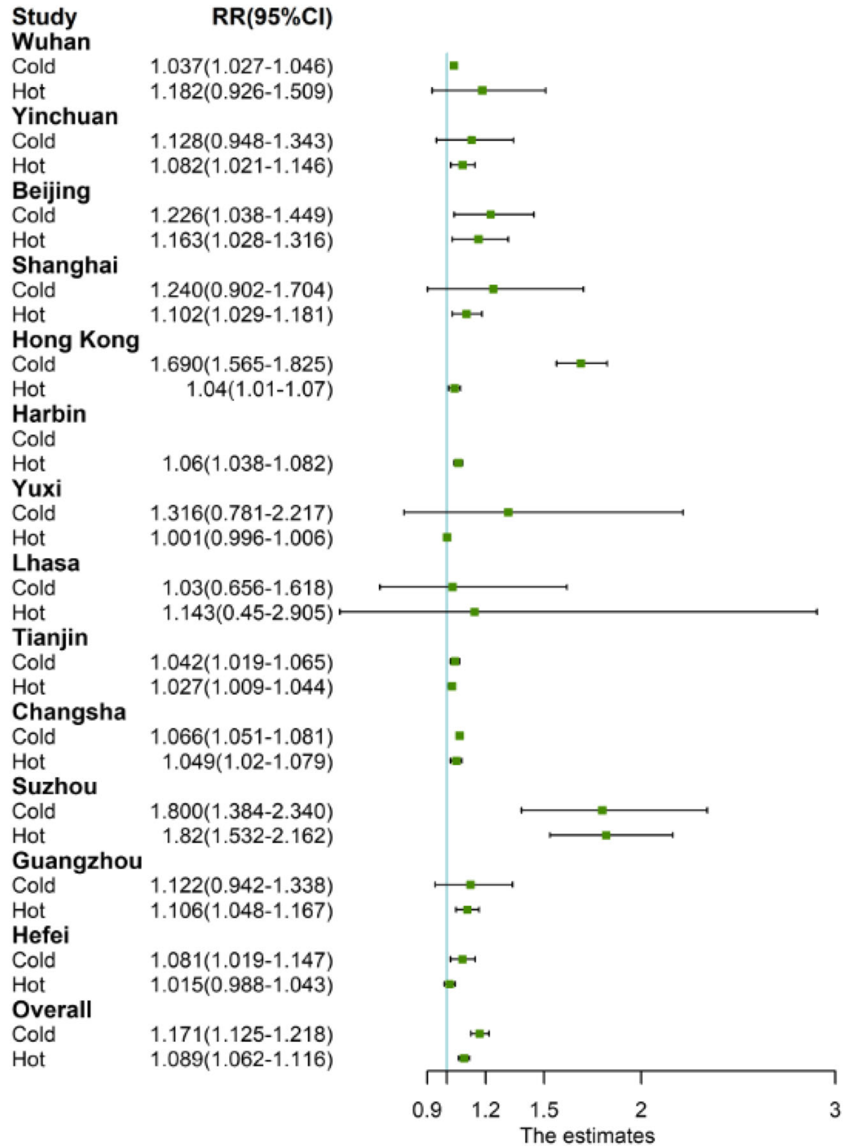

Fig. 4 Forest plot for the effects of hot and cold exposure on cardiovascular diseases in different cities of China

When atmospheric pressure and relative humidity increased from the 5th percentile to the 25th percentile, cardiovascular mortality increased by 2.27% (95% CI: 0.07–4.51%) and 3.97% (95% CI: 0.67–7.39%), respectively (Ou et al. 2014).

The interactions between meteorological factors and air pollutants also affected human health. In Zhejiang Province, the joint effect of low air temperature and high humidity on cardiovascular mortality showed a significant attributable fraction of 31.36% (95% empirical CI: 14.79–38.41%); the joint effect of low air temperature and low humidity showed a significant attributable fraction of 16.74% (95% empirical CI: 0.89–24.44%) (Zeng et al. 2017). In Tianjin, the interaction between PM_{10} and air temperature was statistically significant. For per 10 μg/m^3 increase in PM_{10} concentrations when the air temperature was relatively high, cardiovascular mortality would increase by 0.92% (95% CI: 0.47–1.36%) (Li et al. 2011). In Suzhou, Chen et al. (2013) also showed that the O_3 effects were stronger in cold season and low temperature days. On days with low temperatures (0th–25th percentile), an interquartile range (IQR) increment in 1-h maximum O_3 corresponded to a 18.77% (95% CI: 0.09, 40.95) increase in cardiovascular mortality. On days with normal temperatures (26th–75th percentile) or high temperatures (76th–100th percentile), the estimates were only 7.82% (95% CI: − 15.21, 37.10) or 6.14% (95% CI: − 17.35, 36.31). In Beijing, Luo et al. (2016) further indicated that the associations of $PM_{2.5}$ with cardiovascular mortality in susceptible populations were more sensitive to further adjustments for temperature and relative humidity.

