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The association between temperature variability, morbidity and mortality for specific categories of disease: A systematic review and meta-analysis

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Abstract

While research into temperature-related health outcomes has focused on absolute temperature exposure, an increasing number of studies have explored the distinct effect of temperature variability (TV). However, systematic reviews in this area have focused on a limited number of health outcomes and intra-day TV. A systematic review was therefore conducted for studies of intra- and/or inter-day TV and cardiovascular, respiratory, renal or mental illnesses through April 2023 ($n = 38$). There was a consistent relationship between cardiovascular disease (CVD) or respiratory disease (RD) morbidity, mortality and both diurnal temperature range (DTR) or short-term inter-day TV, particularly for the elderly. The effect of DTR and short-term inter-day TV were stronger on hot days and the warm season for CVD, but on cold days and cold season for RD. Meta-analysis for CVD or RD and DTR showed a significant 0.7 %/C° increase in CVD mortality, but not morbidity, while RD showed a significant 1.0 %/C° and 0.7 %/C° increase in morbidity and mortality, respectively. Most studies focused on CVD, RD, DTR or short-term inter-day TV, while few studies explored renal, GU, or mental health outcomes aside from schizophrenia. Future studies are needed to assess non-linear relationships between TV and disease, and the modifying effect of socioeconomic status.

Keywords

Climate change; Health effects; Extreme weather; Health outcome threshold; Temperature variability; Diurnal temperature range; Mental health

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CRediT authorship contribution statement
Maxwell D. Weidmann: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

1. Introduction

From 2000 to 2019, non-optimal temperatures have been associated with more than 5 million, or about 9.4 % of all deaths globally (Zhao et al., 2021). Approximately 8.5 % of deaths were cold-related and 0.9 % were heat related, though cold-related deaths have decreased by 275,000 per year during this time while the heat-related deaths have increased by 113,000 per year, consistent with increased heat exposure due to Anthropogenic global warming (AGW[1]) (Zhao et al., 2021; IPCC, Climate Change 2023). Numerous studies have demonstrated the effects of increased ambient temperatures on physical disease outcomes (Fletcher et al., 2012; Li et al., 2019; Lin and al., 2012; Lin et al., 2009; Qu et al., 2023; Zeng et al., 2017), including a meta-analyses demonstrating a particularly strong association of heat exposure with all-cause, cardiovascular, cerebrovascular and respiratory mortality (Song et al., 2017). In contrast, meta-analysis showed no significant effect of heat exposure with morbidity for these outcomes, which was only significant for metabolic (e.g. diabetes) or genitourinary diseases (Song et al., 2017). AGW has also been associated with increases in the severity and frequencies of extreme heat events (heatwaves) (IPCC, Climate Change 2023; Rossati, 2017), with heatwaves showing significant increases in all-cause, cardiovascular and respiratory mortality, as well as cardiovascular morbidity (Zhao et al., 2021). Additionally mental health outcomes have also been found to be influenced by heat exposure (Deng et al., 2022), with significant effects on both morbidity and mortality. The greatest mortality effects were found in substance-related mental disorders and organic mental disorders, with increases in morbidity for mood disorders, organic mental disorders, schizophrenia, neurotic and anxiety disorders (Liu et al., 2021).

AGW has typically been associated with changes in average temperature, or excessively high temperature, but its effects on temperature are not the same during the day as compared to night, over the land as compared to ocean, or during different seasons (Easterling et al., 1997; Vose et al., 2005). AGW has had a relatively large impact on daily minimum relative to daily mean or maximum temperatures, with a number of studies observing that minimum temperature has been increasing at approximately twice the rate of maximum temperatures since 1950 (Easterling et al., 1997; Vose et al., 2005; Alexander et al., 2006; Sun et al., 2019; Thorne et al., 2016). As expected, this has resulted in a decrease in the diurnal temperature range (DTR) observed globally, and particularly in the Northern Hemisphere, though the magnitude of these changes varies considerably by geographical location (Sun et al., 2019; Thorne et al., 2016). Indeed, some locations such as the Yangtze River basin and parts of India have been found to have increases in DTR over the late 20th century (Guan et al., 2015; Rai et al., 2012).

AGW has also been shown to affect temperature variability (TV) occurring across other time scales, which is typically measured as standard deviation in mean daily temperatures

[1]**Key Terms:** Cardiovascular disease (CVD), diurnal temperature range (DTR), respiratory disease (RD), temperature variability (TV), mental health (MH), renal/genitourinary disease (GU), anthropogenic global warming (AGW), temperature change between neighboring days (TCN), relative risk (RR), excess risk (ER), confidence interval (CI), acute coronary syndrome (ACS), chronic obstructive pulmonary disease (COPD), distributed lag non-linear model (DLNM), day of the week (DOW), emergency department (ED), generalized additive model (GAM), generalized linear model (GLM), heart failure (HF), International Classification of Disease (ICD), lives lost per death (LLD), respiratory tract infection (RTI), socioeconomic status (SES), weekly temperature variability (WTV), years of life lost (YLL)

over a given time-period (Guo et al., 2021). In addition to diurnal temperature range (DTR), temperature variability has also been characterized as temperature changes between neighboring days (TCN), standard deviation within 3–7 days (synoptic-scale), intra-monthly, 30–90 days (sub-seasonal), seasonal, inter-annual or decadal time scales (Guo et al., 2021). The mechanisms by which AGW influences TV differs both by time scale and regional features (Guo et al., 2021). The Fifth Phase of the Coupled Model Intercomparison Project (CMIP5) projections demonstrate a decrease in TCN for both maximum and minimum temperatures over high latitudes in winter months, but an increase in TCN over the summer months in Europe (Guo et al., 2021). Likewise, over synoptic time scales TV has been found to decrease over the Northern hemisphere due to reduced temperature gradients with high latitudes, but increase over central and eastern Europe (Schneider et al., 2015). It is therefore likely that effects of both intra- and inter-day TV on specific health outcomes are modified by seasonal and climate-specific factors, which vary on a regional basis.

Despite the potential climate implications of inter-day temperature variability across a variety of time scales, there have been no systematic reviews on the effects of inter-day temperature variability of the week to annual timescale on morbidity and mortality related to cardiovascular disease (CVD), respiratory disease (RD), renal/genitourinary disease (GU) or mental health (MH). Only two systematic reviews assessed DTR, with one review focusing on CVD outcomes alone (Phung et al., 2016), to find a small but significant increase in CVD mortality (RR 1.007, 95 % CI 1.002–1.012), but larger increase in CVD morbidity (RR 1.022, 95 % CI 1.006–1.039), with increasing DTR via meta-analysis. The other systematic review included mainly studies assessing CVD, RD or all-cause mortality and only including studies up to 2013 (Cheng et al., 2014).

Therefore, the objectives of this systematic review include: 1) Systematically evaluate studies assessing the effect of exposure to either DTR or inter-day TV on morbidity and mortality related categories of cause-specific illness, such as cardiovascular disease, respiratory disease, renal/genitourinary disease and mental illness; 2) Compare the effects of intra- and inter-day TV exposures on different time scales to identify particularly vulnerable populations and the extent to which the effect of these TV indicators are modified by season and ambient temperature; and 3) Identify gaps and inconsistencies in the current literature that warrant further study.

2. Methods

2.1. Data sources

Searches were conducted on PubMed, Web of Science, EBSCO, and PsycINFO, which are commonly used sources for literature in the biomedical sciences, health and medical fields. The reference lists from selected articles and previous systemic reviews were also included as a data source.

2.2. Search criteria

A systematic literature review was conducted by searching for publications up to March 31st, 2023 containing the weather indicator keywords/terms: “temperature variability or diurnal temperature range," as well as the health indicator keywords/terms: "cardiovascular disease or respiratory disease or renal disease or genitourinary disease or kidney disease or mental health or mental illness" (Table 1). Title and abstract review were used as an initial screen for the inclusion and exclusion criteria defined below. Full-text review of the remaining records was then conducted to confirm that methodologies were in accordance with these criteria.

2.3. Inclusion and exclusion criteria

Articles were then included if: 1) They used an explicit measure of DTR or inter-day temperature variability as an exposure, 2) They included cause-specific morbidity or mortality outcomes including at least one of the following: 3) evaluated outcomes in cardiovascular disease, 4) respiratory disease, 5) renal/genitourinary disease, or 6) mental illness. Studies were excluded if they: 1) Only assessed all-cause mortality or morbidity, 2) Did not include outcomes in one of the disease categories defined above, 3) Were methods studies that did not report on clinical outcomes, or 4) Were not peer-reviewed.

2.4. Meta-analysis

Studies assessing DTR as an exposure were included in a meta-analysis, though there were insufficient studies using uniform methodology to study other indicators of temperature variability for meta-analysis. Within studies assessing the effect of DTR on health outcomes, studies assessing renal/urogenital disease or mental health were not included due to the reduced number of studies and large heterogeneity of study methodology. Studies were also excluded if they assessed multi-day averages of DTR, such as monthly or annual timescales. A random-effects model was used to pool effect sizes of studies assessing the association between DTR and hospitalizations or mortality associated with cardiovascular or respiratory disease. The analysis was completed in R, using the 'meta' package, and the Dersimonian-Laird estimator was used to estimate between-study heterogeneity (DerSimonian and Laird, 1986).

3. Results

3.1. Description of study selection

As shown in Fig. 1, 1149 records were initially retrieved based on initial search criteria, and these were narrowed down to thirty-six records upon review of titles and abstracts for those that did not include the weather indicators of interest, did not include any of the specific outcomes or did not represent primary research (reviews or meta-analyses). Removal of duplicate records that matched into more than one category, records that represented methodological research, records that included disease-specific risk factors rather than outcomes, resulted in a list of twenty-three full-text articles, and review of the reference lists of these articles resulted in an additional fifteen studies included, for a total of thirty-eight studies reviewed.