Environmental factors and respiratory diseases

A strong evidence indicated a link between ambient air temperature and the development of respiratory diseases, including respiratory mortality and morbidity, COPD, bronchitis, upper respiratory infection, and asthma. Exposure to adverse ambient air temperature is associated with the high morbidity of respiratory diseases (Ma et al. 2019; Liu et al. 2014). In Ji'nan of Shandong Province, for per 1 °C increase in the maximum, average, and minimum temperatures that are above the threshold (35, 31, and 26 °C, respectively), the mortality of respiratory diseases would increase by 6.6, 25.3, and 14.7%, respectively (Li et al. 2017). Respiratory mortality has also been linked to extremely cold and hot temperatures (Wang et al. 2016a; Chen et al. 2015a; Song et al. 2017). A multi-city study showed that elderly people and those with respiratory diseases are generally more vulnerable to cold spells, especially in Southern China (Wang et al. 2016b). In Nanjing of Jiangsu Province (located in Eastern China), heat waves (when daily average air temperature is above the 98th percentile for four or more consecutive days) were associated with a 32.0% (95% CI: 8.5–60.5%) increase in respiratory mortality and a 47.6% (95% CI: 14.5–90.3%) increase in COPD mortality (Chen et al. 2015a). As for the effect of DTR, in Taiwan, the number of COPD hospital admissions increased by 14% when DTR increased to above 9.6 °C (Liang et al. 2009). In Shanghai, a 1 °C increase in the 2-day moving average of DTR would lead to a 2.08% (95% CI: 1.24–2.93%) increase in the number of ER visits for respiratory tract infections (Ge et al. 2013); a 1 °C increase in the 4-day moving average of DTR would cause a 1.25% (95% CI: 0.35–2.15%) increase in COPD mortality (Song et al. 2008). In Beijing, a 1 °C increase in DTR could increase respiratory mortality by 1.29% (95% CI: 0.49–2.09%) (Kan et al. 2007). In Changchun of Jilin Province (located in Northeast China), for per 1 °C increase in DTR, the relative risk of COPD could be up to 1.007 (95% CI: 0.994–1.019) during the year, 1.090 (95% CI: 1.077–1.103) during the warm seasons, and 1.115 (95% CI: 1.100–1.129) during the cold seasons (Ma et al. 2018). In particular, the elderly (age 65 and older) are at relatively higher risk of COPD than other people when DTR increases. Respiratory diseases are also affected by other environment factors. A previous study in Hong Kong showed that air pressure had a delayed effect on respiratory admissions (Fong and Ma 2013). In Hefei, the incidence of acute respiratory infection was negatively associated with relative humidity (Duan et al. 2016). In Beijing, among the involved air pollution and meteorological factors, relative humidity showed the most significant effect on COPD incidence, with a relative risk of 1.070 (95% CI: 1.054–1.086) for per 1% increase in relative humidity (Tian et al. 2019).

Joint effects of weather elements also could affect respiratory health. In Beijing, ambient air temperature and humidity showed a joint effect on ER visits for respiratory diseases, upper respiratory infection, and bronchitis. When the humidity level was relatively high, for per 1 °C increase in the average air temperature, the number of ER visits for all respiratory diseases, upper respiratory infection, and bronchitis would increase by 1.84% (95% CI: 1.35–2.13%),1.76% (95% CI: 1.41–2.11%), and 7.48% (95% CI: 4.41–10.65%), respectively (Su et al. 2014). In Tianjin, for per 10 μg/m^3 increase in PM_{10} concentrations when the air temperature was relatively high, respiratory mortality would increase by 0.74% (95% CI: − 0.33–1.82%) (Li et al. 2011). In Chengdu of Sichuan Province (located in Southwest China), the joint effect of particulate matters and low air temperature showed the greatest impact on COPD morbidity. During days with relatively low air temperature, exposure to $PM_{2.5}$ and PM_{10} contributed to 17.30% (95% CI: 12.39–22.19%) and 14.72% (95% CI: 10.38–19.06%), respectively, of the total number of hospital admissions for COPD (Qiu et al. 2018).

Environmental factors and digestive system and endocrine diseases

Environmental factors are also linked to the prevalence of digestive system diseases (Wang et al. 2013b; Li et al. 2014a), endocrine and metabolic mortalities (Li et al. 2014b), diabetes deaths (Yang et al. 2016), renal colic (Yang et al. 2016), and hemorrhagic fever with renal syndrome (Liu et al. 2013a). Some studies have shown the significant influence of temperature on digestive system diseases. Li et al. 2014apointed that for per 1 °C increase in the daily maximum air temperature, daily digestive mortality increased by 23.6 and 8.8%, respectively, in Chongqing and Shenzhen, and daily endocrine and metabolic disease mortality would increase by 31.9% (95% CI: 0.6–73.0%) in Shenzhen and 23.6% (95% CI: 1.2–50.9%) in Chongqing. A multi-city study suggested that short-term exposure to extremely high or low temperatures may contribute to an increase in diabetic deaths, especially for the elderly and people who are at pre-primary education level (Yang et al. 2016). In Guangzhou of Guangdong Province (located in South China), the relative risk of diabetic mortality was 1.10 (95% CI: 0.67–1.79), 1.07 (95% CI: 0.80–1.44), 1.92 (95% CI: 1.21–3.05), and 2.45 (95% CI: 1.50–3.99) for a short-term exposure to extremely low, low, high, and extremely high air temperatures, respectively (Yang et al. 2016). In Beijing, for per 1 °C increase in the 8-day moving average of DTR corresponded to 2.14% (95% CI: 0.71–3.59%) increase in the number of ER admissions for digestive diseases (Wang et al. 2013a). In Junan County of Shandong Province, air temperature and precipitation during the preceding 3 months can affect the endemic intensity of hemorrhagic fever with renal syndrome (Liu et al. 2013a).

Environmental factors and infectious diseases

Studies have shown that infectious diseases are related to environmental factors (Li et al. 2016; Duan et al. 2017; Wang et al. 2015a; Zhao et al. 2016; Ma et al. 2010). In Shanghai, weekly mean maximum, minimum, and average air temperatures showed the most effect on infectious diarrhea (Wang et al. 2015b). In Hefei of Anhui Province, the risk of bacillary dysentery would increase by 18.74% for per 1 °C increase in the average air temperature (Cheng et al. 2017). In Changsha of Hunan province, for per 1 °C increase in the average, maximum, and minimum air temperatures, the incidence of bacillary dysentery would increase by 14.8, 12.9, and 15.5%, respectively (Gao et al. 2014). The monthly average air temperature showed a negative effect on scarlet fever (with a relative risk of 0.962, 95% CI: 0.933–0.992) in Hong Kong but a positive effect on scarlet fever (with a relative risk of 1.196, 95% CI: 1.022–1.399) in Beijing (Duan et al. 2017). In Hefei of Anhui Province, there was a statistically significant correlation between DTR and pediatric bacillary dysentery incidence; for per 5 °C increase in the DTR, the number of pediatric bacillary dysentery cases would increase by 8.0% (95% CI: 2.9–13.4%); children younger than 5 years were relatively more sensitive to changes in DTR (Wen et al. 2016). Temperature changes within a day or between neighboring days also affect infectious diseases. In Huainan of Anhui Province, changes in air temperature between the neighboring days showed an adverse effect on the incidence of pediatric hand, foot, and mouth disease (HFMD) (Xu et al. 2016). In general, males and relatively younger children are more vulnerable to changes in air temperature (Yin et al. 2016; Xu et al. 2016). Moreover, humidity and precipitation are also important factors. In Qingdao of Shandong Province (Jiang et al. 2016), Suzhou of Jiangsu Province (Chen et al. 2015b), and Hong Kong (Wang et al. 2016a), increases in air temperature, precipitation, and relative humidity could all lead to an increase in the incidence of HFMD. In Guangzhou of Guangdong Province (located in South China), the weekly number of HFMD cases would increase by 9.38% (95% CI: 8.17–10.51%) and 4.01% (95% CI: 3.05–5.03%) with per 1 °C increase in the average air temperature and per 1 m/h increase in the wind velocity, respectively (Li et al. 2014a). In Shenzhen of Guangdong Province, the daily number of HFMD cases would increase by 3.93% (95% CI: 2.16–5.73%) for per 1 m/second increase in the wind speed (Zhang et al. 2016b). Environmental factors are also associated with other kinds of infectious diseases (Bi et al. 2013; Zhang et al. 2012; Li et al. 2013; Huang et al. 2011; Tian et al. 2008). In Guangdong Province, the monthly number of malaria cases would increase by 0.90% (3.99%) for per 1 °C increase in the average air temperature (1% increase in the relatively humidity) (Li et al. 2013). In Yongcheng of Henan Province (located in Central China), maximum air temperature and relative humidity both showed significant effects on malaria incidence at a 1-month lag (Zhang et al. 2012). In Guangdong, daily vapor pressure and average and minimum air temperatures were associated with an increase in the risk of dengue fever (Fan et al. 2014). For per 1 °C increase in the maximum and minimum air temperatures, dengue fever incidence would increase by 11.9 and 9.9%, respectively; relative humidity exceeding 78.9% was negatively associated with dengue fever incidence (Xiang et al. 2017). In Linyi of Shandong Province (located in Northern China), monthly average air temperature and relative humidity both showed positive correlations between Japanese encephalitis incidences (Lin et al. 2012). In Gansu Province, measles incidence was positively correlated with the monthly wind speed but negatively correlated with the monthly precipitation (Ma et al. 2017). In Wuhan of Hubei Province and Hong Kong, both average air temperature and precipitation showed significant influences on chickenpox incidence (Chen et al. 2017).

Environmental factors and preterm birth

Changes in ambient air temperature are found to be associated with preterm birth rate. In particular, weather extremes were significantly associated with the risk of preterm birth (Guo et al. 2018). In Guangzhou, when women were exposed to extreme cold (7.6 °C, the 1st percentile) or extreme heat (31.9 °C, the 99th percentile) during the last 4 weeks of pregnancy, the risk of preterm birth would increase by 17.9% (95% CI: 10.2–26.2%) or 10.0% (95% CI: 2.9–17.6%) (He et al. 2015). In Shenzhen of Guangdong Province, cold days were associated with the risk of preterm birth (Liang et al. 2016). In 2008, the cold spell caused a 22.44 and 21.25% increase in vaginal preterm birth in Dongguan and Shenzhen, respectively; the effect of the cold spell on preterm birth lasted for more than a week (Liang et al. 2018).

Indoor environment and human health in China

Nowadays, people tend to spend a large amount of time indoors. In particular, urban people spend approximately 90% of their time indoors (Brasche and Bischof 2005; Klepeis et al. 2001). Therefore, an indoor environment plays an important role in human health. To a certain extent, indoor air quality is correlated with outdoor air quality. The concentrations of outdoor air pollutants are associated with the physical characteristics of indoor air temperature and humidity. In a climate-controlled indoor environment, changes in indoor air temperature and humidity are likely to cause headaches, chest tightness, dry skin, etc.

In China, far fewer studies focused on the impact of indoor environment on human health than on the impact of outdoor environment. In this review, we only collected 17 relevant domestic studies. The involved topics were thermal environment (i.e., air temperature and relative humidity) and asthma/respiratory infections among children (Fan et al. 2017); indoor air pollution and respiratory symptoms (Fan et al. 2017; Liu et al. 2013a; Zhang and Smith 2007); indoor mold/dampness and pediatric allergies and asthma (Wang et al. 2013a; Lu et al. 2016; Qian et al. 2016; Zhang et al. 2015a); and indoor exposure to other factors like renovation, cooking, keeping pets, and human health (Zhang et al. 2013; Deng et al. 2015; Liu et al. 2015).

Overall, the reviewed studies about the impact of indoor environment on human health were mostly conducted in big cities in East China (including Beijing, Shanghai, Nanjing, Changsha, and Wuhan) and Northeast China (including five cities in Liaoning Province). In Beijing, a comprehensive investigation indicated that exposure to indoor low air temperature and low relative humidity in winter and dampness in summer could affect childhood health (Fan et al. 2017). Both dry and humid air were found to be positively associated with dampness indices (Qian et al. 2016). In Changsha, Hunan (Southern China), a study reported that prenatal exposure to indoor mold was significantly correlated to eczema incidence and postnatal exposure to indoor dampness was significantly correlated to asthma incidence (Deng et al. 2016). In Wuhan, Hubei, and Nanjing, Jiangsu, studies suggested that home environmental factors (dampness) were significantly associated with the prevalence of childhood pneumonia (Zheng et al. 2013) and asthma and rhinitis (Zhang et al. 2013). Qian et al. (2016) suggested that parents' perception of odors and relative humidity may be indicators of air pollutants in the surrounding environment and are likely to be the real factors that are associated with children's allergies. In particular, high levels of indoor $PM_{2.5}$ and VOCs (in house dust) were rated as the possible main risk factors for children's health (Hu et al. 2017). In Shanghai, the relative risk of death from stroke was 9.72 (95% CI: 1.88–50.24) among people who are exposed to coal fumes for an extended period of time (Zhang et al. 1988). In addition to indoor meteorological factors and air pollution, indoor renovation, use of gas for cooking, keeping pets, and living with smokers also affect human health (Liu et al. 2014; Zhang et al. 2013; Deng et al. 2015). Yu et al. (2018) also confirmed that solid fuels combusted indoors increased the risk of cardiovascular mortality in rural China. This is because solid fuels generate a large amount of air pollutants, including fine particulate matter.