3.2. Characteristics of the studies included

Key characteristics of the thirty-eight studies included in this review are summarized in Table 2. Twenty-five of the studies (66 %) included some form of cardiovascular disease

(CVD) as an outcome (Liang et al., 2008; Cao et al., 2009; Tam et al., 2009; Luo et al., 2013; Zheng et al., 2016; Tian et al., 2019; Phosri et al., 2020; Kang et al., 2021; Yu et al., 2021; Zha et al., 2021; Zhai et al., 2021; Rahman et al., 2022; Tang et al., 2022; Zhai et al., 2022; Qi et al., 2023; Lim et al., 2015; Lee et al., 2018; Gong et al., 2023; Wang et al., 2022; Kan et al., 2007; Lim et al., 2012; Wang et al., 2013; Qiu et al., 2013), although seven (28 %) of these studies looked only at specific forms of CVD, rather than CVD as a general category of disease (Liang et al., 2008; Cao et al., 2009; Yu et al., 2021; Qiu et al., 2013). Eighteen of the studies (47 %) included respiratory disease (RD) as a health outcome (Luo et al., 2013; Phosri et al., 2020; Rahman et al., 2022; Qi et al., 2023; Lim et al., 2015; Lee et al., 2018; Gong et al., 2023; Wang et al., 2022; Kan et al., 2007; Lim et al., 2012; Wang et al., 2013; Sun et al., 2018; Pedder et al., 2021; Song et al., 2008; Liang et al., 2009; Ge et al., 2013; Xu et al., 2013; Li et al., 2014), but seven of these studies only looked at specific subsets of respiratory disease (Pedder et al., 2021; Song et al., 2008; Liang et al., 2009; Ge et al., 2013; Xu et al., 2013; Li et al., 2014; Chang and Ku, 2023). Only four studies (11 %) looked at renal system diseases as a health outcome (Lee et al., 2018; Wang et al., 2022; Wang et al., 2013; Li et al., 2022). Six studies (16 %) looked at mental health outcomes (Wang et al., 2022; Sung et al., 2011; Hiltunen et al., 2014; Zhao et al., 2016; Zhao et al., 2017; Xue et al., 2019), with four (66 %) of these studies looking at specific mental health outcomes (Sung et al., 2011; Hiltunen et al., 2014; Zhao et al., 2016; Zhao et al., 2017), and one study looking at mental health through self-assessment (17 %) (Xue et al., 2019).

Thirty-two of the studies (84 %) included time series analysis, with only nine studies (24 %) including either another method or a combination of study designs. Of these nine studies, there was one retrospective cohort study (Sung et al., 2011), three prospective cohort studies (Kang et al., 2021; Tang et al., 2022; Sun et al., 2018), two studies with a longitudinal design (one with difference-in-difference analysis) (Liang et al., 2009; Xue et al., 2019), and two studies using the case-crossover method in addition to time series (Cao et al., 2009; Lim et al., 2012). Regarding the location of study populations, twenty-nine of the included studies (74 %) were conducted in China or Taiwan, three (8 %) were conducted in other parts of East Asia, three (8 %) of studies were conducted on populations in the western hemisphere (Lim et al., 2015; Hiltunen et al., 2014; Magalhaes et al., 2011) and only two (6 %) studies conducted in the global south (Pedder et al., 2021).

3.3. Cardiovascular disease outcomes

Out of studies assessing CVD outcomes, twenty (80 %) assessed DTR (Liang et al., 2008; Cao et al., 2009; Tam et al., 2009; Luo et al., 2013; Zheng et al., 2016; Phosri et al., 2020; Zha et al., 2021; Zhai et al., 2021; Tang et al., 2022; Zhai et al., 2022; Qi et al., 2023; Lim et al., 2015; Lee et al., 2018; Wang et al., 2022; Kan et al., 2007; Lim et al., 2012; Wang et al., 2013; Qiu et al., 2013), with eighteen of these (90 %) assessing short-term DTR (single day or averages over a exposure days) (Liang et al., 2008; Cao et al., 2009; Tam et al., 2009; Luo et al., 2013; Zheng et al., 2016; Phosri et al., 2020; Zha et al., 2021; Zhai et al., 2021; Zhai et al., 2022; Lim et al., 2015; Lee et al., 2018; Wang et al., 2022; Kan et al., 2007; Lim et al., 2012; Wang et al., 2013; Qiu et al., 2013) and two (10 %) assessing annually averaged DTR (Tang et al., 2022; Qi et al., 2023). Ten studies looked at the association of short-term DTR with CVD-associated ED or hospital admissions (Liang et al., 2008; Zheng et al., 2016; Zha et al., 2021; Zhai et al., 2021; Zhai et al., 2022; Lee et al., 2018; Wang et al., 2022), and all but one study (Wang et al., 2022) showed an association between increased DTR and CVD admissions (or a subset of CVD, such as HF).

3.3.1. Cardiovascular disease morbidity and DTR: Three studies looking at the relationship between DTR and hospital admission in two rural areas, and one suburban area, of China found similarly shaped bimodal peaks in CVD incidence (Zha et al., 2021; Zhai et al., 2021; Zhai et al., 2022). In two of these studies there was a higher increase in RR of CVD admission for the lower DTR peak (2.24, $p < 0.05$; 2.95, 95 %CI 1.605–5.425), at a DTR of approximately 6 °C, though both low and high DTR (~19 °C) peaks in RR of CVD admission were significant in these studies (Zha et al., 2021; Zhai et al., 2022). However, the other study from rural China found that only the higher DTR (17 °C) peak (RR 1.78, $p <$ 0.05) had a significant effect, particularly for men (RR 1.94) and those <65 years (RR 2.23), while those >65 years were more sensitive to lower DTR, having a higher RR for the 6 °C DTR peak (2.55) (Zhai et al., 2021).

Five studies assessed the association of single-day DTR with morbidity due to subsets of CVD, as cerebrovascular events (strokes) (Magalhaes et al., 2011; Shaposhnikov et al., 2014), myocardial infarction (MI) (Shaposhnikov et al., 2014), acute coronary syndrome (ACS) (Liang et al., 2008), and heart failure (Lim et al., 2012; Qiu et al., 2013). Both studies assessing stroke risk found a significant relationship between DTR and either overall stroke (26 % increase per 10 °C increase from DTR of minimum risk) (Shaposhnikov et al., 2014), or hemorrhagic strokes only (12 % increase per °C) (Magalhaes et al., 2011). Heart failure was also significantly associated with DTR in both studies for which it was assessed, which found similar 3–4 % increase in risk of heart failure admission per 1 °C DTR increase (Lim et al., 2012; Qiu et al., 2013). In contrast, only one of the two studies assessing the effect of acute coronary CVD outcomes found a significant relationship with DTR (34.6 % increase in ACS admissions when DTR >9.6 °C, relative to <9.6 °C) (Liang et al., 2008).

There were mixed results for age stratification, with one study showing a greater association within either >65 or <65 year age groups relative to the overall population (Zhai et al., 2022). Three studies showed a greater association in those >75 years (Zheng et al., 2016; Wang et al., 2013; Qiu et al., 2013), while another study showed greater sensitivity for those <65 years (Zha et al., 2021). There were also mixed results by gender, with three studies from urban areas showing a greater effect of DTR in CVD admissions in women (Zheng et al., 2016; Wang et al., 2013; Qiu et al., 2013) while two studies in rural areas showed greater sensitivity to DTR in men (Zha et al., 2021; Zhai et al., 2021). Other studies showed different effects of DTR on men and women, with two studies in different rural districts of China showing that women were more sensitive to lower DTR (~6 °C), and especially extremely low DTR (<1 %tile), while men were more sensitive to higher DTR (Zhai et al., 2021; Zhai et al., 2022). Only two studies looked at the modifying effect of season on the DTR-CVD admission relationship with the first study in Hong Kong showing that, for heart failure specifically, there was only a significant increase in admissions during the cold season on individual lag days, and the overall effect at lag0–5 days was >6-fold higher in the cold season (Qiu et al., 2013). A later study in Bangkok, Thailand, found that the overall relationship between extremely high DTR (>11.6 °C) and CVD admissions 1.206 (95 % CI:

1.002–1.452), was higher in the winter, but not present in summer or rainy season (Phosri et al., 2020).