Summary

In this review, we summarized studies on the impacts of outdoor meteorological factors on human health and then evaluated the potential risks of indoor environment on human health. In sum, ambient air temperature significantly affects human health, and changes in ambient air temperature are closely related to cardiovascular and respiratory morbidity and mortality. Regarding the indoor environment, air temperature, humidity, and dampness are key factors to human health, especially for the sensitive group (i.e., children).

Funding information This work is supported by the National Natural Science Foundation of China (Grant Nos. 41975141 and 41961028).

Compliance with ethical standards

Conflict of interest The authors have no conflict of interest to declare.

References

Analitis A, Katsouyanni K, Biggeri A, Baccini M, Forsberg B, Bisanti L, Kirchmayer U, Ballester F, Cadum E, Goodman PG, Hojs A, Sunyer A, Tiittanen P, Michelozzi P (2008) Effects of cold weather on mortality: results from 15 European cities within the PHEWE project. Am J Epidemiol 168(12):1397–1408

Ban J, Xu DD, He MZ, Sun QH, Chen C, Wang WT, Zhu PF, Li TT (2017) The effect of high temperature on cause-specific mortality: a multi-county analysis in China. Environ Int 106:19–26

Bi Y, Yu WW, Hu WB, Lin HL, Guo YM, Zhou XN, Tong SL (2013) Impact of climate variability on plasmodium vivax and plasmodium falciparum malaria in Yunnan Province, China. Parasit Vectors 6(1): 357

Brasche S, Bischof W (2005) Daily time spent indoors in German homes-baseline data for the assessment of indoor exposure of German occupants. Int J Hyg Environ Health 208(4):247–253

Burkart K, Khan MMH, Schneider A, Breitner S, Langner M, Krämer A, Endlicher W (2014) The effects of season and meteorology on human mortality in tropical climates: a systematic review. Trans R Soc Trop Med Hyg 108(7):393–401

Carmona R, Díaz J, Mirón IJ, Ortiz C, Luna MY, Linares C (2016) Mortality attributable to extreme temperatures in Spain: a comparative analysis by city. Environ Int 91:22–28

Chen K, Yang HB, Ma ZW, Bi J, Huang L (2013) Influence of temperature to the short-term effects of various ozone metrics on daily mortality in Suzhou, China. Atmos Environ 79:119–128

Chen K, Bi J, Chen J, Chen XD, Huang L, Zhou L (2015a) Influence of heat wave definitions to the added effect of heat waves on daily mortality in Nanjing, China. Sci Total Environ 506-507:18–25

Chen ZR, Sun HP, Yan YD, Wang YQ, Zhu CH, Zhou WF, Huang L, Wang MJ, Mize M, Tian JM, Ji W (2015b) Epidemiological profiles of hand, foot, and mouth disease, including meteorological factors, in Suzhou, China. Arch Virol 160(1):315–321

Chen BH, Sumi A, Wang L, Zhou W, Kobayashi N (2017) Role of meteorological conditions in reported chickenpox cases in Wuhan and Hong Kong, China. BMC Infect Dis 17(1):538

Cheng J, Zhu R, Xu ZW, Xu XQ, Wang X, Li KS, Su H (2014) Temperature variation between neighbouring days and mortality: a distributed lag non-linear analysis. Int J Public Health 59(6):923–931

Cheng J, Xie MY, Zhao KF, Wu JJ, Xu ZW, Song J, Zhao DS, Li KS, Wang X, Yang HH, Wen LY, Su H, Tong SL (2017) Impacts of ambient temperature on the burden of bacillary dysentery in urban and rural Hefei, China. Epidemiol Infect 145(8):1567–1576

Cui LJ, Geng XY, Ding T, Tang J, Xu JX, Zhai JX (2019) Impact of ambient temperature on hospital admissions for cardiovascular disease in Hefei City, China. Int J Biometeorol 63(6):723–734

De Sario M, Katsouyanni K, Michelozzi P (2013) Climate change, extreme weather events, air pollution and respiratory health in Europe. Eur Respir J 42(3):826–843

Deng QH, Lu C, Ou CY, Liu WW (2015) Effects of early life exposure to outdoor air pollution and indoor renovation on childhood asthma in China. Build Environ 93:84–91

Deng QH, Lu C, Ou CY, Chen L, Yuan H (2016) Preconceptional, prenatal and postnatal exposure to outdoor and indoor environmental factors on allergic diseases/symptoms in preschool children. Chemosphere 152:459–467

Ding Z, Li LJ, Wei RQ, Dong WY, Guo P, Yang SY, Liu J, Zhang QY (2016) Association of cold temperature and mortality and effect modification in the subtropical plateau monsoon climate of Yuxi, China. Environ Res 150:431–437

Duan Y, Huang XL, Wang YJ, Zhang JQ, Zhang Q, Dang YW, Wang J (2016) Impact of meteorological changes on the incidence of scarlet fever in Hefei City, China. Int J Biometeorol 60(10):1543–1550

Duan Y, Yang LJ, Zhang YJ, Huang XL, Pan GX, Wang J (2017) Effects of meteorological factors on incidence of scarlet fever during different periods in different districts of China. Sci Total Environ 581-582:19–24

Fan J, Lin H, Wang C, Bai L, Yang S, Chu C, Yang W, Liu Q (2014) Identifying the high-risk areas and associated meteorological factors of dengue transmission in Guangdong Province, China, from 2005 to 2011. Epidemiol Infect 142(3):634–643

Fan GT, Xie JC, Yoshino H, Yanagi U, Hasegawa K, Kagi N, Liu JP (2017) Environmental conditions in homes with healthy and unhealthy schoolchildren in Beijing, China. Build Environ 112:270–284

Fernández-Raga M, Tomás C, Fraile R (2010) Human mortality seasonality in Castile-León, Spain, between 1980 and 1998: the influence of temperature, pressure and humidity. Int J Biometeorol 54(4):379–392

Fong T, Ma E (2013) Effects of meteorological parameters on hospital admission for respiratory and cardiovascular diseases. J Public Health 21(2):175–182

Gao L, Zhang Y, Ding GY, Liu QY, Zhou MG, Li XJ, Jiang BF (2014) Meteorological variables and bacillary dysentery cases in Changsha City, China. Am J Trop Med Hyg 90(4):697–704

Gao HL, Lan L, Yang C, Wang J, Zhao YH (2017) The threshold temperature and lag effects on daily excess mortality in Harbin, China: a time series analysis. Int J Occup Environ Med 8(2):85–95

Gasparrini A, Guo YM, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, Tong S, Rocklöv J, Forsberg B, Leone M, de Sario M, Bell ML, Guo YLL, Wu CF, Kan H, Yi SM, de Sousa Zanotti Stagliorio Coelho M, Saldiva PHN, Honda Y, Kim H, Armstrong B (2015) Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet 386(9991):369–375

Ge WZ, Xu F, Zhao ZH, Zhao JZ, Kan HD (2013) Association between diurnal temperature range and respiratory tract infections. Biomed Environ Sci 26(3):222–225

Ge YH, Liu C, Niu Y, Chen C, Wang WB, Lin ZJ, Chen RJ, Cai J, Kan HD (2018) Associations between ambient temperature and daily hospital admissions for rheumatic heart disease in Shanghai, China. Int J Biometeorol 62(12):2189–2195

Guo YM, Barnett AG, Yu WW, Pan XC, Ye XF, Huang CR, Tong SL (2011) A large change in temperature between neighbouring days increases the risk of mortality. PLoS One 6(2):e16511

Guo YM, Jiang F, Peng L, Zhang J, Geng FH, Xu JM, Zhen CM, Shen XM, Tong SL (2012) The association between cold spells and pediatric outpatient visits for asthma in Shanghai, China. PLoS One 7(7):e42232

Guo TJ, Wang YY, Zhang HG, Zhang Y, Zhao J, Wang Y, Xie XX, Wang L, Zhang Q, Liu DJ, He Y, Yang Y, Xu JH, Peng ZQ, Ma X (2018) The association between ambient temperature and the risk of preterm birth in China. Sci Total Environ 613-614:439–446

He JR, Liu Y, Xia XY, Ma WJ, Lin HL, Kan HD, Lu JH, Feng Q, Mo WJ, Wang P, Xia HM, Qiu X, Muglia LJ (2015) Ambient temperature and the risk of preterm birth in Guangzhou, China (2001-2011). Environ Health Perspect 124(7):1100–1106

Hu JH, Li NP, Yoshino H, Yanagi U, Hasegawa K, Kagi N, He YD, Wei XQ (2017) Field study on indoor health risk factors in households with schoolchildren in south-central China. Build Environ 117:260–273

Huang F, Zhou SS, Zhang SS, Wang HJ, Tang LH (2011) Temporal correlation analysis between malaria and meteorological factors in Motuo County, Tibet. Malar J 10(1):54

Huang JX, Wang JF, Yu WW (2014) The lag effects and vulnerabilities of temperature effects on cardiovascular disease mortality in a subtropical climate zone in China. Int J Environ Res Public Health 11(4):3982–3994

Jiang FC, Yang F, Chen L, Jia J, Han YL, Hao B, Cao GW (2016) Meteorological factors affect the hand, foot, and mouth disease epidemic in Qingdao, China, 2007-2014. Epidemiol Infect 144(11):2354–2362

Jie Y, Hou JH, Meng XX et al (2014) A time series analysis of meteorological factors and hospital outpatient admissions for cardiovascular disease in the Northern district of Guizhou Province, China. Braz J Med Biol Res 47(8):689–696

Kan HD, London SJ, Chen HL, Song GX, Chen GH, Jiang LL, Zhao NQ, Zhang YH, Chen BH (2007) Diurnal temperature range and daily mortality in Shanghai, China. Environ Res 103(3):424–431

Katsouyanni K, Pantazopoulou A, Touloumi G, Tselepidaki I, Moustris K, Asimakopoulos D, Poulopoulou G, Trichopoulos D (1993) Evidence for interaction between air pollution and high temperature in the causation of excess mortality. Arch Environ Health 48(4):235–242

Kelly FJ, Fussell JC (2015) Air pollution and public health: emerging hazards and improved understanding of risk. Environ Geochem Health 37(4):631–649

Klepeis NE, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, Behar J, Hern SC, Engelmann WH (2001) The national human activity pattern survey (NHAPS): a resource for assessing exposure to environmental pollutants. J Expo Anal Environ Epidemiol 11(3):231–252

Kovats RS, Hajat S (2008) Heat stress and public health: a critical review. Annu Rev Public Health 29:41–55

Li GX, Zhou MG, Cai Y, Zhang YJ, Pan XC (2011) Does temperature enhance acute mortality effects of ambient particle pollution in Tianjin City, China. Sci Total Environ 409(10):1811–1817

Li TG, Yang ZC, Wang M (2013) Temperature, relative humidity and sunshine may be the effective predictors for occurrence of malaria in Guangzhou, Southern China, 2006-2012. Parasit Vectors 6(1):155