3.3.2. Cardiovascular disease mortality and DTR: There were also eight studies looking at the effect of DTR on CVD-related mortality (Cao et al., 2009; Tam et al., 2009; Luo et al., 2013; Tang et al., 2022; Qi et al., 2023; Lim et al., 2015; Lee et al., 2018; Kan et al., 2007), all of which showed a significant increase in CVD mortality with increasing DTR. There was significant variation in the magnitude of the effects seen for short and long-term DTR, however, with one study looking specifically at coronary heart disease finding up to a 3.6 % increase in mortality per 1 °C increase in short-term DTR (peaking at lag 3 days) using a unidirectional case-crossover design (Cao et al., 2009). In contrast, a time series analysis of data from Hong Kong found cumulative RR at lag0–3 and lag0–4 of 1.7 % per 1 °C increase in DTR (Tam et al., 2009), and a study spanning 95 communities in the US found only a 0.35 % increase in CVD mortality per 1 °C of DTR increase, with a nearly two-fold higher risk in the elderly (0.39 % vs 0.21 %, $p < 0.05$) (Lim et al., 2015). A Japanese-wide study using IQR intervals of DTR as a metric found that each IQR increase corresponded to 2 % increase in CVD mortality risk, and that this relationship stronger with increasing ambient temperature ($p < 0.001$) (Lee et al., 2018). Finally, a Chinese study looking at two urban districts found large increases in RR of mortality with extremely low DTR (<1 %tile) at longer lag times than assessed in the previous studies (lag0–13 and 0–20) while increases in CVD mortality due to extremely high DTR (>99 %tile) were only significant at shorter lags (0–6 and 0–13) (Luo et al., 2013). Studies looking at long-term DTR also found a large range of effect sizes on CVD mortality, with one country-wide time series study from China finding a small but significant 3 % increase in CVD mortality per 10 °C increase in DTR (annual), with the greatest effect at lower elevations (<500 m) (Qi et al., 2023). In contrast, a prospective cohort study spanning 14 Chinese provinces found a 12 % increase in risk for CVD mortality per 1 °C increase in annually averaged DTR, with a linear increase in risk with increasing DTR, while stroke risk increased by 9 % per 1 ° C of DTR, but showed a logarithmic increase at DTRs >10 °C (Tang et al., 2022).

3.3.3. Cardiovascular disease and inter-day TV: There were eight studies assessing CVD outcomes and some form of inter-day temperature variability (TV) indicator, four included an indicator that combined intra-day and inter-day TV (Tian et al., 2019; Yu et al., 2021; Rahman et al., 2022; Gong et al., 2023), two included both DTR and inter-day TV indicators (Shaposhnikov et al., 2014; Wang et al., 2022), while the remaining two assessed only inter-day TV (Kang et al., 2021; Jin et al., 2022). These latter two studies used prospective cohort design to assess long-term TV, wherein the standard deviations of daily mean temperatures were averaged over the year prior to each survey (Kang et al., 2021; Jin et al., 2022). Kang et al., (2021) looked at overall CVD risk to find an overall 6 % increase per 1C increase in long-term TV and the greatest effect for those aged 35–65 years. One of two studies assessing the association of intra-day TV and stroke found significant associations (Tian et al., 2019; Shaposhnikov et al., 2014), finding that ischemic stroke had the greatest association (0.82 %/ °C increase in TV from day 0–1 prior) of all CVD categories assessed (Tian et al., 2019), while no significant association was found for TCN and overall stroke (Shaposhnikov et al., 2014). The former study also found significant associations between inter-day TV and ischemic heart disease, heart failure and arrhythmia hospital admissions peaking for TV from 0–1 days prior to admission (Tian et al., 2019), while no significant association with inter-day TV from days 0–7 prior to admission was found for acute aortic dissection (Yu et al., 2021).

Of the four studies looking at short-term TV metrics that combined intra- and inter-day variability, those looking at risk of overall CVD hospital or ED admission found a more modest effect, with either a 0.44 % or 1 % increase in CVD risk per 1 ° C of TV, peaking at lag0–1 days (Tian et al., 2019; Rahman et al., 2022). A greater magnitude increase in CVD admissions per 1 °C TV increase was seen for men (0.51 %), those >75 years (0.81 %), those living in warmer regions (0.58 %), and for ischemic heart disease (0.82 %) amongst a Chinese urban population spanning 184 cities (Tian et al., 2019). Another study examining years of life lost (YLL) and life-lost per death (LLD) from CVD found most LLD attributable to short-term TV (lag0–1) was due to TV greater than 2.5 °C (96.6 %), and was greater for those <65 years, as well as warmer, humid, lower latitude and high altitude areas (Gong et al., 2023). In contrast, a study looking specifically at short-term TV effect on acute aortic dissection in Wuhan China found a protective or null effect of increased TV except for lag0–2 and 0–3 exposure days for women only (Yu et al., 2021).

3.4. Respiratory disease outcomes

Of the eighteen studies looking at RD outcomes, fifteen (83 %) assessed DTR as an indicator (Luo et al., 2013; Phosri et al., 2020; Qi et al., 2023; Lim et al., 2015; Lee et al., 2018; Wang et al., 2022; Kan et al., 2007; Lim et al., 2012; Wang et al., 2013; Pedder et al., 2021; Song et al., 2008; Liang et al., 2009; Ge et al., 2013; Xu et al., 2013; Li et al., 2014), with only one study looking at long-term DTR (Qi et al., 2023). The latter study, assessing annually averaged DTR across 266 cities in China, found a 4 % increase in RD mortality per 10 °C rise in DTR, only at elevations above 500 m (Qi et al., 2023). Of the remaining fourteen studies, four looked at the relationship between DTR and overall RD hospital admissions, with one study in Bangkok, Thailand finding no association between DTR and RD admissions (Phosri et al., 2020). Though another study spanning 20 sites in China found a 1.5 % increase in RD visits to the ED for each 1 °C increase in DTR only during the autumn (Wang et al., 2022). Wang et al. (2013) found a similar increase of ~2 % per 1C DTR increase, with a larger effect found in men (Wang et al., 2013), and Lim et al., (2012) used both case-crossover and time series designs to find a significant 1 % increase in RD hospital admissions per 1 °C DTR increase for both approaches. The latter study also found that COPD admissions had a more pronounced 2 % increase per 1 °C DTR increase by the time series analysis, while asthma had a more pronounced effect by case-crossover analysis (2 %/1 °C DTR), and particularly in those >75 years (4 %/1 °C DTR).

3.4.1. Respiratory disease morbidity and DTR:

There were an additional five studies that assessed subsets of RD morbidity. One assessed the role of DTR in COPD morbidity, finding a roughly 3 % increase in COPD admissions to the ED per 1 °C increase in DTR (Liang et al., 2009). One study assessed the role of DTR in childhood asthma morbidity, finding an ~6 % increase in risk per 1 °C increase in DTR (from 10 °C to 15 °C), and this was only significant for male children, with a larger effect in children age

5–9 years (18 %/1 °C) (Xu et al., 2013). Two studies also looked at ED admissions for overall respiratory tract infection (RTI), with similar findings for the RTI morbidity-DTR association peaking at lag1 or lag2 days, with overall lag0–1 or lag0–2 effect of ~2 % increase in admissions for RTI per 1 °C DTR increase (Ge et al., 2013; Li et al., 2014). A study from one district of South Africa also found a significant association between DTR and pneumonia admissions only when DTR was greater than 21 °C, which occurred 12 days per year at this location (Pedder et al., 2021).

3.4.2. Respiratory disease mortality and DTR: Five studies assessed the relationship between RD mortality and short-term effect of DTR. Two studies found a similar ~1 % increase in RD mortality risk per 1 °C increase in DTR, one spanning all of Japan over a 43-year period found this effect peaking at lag 2 days for hot days (>75 %tile) and lag >8 days for cold days (<25 %tile) (Lee et al., 2018), while another large study in Shanghai found significant effects at lag0, lag1 and lag4 days, and the DTR effect was only significant on relatively cool days (<23 °C) (Kan et al., 2007). A third study of 95 communities across the US looking at DTR as a continuous variable found a smaller 0.3 % (95 % CI 0.2–0.4 %) increase in RD mortality per 1 °C increase in DTR at cumulative lag0–3 days, and was only significant for those >65 years by subgroup analysis (0.33 %, 95 % CI 0.22–0.44 %) (Lim et al., 2015). The fourth study in two districts of China looked only at DTR by percentile, and for longer lags up to 27 days, finding a 381 % increase in RD mortality cumulative excessive rate (annual) over the entire lag period for extremely low DTR (<1 %tile), and that both <1 %tile and >99 %tile DTR showed significantly increased risk of RD mortality during the cold season, with longer cumulative lag (0–20 and 0–27 days) (Luo et al., 2013). Finally, Song et al., (2008) looked exclusively at COPD deaths in Shanghai to find a 1.25 % increase per 1 °C DTR increase, but found a larger 1.57 % increase on cold days (<22 °C) (Song et al., 2008).

3.4.3. Respiratory disease and inter-day TV: Four studies assessed the relationship between RD outcomes and inter-day TV, with two studies looking at combined metrics of inter- and intra-day variability, one looking at short-term inter-day variability and the remaining looking at three-month (seasonal) inter-day variability (Rahman et al., 2022; Gong et al., 2023; Wang et al., 2022; Sun et al., 2018). Sun et al., (2018) was a prospective cohort study of Hong Kong residents >65 years looking at seasonal TV, and finding a 20 % increase in risk of RD hospital admission per 1 °C of increased TV during the winter, but not summer (Sun et al., 2018). Wang et al. (2022) also looked at RD visits to the ED at 20 sites spanning most of China, but looked at short-term temperature change on neighboring days (TCN) to find a significant increase of 4.8 % in visits for RD per 1 °C increase in TCN in winter (relative to 2 %/1 °C overall), while the effect for DTR was only 1.5 %/1 °C and specific for autumn (Wang et al., 2022). Studies looking at mixed short-term TV metrics found increased risk of RD admission the ED (2.1 %/1C increase in TV) at short lag periods (cumulative 0–1 and 0–7 days), with greater effect in those >50 years, during the hot/dry or monsoon seasons (Rahman et al., 2022). The only study assessing the effect of TV (lag 0–1 days) on mortality found overall 0.54 LLD for RD, with highest levels of YLL at extremely low (<2 °C) or high TV (>10 °C), and greater overall association of TV on YLL in the elderly (>65 years), with mortality data from 5 Chinese provinces (Gong et al., 2023).

3.5. Renal/Genitourinary (GU) disease outcomes

Of the four studies that assessed either intra- or inter-day TV and renal disease, Wang et al. (2022) represents the largest study of GU outcomes, assessing both metrics to find an increase of 4 % in GU ED visits per 1 °C increase in TCN, which was attributed entirely to a summer season effect of 8.3 %/1 °C, with no significant change for the other seasons or with DTR (Wang et al., 2022). The other three studies assessed DTR only, with Wang et al. (2013) finding that there was a significant increase in GU morbidity peaking at lag0–5 of 1.81 % per 1 °C DTR increase, but was only significant for men and those >75 years (Wang et al., 2013). Li et al. (2022) found a significant increase in the RR of renal disease when DTR was either below 5 %tile or greater than 95 % tile at lag 0–7, lag0–14 and lag0–21, peaking at lag0–21 with RR of 6.96 (5 %tile) and 5.96 (95 %tile). Lee et al. (2018) assessed renal disease mortality, finding a 3–4 % increase per IQR increase in DTR (IQR = 4.6 °C overall), which was greater in warmer regions (4–5 %) and peaked with <2-day lag for extremely hot days (>99 %tile) and 3–4 day lag for extremely cool days (<1 %tile).

3.6. Mental health (MH) outcomes

Of the three studies assessing the role of TV in schizophrenia outcomes, two studies from the same Chinese province (Anhui) looked at the association between ED admissions and either DTR alone (Zhao et al., 2016) or both DTR and TCN (Zhao et al., 2017). For single lag days, the peak increase in ED admission risk for schizophrenia was at a 2.7 % increase for DTR of >95 %tile at lag0, and a 18.7 % increased risk for cumulative lag0–11 days, with greater risk for those aged 15–29, 50–64 and born in spring or autumn (Zhao et al., 2016). For both DTR and TCN, increase in RR peaked at lag3 and lag4 for those born in the spring at 95 %tile (DTR only) and 99 %tile (DTR and TCN). A retrospective cohort study across 21 of 25 districts in Taiwan also found that increasing DTR was associated with increased risk of schizophrenia hospital admission, beginning at 10–24 %tile and peaking at the highest DTRs (>99 %tile) with a 22 % increase ($p < 0.01$). One study looking at the association of suicide rates in Finland with DTR and short-term inter-day TV (from lag0–1 to lag0–5) found that only two of six sites had significant increases in suicide rates for men at lag0–1 and lag0–5 for men and lag0–5 at a third site for women ($p = 0.02$), while DTR was only significantly associated with suicide risk for women at one site at (2.4 %/1 °C, $p = 0.02$).

Two studies looked at the relationship between TV and overall mental health outcomes, Wang et al. (2022) assessing 20 sites across China to find an 11.8 % (95 % CI 3.6–21.2) increase in risk of ED visit for mental illness per 1 °C increase in TCN in Spring only, and no significant effect for DTR (Wang et al., 2022). Xue et al. (2019) assessed annual TV relationship with “mental health score” (MHS) in a questionnaire-based longitudinal study spanning 25 provinces of China, and finding a 15 % decrease in MHS per 1 °C increase in TV, and more specifically that increasing TV was associated with reports of nervousness, upset, hopelessness and meaninglessness (Xue et al., 2019).

3.7. Confounding factors

Table 2 details confounding factors controlled for in each of the studies, with the most common being daily mean temperature ($n = 29$), relative humidity ($n = 27$), as well as some form of air pollutant (such as (O_3, $PM_{2.5}$, PM_{10}, SO_2, CO, NO, or NO_2) ($n = 22$). Another prominent confounder noted in most studies, but only included in 24 % of studies ($n = 9$) was socioeconomic status (SES).

3.8. Limitations of included studies

The most common limitation, which was present in all studies assessed, was the dependence on ecologic methods of temperature assessment. While the resolution of temperature assessment varied greatly from 1 km (by interpolation) to >50 km for districts in which as few as a single were available, no study included data on local temperature exposure in the workplace or home setting. As access to indoor heating and cooling systems may greatly influence exposure to temperature variability, this is a major limitation. Twenty-seven (75 %) of the studies did not contain any metric of socio-economic status (SES), such as income or education level, in their model or stratified analysis, which may reduce confounding due to unknown indoor temperature exposure but does not serve as a proxy for such exposure data. Twenty-five (69 %) of the studies only covered one city or district, therefore representing only a narrow geographic area that may not be representative of other regions.

3.9. Meta-analysis

Due to methodological differences, only eight studies reviewed here were suitable for meta-analysis for an exposure of DTR (Figs. 2–3). The pooled effect of studies assessing the association between DTR and hospitalizations due to respiratory disease, but not cardiovascular disease, was found to be significant, with a 1.0 % increase in hospitalizations per degree Celsius (Fig. 2A–B). When both respiratory and cardiovascular hospitalizations were combined, there was also no significant pooled effect (Fig. 2C). In contrast, both cardiovascular and respiratory disease mortality produced a pooled effect that was significant, with an effect size was only 0.7 % per degree Celsius increase in DTR (Fig. 3A–B), and this was consistent with a significant pooled effect when both disease categories were combined across mortality outcomes (Fig. 3C). There was a high level of heterogeneity ($I^2 > 0.75$) for all groups and subgroups assessed, with the exception of hospital admissions due to respiratory disease.

4. Discussion

4.1. Overview

Here we have reviewed studies assessing a wide range of intra- and inter-day TV metrics. Our meta-analysis assessing the effect of intra-day TV (DTR) on CVD and RD showed a consistent association between increasing DTR and disease-specific mortality. However, the meta-analysis assessing the effect of DTR on hospital admissions only showed a significant effect for respiratory disease, with a non-significant trend towards increased risk with increasing DTR. Combined with a high degree of heterogeneity for all outcome and exposure groups assessed by meta-analysis, our review of the literature suggests that the associations between DTR and CVD or RD outcomes are not linear. Instead, it is likely that extremely low or high DTR impacts these outcomes in a manner influenced by regional climate and seasonality.

4.2. Diurnal temperature range, health outcomes and vulnerable groups

The effect of DTR on CVD morbidity showed an unexpectedly bimodal peak in studies assessing rural areas, with effects at both low and high DTR, but with effects diminishing at extremely low and high DTR. Overall, these studies suggest that the relationship between age and gender on vulnerability to the CVD risk cause by DTR are not always linear. Studies that only looked at linear relationships found mixed results, though there was consensus around greater effect of DTR on CVD morbidity for those >75 years or >65 years (Zheng et al., 2016; Lim et al., 2015; Wang et al., 2013; Qiu et al., 2013), while other found greater effect for <65 years (Zha et al., 2021). However, when one looks at low and high DTR peaks separately, the high DTR peak (~17 °C) was found to have a greater impact on CVD admissions for <65 years and men, while the opposite relationship for age and gender was found for the low DTR peak (6 °C). It is also possible that the bimodal peaks found in studies assessing rural areas of China, and farmers who have increased outdoor exposure, may represent a specific subpopulation, and further studies into such non-linear relationships across a large range of DTRs should be repeated in urban areas.

Studies assessing the relationship between DTR and CVD mortality found a strong relationship between CVD mortality risk and increasing DTR, albeit of a variety of magnitudes. However, many of these studies looked only at the linear relationship between DTR and CVD mortality. Only one study assessed the effects of extremely low DTR on CVD mortality, finding significant increases only at longer lag times than included for most studies, over a period of 2–3 weeks, while elevated DTR had a more immediate effect, within one week or less (Tam et al., 2009; Luo et al., 2013). Only one study assessed short-term DTR and CVD mortality stratified by age or gender, finding a far greater risk of mortality in the elderly (>65 years) per 1 °C increase in DTR, though there was still a significant increase for those <65 years (Lim et al., 2015). A large prospective cohort study assessing annually-averaged DTR found that there was no association between risk of CVD mortality and age, but gender stratification found that there was only a significant effect of increasing DTR in men (HR 1.21 vs 1.03; $p = 0.063$) (Tang et al., 2022).

For both RD morbidity and mortality, most studies assessed only the linear relationship between increasing DTR and health outcomes. However, the one study assessing both extremely low and high DTR found that only extremely low DTR (<1 %tile) had a significant effect on RD mortality over the full lag period assessed (27 days) (Luo et al., 2013). Only one study included a stratified analysis of overall RD morbidity and DTR by age and gender, finding no difference by age, but a larger effect in men, while COPD admissions specifically were more affected by DTR in those >75 (Wang et al., 2013). Two studies of asthma-related admissions also found a larger effect of DTR on male children, ages 5–9 years, and amongst adults those >75 years were more vulnerable (Lim et al., 2012; Xu et al., 2013). Only one study exploring the relationship between DTR and RD mortality conducted stratified analyses for age or gender, finding that increase in RD mortality associated with short-term DTR (lag0–3 days) was only significant in the elderly (>65 years) (Lim et al., 2015). However, this group did not assess the effect of DTR on RD morbidity.

Among studies assessing the effect of DTR on renal disease, only one study from Beijing stratified by age and gender, finding that there was only a significant effect of DTR on GU admissions in men or those >75 years (Wang et al., 2013). Among mental health outcomes, there was a consistent finding of significant increase in schizophrenia-related ED or hospital admission with increasing DTR, but only one study looked at gender and age differences, finding a greater effect for those <65 years and in men (Zhao et al., 2016).