Li YH, Cheng YB, Cui GQ, Peng CQ, Xu Y, Wang YL, Liu YC, Liu JY, Li CC, Wu Z, Bi P, Jin YL (2014a) Association between high temperature and mortality in metropolitan areas of four cities in various climatic zones in China: a time-series study. Environ Health 13(1):65–72

Li T, Yang Z, Di B, Wang M (2014b) Hand-foot-and-mouth disease and weather factors in Guangzhou, Southern China. Epidemiol Infect 142(8):1741–1750

Li Y, Ma ZQ, Zheng CJ, Shang Y (2015) Ambient temperature enhanced acute cardiovascular-respiratory mortality effects of PM2.5 in Beijing, China. Int J Biometeorol 59(12):1761–1770

Li Q, Yang YY, Chen RJ, Kan HD, Song WM, Tan JG, Xu F, Xu JH (2016) Ambient air pollution, meteorological factors and outpatient visits for eczema in Shanghai, China: a time-series analysis. Int J Environ Res Public Health 13(11):1106

Li J, Xu X, Yang J, Liu ZD, Xu L, Gao JH, Liu XB, Wu HX, Wang J, Yu JQ, Jiang BF, Liu QY (2017) Ambient high temperature and mortality in Jinan, China: a study of heat thresholds and vulnerable populations. Environ Res 156:657–664

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

Liang ZJ, Lin Y, Ma YZ, Zhang L, Zhang X, Li L, Zhang SQ, Cheng YL, Zhou XM, Lin HL, Miao HZ, Zhao QG (2016) The association between ambient temperature and preterm birth in Shenzhen, China: a distributed lag non-linear time series analysis. Environ Health 15(1):84

Liang ZJ, Wang P, Zhao QG, Wang BQ, Ma YZ, Lin HL, Xiao JP, Zhou JY (2018) Effect of the 2008 cold spell on preterm births in two subtropical cities of Guangdong Province, Southern China. Sci Total Environ 642:307–313

Lin HL, Yang LQ, Liu QY, Wang T, Hossain SR, Ho SC, Tian LW (2012) Time series analysis of Japanese encephalitis and weather in Linyi City, China. Int J Public Health 57(2):289–296

Lin HL, Zhang YH, Xu YJ, Xu XJ, Liu T, Luo Y, Xiao JP, Wu W, Ma WJ (2013) Temperature changes between neighboring days and mortality in summer: a distributed lag non-linear time series analysis. PLoS One 8(6):e66403

Liu MM, Wang D, Zhao Y, Liu YQ, Huang MM, Liu Y, Sun J, Ren WH, Zhao YD, He QC, Dong GH (2013a) Effects of outdoor and indoor air pollution on respiratory health of Chinese children from 50 kindergartens. J Epidemiol 23(4):280–287

Liu J, Xue FZ, Wang JZ, Liu QY (2013b) Association of haemorrhagic fever with renal syndrome and weather factors in Junan County, China: a case-crossover study. Epidemiol Infect 141(4):697–705

Liu F, Zhao Y, Liu YQ, Liu Y, Sun J, Huang MM, Liu Y, Dong GH (2014) Asthma and asthma related symptoms in 23,326 Chinese children in relation to indoor and outdoor environmental factors: the Seven Northeastern Cities (SNEC) study. Sci Total Environ 497-498:10–17

Liu W, Huang C, Hu Y, Zou ZJ, Shen L, Sundell J (2015) Associations of building characteristics and lifestyle behaviors with home dampness-related exposures in Shanghai dwellings. Build Environ 88:106–115

Lu C, Deng QH, Li YG, Sundell J, Norbäck D (2016) Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China. Sci Total Environ 560-561:186–196

Luo Y, Zhang YH, Liu T, Rutherford S, Xu YJ, Xu XJ, Wu W, Xiao JP, Zeng WL, Chu C, Ma WJ (2013) Lagged effect of diurnal temperature range on mortality in a subtropical megacity of China. PLoS One 8(2):e55280

Luo K, Li WJ, Zhang R, Li RK, Xu Q, Cao Y (2016) Ambient fine particulate matter exposure and risk of cardiovascular mortality: adjustment of the meteorological factors. Int J Environ Res Public Health 13(11):1082

Ma YX, Wang SG, Shang KZ (2010) Effect of meteorological conditions on occurrence of intestinal epidemic in Lanzhou, China. Int Conf Bioinform Biomed Eng.

Ma WJ, Chen RJ, Kan HD (2014) Temperature-related mortality in 17 large Chinese cities: how heat and cold affect mortality in China. Environ Res 134:127–133

Ma YX, Zhou JD, Yang SX, Zhao YX, Zheng XD (2017) Assessment for the impact of dust events on measles incidence in Western China. Atmos Environ 157:1–9

Ma YX, Zhao YX, Zhou JD, Yang SX, Yu ZA (2018) The relationship between diurnal temperature range and COPD hospital admissions in Changchun China. Environ Sci Pollut Res 25(18):17942–17949

Ma YX, Zhou JD, Yang SX, Yu ZA, Wang F, Zhou J (2019) Effects of extreme temperatures on hospital emergency room visits for respiratory diseases in Beijing, China. Environ Sci Pollut Res 26(3): 3055–3064

Medina-Ramón M, Schwartz J (2007) Temperature, temperature extremes, and mortality: a study of acclimatization and effect modification in 50 United States cities. Occup Environ Med 64(12):827–833

Ou CQ, Yang G, Ou QQ, Liu HZ, Lin GZ, Chen PY, Qian J, Guo YM (2014) The impact of relative humidity and atmospheric pressure on mortality in Guangzhou, China. Biomed Environ Sci 27(12):917–925

Peng ZX, Wang Q, Kan HD, Chen RJ, Wang WB (2017) Effects of ambient temperature on daily hospital admissions for mental disorders in Shanghai, China: a time-series analysis. Sci Total Environ 590-591:281–286