4.3. Inter-day temperature variability and health outcomes and vulnerable groups

Interestingly, there were marked differences seen in the effects of intra-annual TV (long-term) versus TCN and synoptic time scales (short-term). Most studies assessing the association of inter-day TV and CVD risk looked only at morbidity, but the effect of intra-annual TV had the greatest effect on adults aged 35–65 years (with no difference by gender) (Kang et al., 2021), while the greatest effect of TV on CVD morbidity on the scale of days was found in those >75 years and men (Tian et al., 2019). Short-term TV was also more closely associated with RD morbidity in those >50, and >65 for RD mortality (Rahman et al., 2022; Gong et al., 2023). This is understandable as different mechanisms are likely to occur related to chronic exposure to higher TV relative to sharper swings in temperature on day to week time scales. As with increased ambient temperature, increased short-term TV had greatest effect with a short lag of 2–3 days or less, but since few studies adjusted for SES, not to mention employment, access to indoor cooling or outdoor exposure, further work needs to be done to determine whether increased influence of inter-annual TV on middle-aged adults is due to such a confounding variable.

None of the studies reviewed here that assessed inter-day TV and renal/GU outcomes performed a stratified analysis by age, gender or SES co-variates and specific outcomes. Though Wang et al. (2022) did find an increased effect of TCN in those aged <44 years, relative to those >45 years for all ED visits, there was no stratification by age or gender and cause-specific morbidity (Wang et al., 2022). Only one study reviewed here assessed the association between inter-day TV and MH status with analysis stratified by demographic and SES variables, finding no significant modifying effect by any of the variables assessed (including age, gender, education level, income, or urbanity of residence) (Xue et al., 2019).

For all TV time-scales, CVD morbidity was associated with increasing TV, however, the one study assessing CVD and RD mortality associations with short-term TV found that, while most LLD due to TV were for TV >2.5 °C, extremely low TV also produced a significant increase in both CVD and RD mortality (Gong et al., 2023). Interestingly, there was strong evidence from a prospective cohort study that was excluded from this review that a 1 °C increase in intra-annual TV was associated with an 8.3 % increase in dyslipidemia risk (Jin et al., 2022). Dyslipidemia has been found to represent a major risk factor for cardiovascular disease and suggests one potential etiology for the relationship observed between CVD risk and intra-annual TV found by Kang et al. 2021 (Kang et al., 2021; Jin et al., 2022).

4.4. The modifying effect of ambient temperature and season on TV-related health outcomes

Several studies demonstrated that the relationship between DTR and CVD mortality was significantly modified by day-to-day ambient temperature changes, while the effect of DTR on RD mortality was more influenced by seasonal effects and regional climate (Luo et al., 2013; Lee et al., 2018). The CVD mortality risk attributable to increasing DTR was greater for relatively hot compared to cold days across Japan, while RD mortality was more influenced by DTR in cooler regions (Lee et al., 2018; Kan et al., 2007), and during the cold season for extremely high or low DTR (Luo et al., 2013), but not for relatively hot or cool days. Interestingly, the effects of ambient temperature on the morbidity/DTR relationship were different, with extremely high DTR having a greater effect on CVD morbidity in the winter, while RD morbidity was more affected by DTR in the autumn (Phosri et al., 2020; Wang et al., 2022; Qiu et al., 2013). Overall, the effect of increasing DTR, as well as extremely high and low DTR, on RD appeared to have a longer lag relative to CVD, especially on relatively cold days and in the cold season, pointing to different mechanisms of influence on RD in the setting of high vs. low ambient temperature (Luo et al., 2013; Lee et al., 2018).

In contrast, CVD morbidity and mortality were more affected by short-term inter-day TV in warmer regions of China, with mortality also associated with more humid and lower latitude areas (Tian et al., 2019; Gong et al., 2023). The modifying effect of season was more similar for RD morbidity between DTR and short-term TV, with the latter having a greater effect during the winter in two of the three studies assessing seasonality (Wang et al., 2022; Sun et al., 2018), with the third being a time-series limited to a single city (Rahman et al., 2022).

Only one study assessed the effect of ambient temperature or seasonality on MH outcomes, finding that increasing TCN (short-term TV) only had a significant effect MH-related ED visits in the Spring, a transitional month (Wang et al., 2022). However, this study did not assess the effect of different types of mental illness. There was a consistently greater effect of increasing short-term inter-day TV or DTR on renal/-genitourinary disease morbidity and mortality in the summer season and in warmer regions, respectively (Lee et al., 2018; Wang et al., 2022). However, these trends for summer season in China and warmer regions of Japan represent only two studies, and with overlapping but different definitions of renal vs. genitourinary disease (Lee et al., 2018; Wang et al., 2022)

4.5. Biological plausibility

The physiological mechanisms explaining the vulnerability of the human body to TV has been studied to the greatest extent for DTR. Specifically for CVD, high intra-day variability in temperature has been found to increase cardiac load via relatively rapid changes in blood pressure, oxygen diffusion and heart rate (Liang et al., 2008; Imai et al., 1998). The relation of RD to increasing DTR and TV in studies reviewed here was found to be particularly large on colder days and in winter, which may related to a combination of reduced respiratory immunity and thickened secretions during cold periods, combined with increased risk of bronchospasm with sudden temperature increase (Diesel et al., 1991; Graudenz et al., 2006). Finally, the autonomic nervous system has been found to be influenced by short-term changes in temperature (1–2 days) and seasonal differences, and the resulting dysregulation with increasing DTR or inter-day TV may be related to any of the health outcome categories assessed here (Cheng et al., 2014; Shinkawa et al., 1990; Mercer et al., 1999).

4.6. Key gaps and areas for future research

Overall, there was a particular paucity of research into renal disease and mental illness. Three of four studies assessing renal disease looked at morbidity only, and only one study assessed renal disease mortality and DTR. There were no studies assessing inter-day TV and renal disease mortality, and only one study assessing renal disease morbidity and inter-day TV. For mental health outcomes, only one study assessed overall mental illness and there were no studies in which the morbidity related to different types of mental illnesses were compared. Since mental health is a broad category of diverse neurophysiological and psychological processes, future studies assessing the effects of TV on related subgroups of mental illness is crucial. While one study assessed suicide rate, there were no studies assessing mood disorders, anxiety disorders, substance abuse disorders or “organic” mental health disorders (such as personality disorders or dementia) despite clear evidence of their relationship to heat exposure and similar biological plausibility as to the influence of temperature variability, particularly on the day-to-week timescale (Liu et al., 2021). Consequently, there were no stratified analyses by age, gender or other demographic variables to assess which groups were most vulnerable to mental illness related to intra- or inter-day TV.

The only prospective cohort studies we found conducted for TV assessed CVD (Kang et al., 2021; Tang et al., 2022; Jin et al., 2022) or RD (Sun et al., 2018) outcomes only, with no prospective cohort studies for renal or mental health outcomes. For RD outcomes, only ED admissions were assessed by prospective cohort (Sun et al., 2018), there were only one such study each for overall CVD hospitalizations or mortality, and all of these were conducted in China (Kang et al., 2021; Tang et al., 2022). As the vast majority (74 %) of studies were conducted in China or Taiwan, future studies that represent a more diverse range of regional climates are necessary for generalizable evidence on the relationship between TV and each of the health outcomes reviewed here, as well as assessment of which trends are related to regional differences. While there has been increasing attention to the relationship between extreme heat or cold and specific health outcomes in the western hemisphere such as North America and Europe (Fletcher et al., 2012; Li et al., 2019; Lin and al., 2012; Lin et al., 2009; Qu et al., 2023; Song et al., 2017), the relationship between temperature variability and specific health outcomes has not been as frequently assessed in these areas (Phung et al., 2016; Cheng et al., 2014). There were also only three studies that focused on rural areas, and in particular subpopulations such as farmers who may have greater exposure to outdoor temperatures, with each finding a pronounced effect of lower DTR on CVD risk (Zha et al., 2021; Zhai et al., 2021; Zhai et al., 2022). Additional research is required to assess the modifying effect of such outdoor occupations, as well as SES markers that correlate with access to indoor temperature regulation, in order to prevent exposure misclassification for those who spend the majority of their time indoors.

Except for studies in CVD morbidity and DTR, there were relatively few studies looking at non-linear relationships in either intra- or inter-day TV and specific health outcomes. In particular, there was a paucity of publications assessing the effects of lower-than-average TV on respiratory, renal or mental health outcomes. This may be particularly significant for DTR, as climate change is projected to cause a decrease in DTR in many regions, and studies using non-linear models such as DLNM to study DTR have found a marked increase in risk of CVD morbidity for low DTR, peaking at 6C and with a larger effect for those >65 years. Further, only one study assessed the modifying effect of transitional seasons on the relationship between TV and health outcomes, and this study only assessed DTR and TCN (Wang et al., 2022), but found that some outcomes (MH and RD) only had significant effects during transitional seasons (Spring and Autumn, respectively). While a second study assessed TV on a seasonally averaged scale, it did not include transitional months (Sun et al., 2018). Therefore, future studies should address the modifying effect of transitional season on the association between TV and specific health outcomes, in particular at the month to seasonal timescales of TV.

None of the studies reviewed here controlled for the cumulative effect of heat or cold waves, which may introduce negative confounding if there is a significant inverse relationship between such periods and temperature variability. While most studies controlled for mean daily temperature, or the mean temperature during longer intervals of analysis (Tian et al., 2019; Rahman et al., 2022), this does not account for the cumulative effect of heat or cold waves over multiple days, or account for how duration of the event may impact health outcomes. There is an increasing number of studies showing that, in addition to heatwave intensity, heatwave duration represents a significant secondary effect that is not controlled for in studies of temperature variability (Anderson and Bell, 2011; Gasparrini and Armstrong, 2011). Particularly for studies assessing metrics of inter-day TV, controlling for contemporaneous heat wave or cold wave duration would reduce potential confounding from increased health effects of prolonged extreme temperatures.

Finally, only two studies reviewed here included modeling of future cause-specific mortality related to DTR based on prior trends, and these studies looked only at annually-averaged DTR (Tang et al., 2022; Qi et al., 2023). Future studies that model morbidity rates for each category of health outcomes addressed here should incorporate region-specific data on the effects of DTR and inter-day TV at shorter time scales.

4.7. Study strengths and limitations

This review represents the first attempt to systematically include both studies of intra-day temperature variability (DTR) as well as inter-day variability at scales ranging from neighboring days to annually averaged TV. In addition, we are the first study to include a wide range of health outcomes, including MH and renal/GU outcomes, and including an increasing number of large-scale studies on this topic that have been published since the last similar review in 2014 (Cheng et al., 2014), which also did not include cohort studies that have since been conducted related to CVD and RD outcomes.

There are several limitations to the current review, including the lack of meta-analysis for inter-day TV, which is due in part to the variety of study designs included in the studies reviewed here. Additionally, there were slightly different definitions of CVD used in several studies, some including stroke and non-cardiac related circulatory disease, while others only included those relating strictly to the cardiovascular system, and this made the interpretation of these findings challenging when subgroups were not included for those specific categories. Similarly, some studies used the category of renal disease, while others looked at GU or urinary disease. While there was some overlap here, our assessment of these terms together was largely due to the paucity of studies in this area, and further studies are needed in each category to determine if there are meaningful differences for each category's relationship to TV. Finally, our inclusion of a wide range of health outcomes prevented a more fine-grained analysis of disease subgroups for each health outcomes, though significant findings for each are included in Table 2. In particular, CVD and RD included enough studies such that more detailed disease subgroup analysis is warranted. The limited number of studies ($n < 10$) with compatible outcome metrics (cardiovascular vs. respiratory disease, morbidity vs. mortality) for comparison by meta-analysis prevented meaningful assessment of publication bias by funnel plot analysis. However, p-value contours of plots including all DTR metrics suggested that there was a bias against publication of small studies quantifying the relationship between DTR and CVD or RD with non-significant results (data not shown).

5. Conclusions

In summary, here we find strong evidence that both CVD and RD morbidity and mortality increase as DTR increases above mean values for a particular area and with increasing inter-day temperature variability on the scale of one week. There is also strong evidence that the elderly, particularly >75 years are more vulnerable to CVD morbidity and mortality at high DTR, with more limited evidence for this relationship at low DTR. However, additional studies including analyses stratified by age, gender and particularly SES are needed to identify vulnerable groups, particularly for RD, renal/GU disease and mental illness. While a significant relationship between increasing DTR or TCN and schizophrenia morbidity has been demonstrated, future study into the effects of TV on other types of mental illness must still be assessed.

Additional studies conducted in the global south and western hemisphere are necessary to generalize findings from studies in Asia, and particularly to assess TV effects on health during transitional seasons such as Spring and Fall in temperate regions. There has also been little investigation into the effects of extremely low DTR on health outcomes, but early findings indicate that it may have a particularly large effect on CVD morbidity and mortality, as well as RD mortality, particularly for vulnerable groups such as women and outdoor workers (e.g. farmers). Considering the global trend towards lower DTR due to climate change, the effects of low DTR on CVD and RD outcomes will be important to effectively model the overall impact of climate change on human health.

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References

Alexander LV, et al. , 2006. Global observed changes in daily climate extremes of temperature and precipitation. J. Geophys. Res.-Atmosph 111 (D5).

Anderson GB, Bell ML, 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US. communities. Environ. Health Perspect 119 (2), 210–218. [PubMed: 21084239]

Cao J, et al. , 2009. Diurnal temperature range is a risk factor for coronary heart disease death. J. Epidemiol 19 (6), 328–332. [PubMed: 19749499]

Chang M, Ku Y, 2023. LSTM model for predicting the daily number of asthma patients in Seoul, South Korea, using meteorological and air pollution data. Environ. Sci. Pollut. Res. Int 30 (13), 37440–37448. [PubMed: 36574119]

Cheng J, et al. , 2014. Impact of diurnal temperature range on human health: a systematic review. Int. J. Biometeorol 58 (9), 2011–2024. [PubMed: 24535132]

Deng X, et al. , 2022. Identifying joint impacts of sun radiation, temperature, humidity, and rain duration on triggering mental disorders using a high-resolution weather monitoring system. Environ. Int 167, 107411. [PubMed: 35870379]

DerSimonian R, Laird N, 1986. Meta-analysis in clinical trials. Control. Clin. Trials 7 (3), 177–188. [PubMed: 3802833]

Diesel DA, Lebel JL, Tucker A, 1991. Pulmonary particle deposition and airway mucociliary clearance in cold-exposed calves. Am. J. Vet. Res 52 (10), 1665–1671. [PubMed: 1767989]

Easterling DR, et al. , 1997. Maximum and minimum temperature trends for the globe. Science (1979) 277 (5324), 364–367.

Fletcher BA, et al. , 2012. Association of summer temperatures with hospital admissions for renal diseases in New York State: a case-crossover study. Am. J. Epidemiol 175 (9), 907–916. [PubMed: 22455834]

Gasparrini A, Armstrong B, 2011. The impact of heat waves on mortality. Epidemiology. (Fairfax) 22 (1), 68–73.

Ge WZ, et al. , 2013. Association between diurnal temperature range and respiratory tract infections. Biomed. Environ. Sci 26 (3), 222–225. [PubMed: 23425805]

Gong W, et al. , 2023. Mortality burden attributable to temperature variability in China. J. Expo Sci. Environ. Epidemiol 33 (1), 118–124. [PubMed: 35332279]

Graudenz GS, et al. , 2006. The role of allergic rhinitis in nasal responses to sudden temperature changes. J. Allergy Clin. Immunol 118 (5), 1126–1132. [PubMed: 17088139]

Guan YH, et al. , 2015. Trends and variability of daily temperature extremes during 1960-2012 in the Yangtze River Basin, China. Glob. Planet. Change 124, 79–94.

Guo F, et al. , 2021. Trends of temperature variability: which variability and what health implications? Sci. Total. Environ 768, 144487. [PubMed: 33444866]

Haddaway NR, et al. , 2022. PRISMA2020: an R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. Campbell Systemat. Rev 18 (2), e1230.

Hiltunen L, et al. , 2014. Local daily temperatures, thermal seasons, and suicide rates in Finland from 1974 to 2010. Environ. Health Prev. Med 19 (4), 286–294. [PubMed: 24794752]

Imai Y, et al. , 1998. Acute myocardial infarction induced by alternating exposure to heat in a sauna and rapid cooling in cold water. Cardiology 90 (4), 299–301. [PubMed: 10085493]

IPCC, Climate Change, 2023. Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, p. 2023.

Jin J, et al. , 2022. Long-term temperature variability and risk of dyslipidemia among middle-aged and elderly adults: a prospective cohort study - China, 2011-2018. China CDC. Wkly 4 (26), 561–564. [PubMed: 35919457]

Kan H, et al. , 2007. Diurnal temperature range and daily mortality in Shanghai, China. Environ. Res 103 (3), 424–431. [PubMed: 17234178]

Kang Y, et al. , 2021. Long-term temperature variability and the incidence of cardiovascular diseases: a large, representative cohort study in China. Environ. Pollut 278, 116831. [PubMed: 33711625]

Lee W, et al. , 2018. Association between diurnal temperature range and mortality modified by temperature in Japan, 1972-2015: investigation of spatial and temporal patterns for 12 cause-specific deaths. Environ. Int 119, 379–387. [PubMed: 30005186]

Li M, et al. , 2019. Impact of extremely hot days on emergency department visits for cardiovascular disease among older adults in New York State. Int. J. Environ. Res. Public Health 16 (12).

Li T, Yang Z, Wang M, 2014. Diurnal temperature range may be the risk factor for respiratory tract infections among the elderly in Guangzhou, China. Int. J. Biometeorol 58 (3), 309–310. [PubMed: 24057083]

Li Y, et al. , 2022. Ambient temperature, humidity, and urinary system diseases: a population-based study in Western China. Environ. Sci. Pollut. Res. Int 29 (19), 28637–28646. [PubMed: 34988822]

Liang WM, et al. , 2008. Ambient temperature and emergency room admissions for acute coronary syndrome in Taiwan. Int. J. Biometeorol 52 (3), 223–229. [PubMed: 17960427]

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. [PubMed: 18989710]

Lim YH, et al. , 2015. Diurnal temperature range and short-term mortality in large US communities. Int. J. Biometeorol 59 (9), 1311–1319. [PubMed: 25465402]

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. [PubMed: 22281041]

Lin S, et al. , 2009. Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. Epidemiology. (Fairfax) 20 (5), 738–746.

Lin S, et al. , 2012. Excessive heat and respiratory hospitalizations in New York State: estimating current and future public health burden related to climate change. Environ. Health Perspect 120 (11), 1571–1577. [PubMed: 22922791]

Liu J, et al. , 2021. Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis. Environ. Int 153, 106533. [PubMed: 33799230]

Luo Y, et al. , 2013. Lagged effect of diurnal temperature range on mortality in a subtropical megacity of China. PLoS. One 8 (2), e55280. [PubMed: 23405130]

Magalhaes R, et al. , 2011. Are stroke occurrence and outcome related to weather parameters? Results from a population-based study in northern portugal. Cerebrovasc. Dis 32 (6), 542–551. [PubMed: 22104569]

Mercer JB, Osterud B, Tveita T, 1999. The effect of short-term cold exposure on risk factors for cardiovascular disease. Thromb. Res 95 (2), 93–104. [PubMed: 10418798]

Pedder H, et al. , 2021. Lagged Association between Climate Variables and Hospital Admissions for pneumonia in South Africa. Int. J. Environ. Res. Public Health 18 (12).