Qian ZM, He QC, Lin HM, Kong LL, Bentley CM, Liu WS, Zhou DJ (2008) High temperatures enhanced acute mortality effects of ambient particle pollution in the “oven” city of Wuhan, China. Environ Health Perspect 116(9):1172–1178

Qian H, Zheng XH, Zhang M, Weschler L, Sundell J (2016) Associations between parents’ perceived air quality in homes and health among children in Nanjing, China. PLoS One 11(5):e0155742

Qiu H, Tan K, Long FY, Wang LY, Yu HY, Deng R, Long H, Zhang YL, Pan JP (2018) The burden of COPD morbidity attributable to the interaction between ambient air pollution and temperature in Chengdu, China. Int J Environ Res Public Health 15(3):492

Revich B, Shaposhnikov D (2008) Temperature-induced excess mortality in Moscow, Russia. Int J Biometeorol 52(5):367–374

Song GX, Chen GH, Jiang LL, Zhang YH, Zhao NQ, Chen BH, Kan HD (2008) Diurnal temperature range as a novel risk factor for COPD death. Respirology 13(7):1066–1069

Song XP, Wang SG, Li TS, Tian JH, Ding GW, Wang JX, Wang JX, Shang KZ (2017) The impact of heat waves and cold spells on respiratory emergency department visits in Beijing, China. Sci Total Environ 615:1499–1505

Su Q, Liu HS, Yuan XL, Xiao Y, Zhang X, Sun RJ, Dang W, Zhang JB, Qin YH, Men BZ, Zhao XD (2014) The interaction effects of temperature and humidity on emergency room visits for respiratory diseases in Beijing, China. Cell Biochem Biophys 70(2):1377–1384

Tian LW, Bi Y, Ho SC, Liu WJ, Liang S, Goggins WB, Chan EYY, Zhou SS, Sung JJY (2008) One-year delayed effect of fog on malaria transmission: a time-series analysis in the rain forest area of Mengla County, Southwest China. Malar J 7(1):110

Tian ZX, Li SS, Zhang JL, Jaakkola JJK, Guo YM (2012) Ambient temperature and coronary heart disease mortality in Beijing, China: a time series study. Environ Health 11(1):56

Tian L, Yang C, Zhou Z, Wu Z, Pan X, Clements ACA (2019) Spatial patterns and effects of air pollution and meteorological factors on hospitalization for chronic lung diseases in Beijing, China. Sci China-Life Sci 2019:1–8

Wang TT, Zhao ZH, Yao H, Wang SL, Norback D, Chen J, Ma JF, Ji XL, Wang L, Sundell J (2013a) Housing characteristics and indoor environment in relation to children’s asthma, allergic diseases and pneumonia in Urumqi, China. Chin Sci Bull 58(34):4237–4244

Wang MZ, Zheng S, He SL, Li B, Teng HJ, Wang SG, Yin L, Shang KZ, Li TS (2013b) The association between diurnal temperature range and emergency room admissions for cardiovascular, respiratory, digestive and genitourinary disease among the elderly: a time series study. Sci Total Environ 456-457(7):370–375

Wang YM, Li J, Gu JZ, Zhou ZL, Wang ZJ (2015a) Artificial neural networks for infectious diarrhea prediction using meteorological factors in Shanghai (China). Appl Soft Comput 35:280–290

Wang XY, Li GX, Liu LQ, Westerdahl D, Jin XB, Pan XC (2015b) Effects of extreme temperatures on cause-specific cardiovascular mortality in China. Int J Environ Res Public Health 12(12):16136–16156

Wang P, Goggins WB, Chan EYY (2016a) Hand, foot and mouth disease in Hong Kong: a time-series analysis on its relationship with weather. PLoS One 11(8):e0161006

Wang LJ, Liu T, Hu MJ, Zeng WL, Zhang YH, Rutherford S, Lin HL, Xiao JP, Yin P, Liu GM, Chu C, Tong SL, Ma WJ, Zhou MG (2016b) The impact of cold spells on mortality and effect modification by cold spell characteristics. Sci Rep 6(1):38380

Wen LY, Zhao KF, Cheng J, Wang X, Yang HH, Li KS, Xu ZW, Su H (2016) The association between diurnal temperature range and childhood bacillary dysentery. Int J Biometeorol 60(2):269–276

WHO (2008) Protecting health from climate change: World Health Day 2008. Geneva.

WHO (2016) Global health observatory data repository: deaths attributable to the environment data by country. http://apps.who.int/gho/data/node.main.162?lang=en. Accessed 9 Mar 2016

Wu JJ, Cheng J, Xu ZW, Zhao KF, Zhao DS, Xie MY, Yang HH, Wen LY, Li KS, Su H (2016) Nonlinear and interactive effects of temperature and humidity on childhood hand, foot and mouth disease in Hefei, China. Pediatr Infect Dis J 35(10):1086–1091

Xiang JJ, Hansen A, Liu QY, Liu XB, Tong MXL, Sun YH, Cameron S, Hanson-Easey S, Han GS, Williams C, Weinstein P, Bi P (2017) Association between dengue fever incidence and meteorological factors in Guangzhou, China, 2005-2014. Environ Res 153:17–26

Xu ZW, Huang CR, Su H, Turner LR, Qiao Z, Tong SL (2013) Diurnal temperature range and childhood asthma: a time-series study. Environ Health 12(1):12

Xu J, Zhao D, Su H, Xie M, Cheng J, Wang X, Li K, Yang H, Wen L, Wang B (2016) Impact of temperature variability on childhood hand, foot and mouth disease in Huainan, China. Public Health 134:86–94

Yang J, Ou CQ, Ding Y, Zhou YX, Chen PY (2012) Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou. Environ Health 11(1):63

Yang BY, Zhang Y, Xu CY, Jia BT, Wang CJ, Jia ZJ, Ni H, Wang DH, Zhang Z, Zhao G, Yang LM (2013) Effects of meteorological elements on admission rates of cerebral infarction patients with hypertensive nephropathy from nine hospitals in Changchun City, Jilin Province. Chin Med J 126(10):1934–1938