Phosri A, Sihabut T, Jaikanlaya C, 2020. Short-term effects of diurnal temperature range on hospital admission in Bangkok, Thailand. Sci. Total. Environ 717, 137202. [PubMed: 32062282]

Phung D, et al. , 2016. Ambient temperature and risk of cardiovascular hospitalization: an updated systematic review and meta-analysis. Sci. Total. Environ 550, 1084–1102. [PubMed: 26871555]

Qi J, et al. , 2023. Projecting the excess mortality related to diurnal temperature range: a nationwide analysis in China. Sci. Total. Environ 864, 160971. [PubMed: 36535487]

Qiu H, et al. , 2013. Is greater temperature change within a day associated with increased emergency hospital admissions for heart failure? Circ. Heart. Fail 6 (5), 930–935. [PubMed: 23935005]

Qu Y, et al. , 2023. Associations between ambient extreme heat exposure and emergency department visits related to kidney disease. Am. J. Kidney Dis 81 (5), 507–516.e1. [PubMed: 36241010]

Rahman MM, et al. , 2022. Temperature variability associations with cardiovascular and respiratory emergency department visits in Dhaka. Bangladesh. Environ. Int 164, 107267. [PubMed: 35533532]

Rai A, Joshi MK, Pandey AC, 2012. Variations in diurnal temperature range over India: under global warming scenario. J. Geophys. Res.-Atmosph 117.

Rossati A, 2017. Global warming and its health impact. Int. J. Occup. Environ. Med 8 (1), 7–20. [PubMed: 28051192]

Schneider T, Bischoff T, Plotka H, 2015. Physics of changes in synoptic midlatitude temperature variability. J Clim 28 (6), 2312–2331.

Shaposhnikov D, et al. , 2014. The influence of meteorological and geomagnetic factors on acute myocardial infarction and brain stroke in Moscow, Russia. Int. J. Biometeorol 58 (5), 799–808. [PubMed: 23700198]

Shinkawa A, et al. , 1990. Seasonal variation in stroke incidence in Hisayama, Japan. Stroke 21 (9), 1262–1267. [PubMed: 2396260]

Song G, et al. , 2008. Diurnal temperature range as a novel risk factor for COPD death. Respirology. 13 (7), 1066–1069. [PubMed: 18922144]

Song X, et al. , 2017. Impact of ambient temperature on morbidity and mortality: an overview of reviews. Sci. Total. Environ 586, 241–254. [PubMed: 28187945]

Sun S, et al. , 2018. Seasonal temperature variability and emergency hospital admissions for respiratory diseases: a population-based cohort study. Thorax. 73 (10), 951–958. [PubMed: 29622691]

Sun XB, et al. , 2019. Global diurnal temperature range (DTR) changes since 1901. Clim. Dyn 52 (5–6), 3343–3356.

Sung TI, et al. , 2011. Relationship between mean daily ambient temperature range and hospital admissions for schizophrenia: results from a national cohort of psychiatric inpatients. Sci. Total. Environ 410-411, 41–46. [PubMed: 22018962]

Tam WW, et al. , 2009. Diurnal temperature range and daily cardiovascular mortalities among the elderly in Hong Kong. Arch. Environ. Occup. Health 64 (3), 202–206. [PubMed: 19864223]

Tang H, et al. , 2022. Long-term impacts of diurnal temperature range on mortality and cardiovascular disease: a nationwide prospective cohort study. Metabolites. 12 (12).

Thorne PW, et al. , 2016. Reassessing changes in diurnal temperature range: intercomparison and evaluation of existing global data set estimates. J. Geophys. Res-Atmosph 121 (10), 5138–5158.

Tian Y, et al. , 2019. Association between temperature variability and daily hospital admissions for cause-specific cardiovascular disease in urban China: a national time-series study. PLoS. Med 16 (1), e1002738. [PubMed: 30689640]

Vose RS, Easterling DR, Gleason B, 2005. Maximum and minimum temperature trends for the globe: an update through 2004. Geophys. Res. Lett 32 (23).

Wang MZ, et al. , 2013. 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, 370–375. [PubMed: 23624010]

Wang Y, et al. , 2022. Seasonal variation in association between temperature change and emergency department visits: a multi-site study in China. Environ. Res 214 (Pt 3), 113963. [PubMed: 35963321]

Xu Z, et al. , 2013. Diurnal temperature range and childhood asthma: a time-series study. Environ. Health 12, 12. [PubMed: 23374669]

Xue T, et al. , 2019. Declines in mental health associated with air pollution and temperature variability in China. Nat. Commun 10 (1), 2165. [PubMed: 31092825]

Yu X, et al. , 2021. Association of daily mean temperature and temperature variability with onset risks of acute aortic dissection. J. Am. Heart. Assoc 10 (13), e020190. [PubMed: 34169738]

Zeng J, et al. , 2017. Humidity may modify the relationship between temperature and cardiovascular mortality in Zhejiang Province, China. Int. J. Environ. Res. Public Health 14 (11).

Zha Q, et al. , 2021. Effects of diurnal temperature range on cardiovascular disease hospital admissions in farmers in China's western suburbs. Environ. Sci. Pollut. Res. Int 28 (45), 64693–64705. [PubMed: 34318420]

Zhai G, et al. , 2022. A comparison of the effect of diurnal temperature range and apparent temperature on cardiovascular disease among farmers in Qingyang. Northwest China. Environ. Sci. Pollut. Res. Int 29 (19), 28946–28956. [PubMed: 34988800]

Zhai G, Qi J, Chai G, 2021. Impact of diurnal temperature range on cardiovascular disease hospital admissions among Chinese farmers in Dingxi (the Northwest China). BMC. Cardiovasc. Disord 21 (1), 252. [PubMed: 34022788]

Zhao D, et al. , 2016. Is greater temperature change within a day associated with increased emergency admissions for schizophrenia? Sci. Total. Environ 566-567, 1545–1551. [PubMed: 27320736]

Zhao D, et al. , 2017. Impact of short-term temperature variability on emergency hospital admissions for schizophrenia stratified by season of birth. Int. J. Biometeorol 61 (4), 589–599. [PubMed: 27539022]

Zhao Q, et al. , 2021. Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. Lancet Planet. Health 5 (7), e415–e425. [PubMed: 34245712]

Zheng S, et al. , 2016. Gender, age and season as modifiers of the effects of diurnal temperature range on emergency room admissions for cause-specific cardiovascular disease among the elderly in Beijing. Int. J. Environ. Res. Public Health 13 (5).

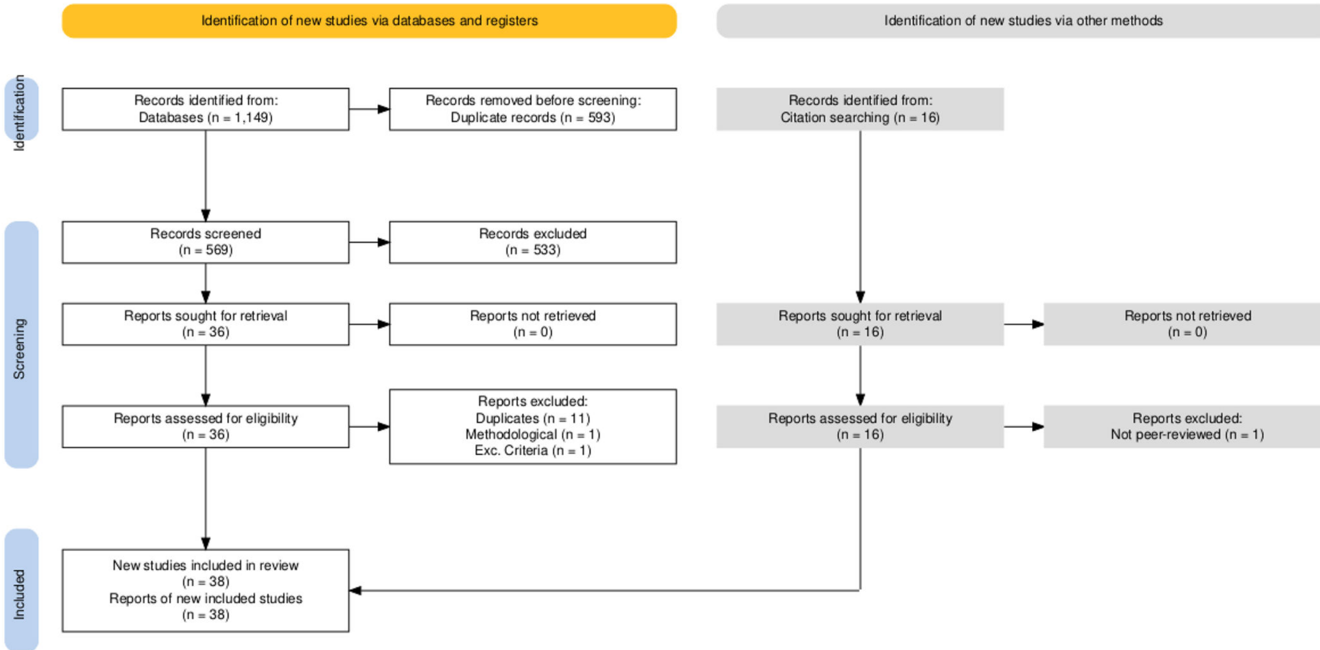

Fig. 1.
Study Eligibility Selection Process. (Haddaway et al., 2022).