Yang QY, Fu CX, Wang NZ, Dong ZQ, Hu WS, Wang M (2014) The effects of weather conditions on measles incidence in Guangzhou, Southern China. Human Vaccines Immunother 10(4):1104–1110

Yang CY, Chen XY, Chen RJ, Cai J, Meng X, Wan Y, Kan HD (2016) Daily ambient temperature and renal colic incidence in Guangzhou, China: a time-series analysis. Int J Biometeorol 60(8):1135–1142

Yang J, Zhou MG, Li MM, Yin P, Wang BG, Liu Pilot E, YN, Hoek WVD, Asten LV, Krafft T, Liu QY, (2018) Diurnal temperature range in relation to death from stroke in China. Environ Res 164(7):669–675

Yin Q, Wang JF (2017) The association between consecutive days' heat wave and cardiovascular disease mortality in Beijing, China. BMC Public Health 17(1):223

Yin F, Zhang T, Liu L, Lv Q, Li XS (2016) The association between ambient temperature and childhood hand, foot, and mouth disease in Chengdu, China: a distributed lag non-linear analysis. Sci Rep 6: 27305

Yu K, Qiu GH, Chan KH, Lam KBH, Kurmi OP, Bennett DA, Yu CQ, Pan A, Lv J, Guo Y, Bian Z, Yang L, Chen YP, Hu FB, Chen ZM, Li LM, Wu TC (2018) Association of solid fuel use with risk of cardiovascular and all-cause mortality in rural China. JAMA. 319(13):1351–1361

Zanobetti A, Schwartz J (2008) Temperature and mortality in nine US cities. Epidemiology 19(4):563–570

Zeng J, Zhang XH, Yang J, Bao JZ, Xiang H, Dear K, Liu QY, Lin S, Lawrence WR, Lin AH, Huang CR (2017) Humidity may modify the relationship between temperature and cardiovascular mortality in Zhejiang Province, China. Int J Environ Res Public Health 14(11): 1383

Zhan ZY, Zhao Y, Pang SJ, Zhong X, Wu C, Ding Z (2017) Temperature change between neighbouring days and mortality in United States: a nationwide study. Sci Total Environ 584-585:1152–1161

Zhang JF, Smith KR (2007) Household air pollution from coal and biomass fuels in China: measurements, health impacts, and interventions. Environ Health Perspect 115(6):848–855

Zhang ZF, Yu SZ, Zhou GD (1988) Indoor air pollution of coal fumes as a risk factor of stroke, Shanghai. Am J Public Health 78(8):975–977

Zhang Y, Liu QY, Luan RS, Liu XB, Zhou GC, Jiang JY, Li HS, Li ZF (2012) Spatial-temporal analysis of malaria and the effect of environmental factors on its incidence in Yongcheng, China, 2006-2010. BMC Public Health 12(1):544

Zhang M, Zhou ES, Ye X, Sun YX, Sundell J, Yang X (2013) Indoor environmental quality and the prevalence of childhood asthma and rhinitis in Wuhan area of China. Chin Sci Bull 58(34):4223–4229

Zhang YS, Li SS, Pan XC, Tong SL, Jaakkola JJK, Gasparrini A, Guo YM, Wang S (2014) The effects of ambient temperature on cerebrovascular mortality: an epidemiologic study in four climatic zones in China. Environ Health 13(1):24

Zhang YQ, He MQ, Wu SM, Zhu YH, Wang SQ, Shima M, Tamura K, Ma L (2015a) Short-term effects of fine particulate matter and, temperature on lung function among healthy college students in Wuhan, China. Int J Environ Res Public Health 12(7):7777–7793

Zhang Y, Yan CY, Kan HD, Cao JS, Peng L, Xu JM, Wang WB (2015b) Effect of ambient temperature on emergency department visits in Shanghai, China: a time series study. Environ Health 13:100

Zhang JP, Zhang YP, Sundell J, Qu F, Li GN (2015c) Association between home environment and allergies among children in Beijing, China. Procedia Engineering 121:477–484

Zhang YQ, Li CL, Feng RJ, Zhu YH, Wu K, Tan XD, Ma L (2016a) The short-term effect of ambient temperature on mortality in Wuhan, China: a time-series study using a distributed lag non-linear model. Int J Environ Res Public Health 13(7):722

Zhang Z, Xie X, Chen XL, Li Y, Lu Y, Mei SJ, Liao YX, Lin HL (2016b) Short-term effects of meteorological factors on hand, foot and mouth disease among children in Shenzhen, China: Non-linearity, threshold and interaction. Sci Total Environ 539:576–582

Zhang Q, Liu W, Ma W, Zhang L, Shi Y, Wu Y, Zhu Y, Zhou M (2018) Impact of meteorological factors on scarlet fever in Jiangsu Province, China. Public Health 161:59–66

Zhao DS, Wang LL, Cheng J, Xu J, Xu ZW, Xie MY, Yang HH, Li KS, Wen LY, Wang X, Zhang H, Wang SS, Su H (2016) Impact of weather factors on hand, foot and mouth disease, and its role in short-term incidence trend forecast in Huainan City, Anhui Province. Int J Biometeorol 61(3):453–461

Zheng XH, Qian H, Zhao YL, Shen HP, Zhao ZH, Sun YX, Sundell J (2013) Home risk factors for childhood pneumonia in Nanjing, China. Chin Sci Bull 58(34):4230–4236

Zhou XD, Zhou YB, Chen RJ, Ma WJ, Deng HJ, Kan HD (2013) High temperature as a risk factor for infectious diarrhea in Shanghai, China. J Epidemiol 23(6):418–423

Zhou XD, Zhao A, Meng X, Chen RJ, Kuang XY, Duan XL, Kan HD (2014) Acute effects of diurnal temperature range on mortality in 8 Chinese cities. Sci Total Environ 493:92–97