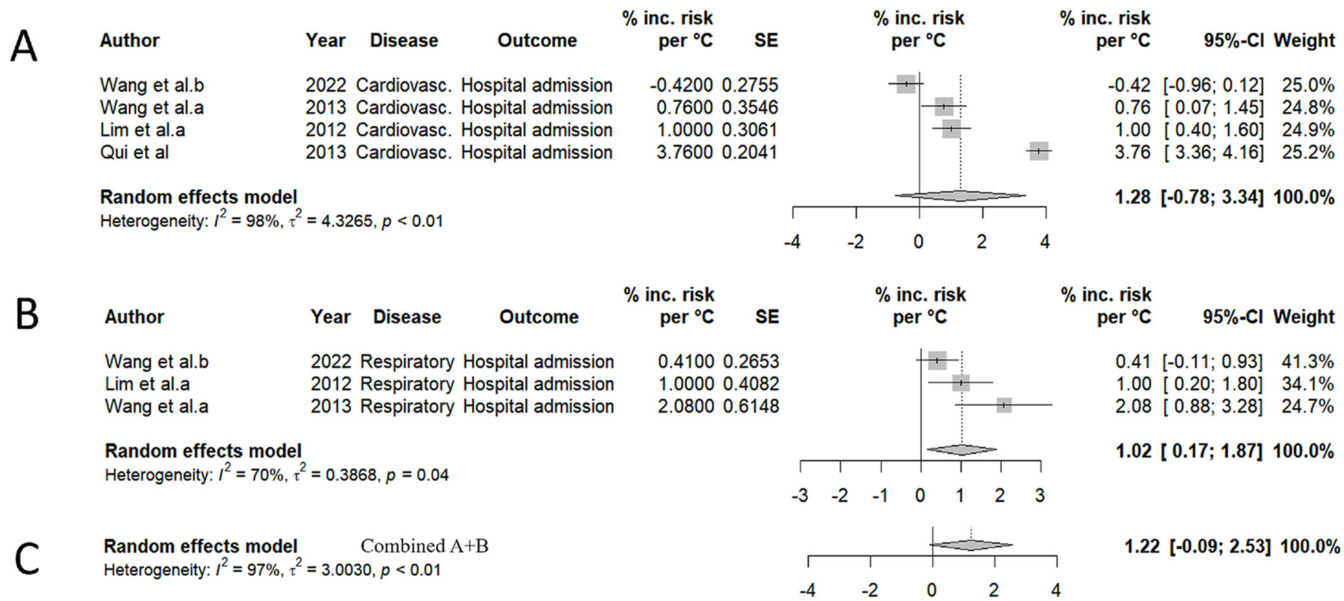

Fig. 2. The effect of Diurnal Temperature Range (DTR) on hospital admissions due to cardiovascular or respiratory disease.

Forest plots displaying the individual and pooled effect sizes of studies assessing the percent increase per degree Celsius of DTR for hospitalizations due to cardiovascular disease (A), respiratory disease (B) or the pooled effect of both exposures (C).

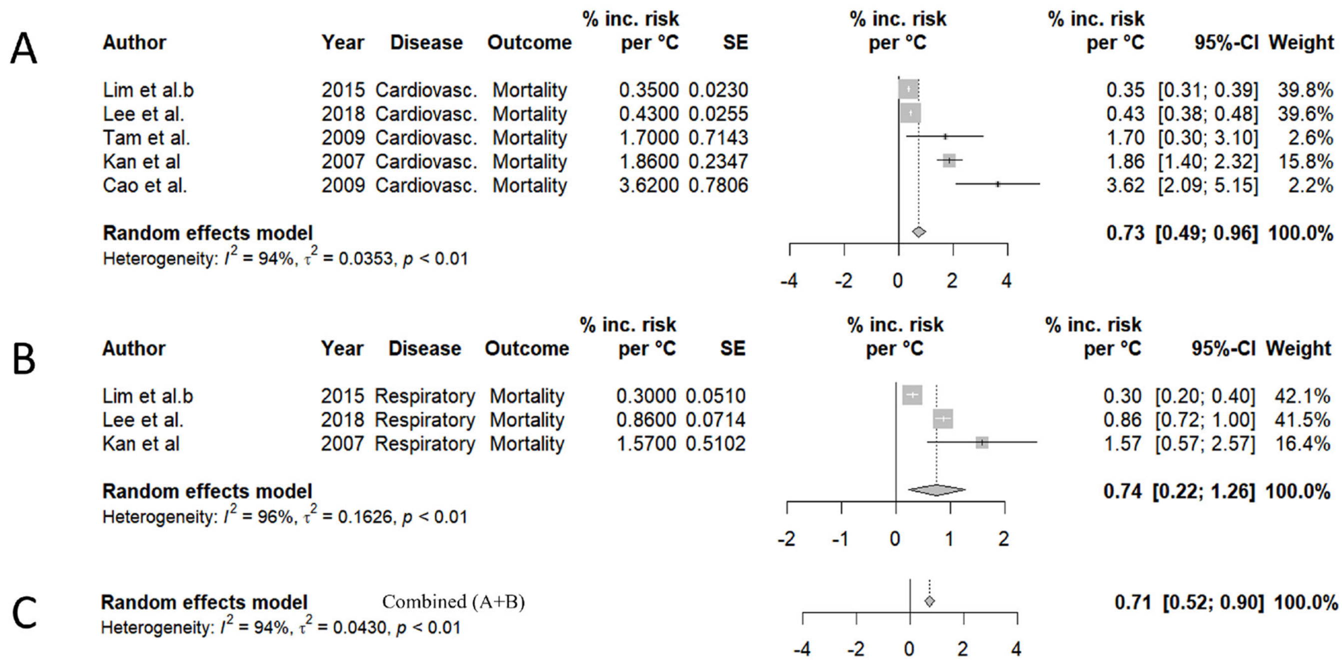

Fig. 3. The effect of Diurnal Temperature Range (DTR) on mortality due to cardiovascular or respiratory disease.

Forest plots displaying the individual and pooled effect sizes of studies assessing the percent increase per degree Celsius of DTR for mortality due to cardiovascular disease (A), respiratory disease (B) or the pooled effect of both exposures (C).

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Table 1

Search strategy for articles.

Temperature variability indicator (Combined by ’OR’) (a)	Health indicators (Combined by ’OR’) (b)	Descriptor (Combined by ’OR’) (c)
temperature variability	cardiovascular	disease
temperature variation	respiratory	disorder
diurnal temperature range	renal	illness
	genitourinary	
	kidney	
	mental	

Note: Boolean operator ’AND used to combine a, b, c groups.

Table 2

Summary of studies reviewed.

Author/year*	Study design/ population	Objective	Exposure	Outcome	Models/Methods	Findings	Limitations
Kan et al., 2007	Time Series/173,911 non-accidental deaths occurring from January 2001 to December 2004 in the nine urban districts of Shanghai, China	Examine the association between DTR and mortality	DTR as a continuous variable, expressed at single day lag (0-5) or cumulative lag (0-1 to 0-5)	Mortality due to CVD (ICD-9 390-459; ICD-10 100-199) or RD (ICD-9 460-519; ICD-10 J00-J98)	GAM with log link and Poisson error with smoothing terms for trend on days, daily temp, relative humidity, DOW and air pollutants (O_3, PM_{10}, SO_2, NO_2); stratified analysis by age, gender and warm/ cold days (based on daily temp effect on mortality)	-CVD mortality peaked on lag1 at 0.97%/1°C (0.66-1.29), was significant, from lag0-lag3, and lag0-2 peak cum. lag at 1.86%/1°C (1.40-2.32) -RD mortality peaked at lag0 at 0.83%/1°C (0.19-1.47), was significant at lag0, lag1 and lag4, with lag 0-5 peak cum. lag at 1.57%/1°c (0.67-2.47) -CVD mortality significant inc. when daily temp >23°C or <23°C, but RD only significant inc. when temp <23°C (1.47% at lag0-2, 0.57-2.37)	-Study conducted in single urban area -Only one weather monitoring station used -Only assessed mortality -Did not include SES data
Liang et al., 2008	Time series/1020 patients admitted to ED for ACS in Taichung City, Taiwan from January 1st, 2001 to March 31st, 2003	Assess the relationship between ACS events, average daily temperature and DTR	DTR as categorical variable	ED Admission for ACS (ICD-9 codes 491-496)	Poisson regression model adjusting for the effects of holiday, season, and air pollutant concentrations (O_3, PM_{10}, SO_2, CO, NO, NO_2).	ACS admissions increased 34.4% when DTR greater than 9.6°C ($p < 0.05$)	-Only looked at ED admissions
Song et al., 2008	Time series/17,874 deaths due to COPD in nine districts of Shanghai, China from January 2001 to December 2004	Determine the relationship between DTR and mortality due to COPD in Shanghai	DTR as expressed as a 4-day moving average	Daily COPD deaths (codes 490-496 in ICD9, and as codes J40-J47 in ICD10)	GAM with smoothing for daily mean temp, relative humidity, and adjusting for DOW, air pollution (PM_{10}, SO_2 ,NO_2 and O_3) and stratified analysis for daily mean temp above and below 22°C based on COPD risk from daily mean temp	−1.25% (95%CI 0.35-2.15) increase in COPD mortality per 1°C inc. in DTR −1.57% inc. in COPD mortality on when daily mean temp <22°C −0.51% inc. in COPD mortality when daily mean temp >22°C	-Single geographic location -Did not include SES data or stratify around age, gender or other demographic variables -Assessed only for mortality
Liang et al., 2009	Longitudinal/3,263 COPD admissions in a single university hospital in Taichung City, Taiwan from January 2001 to December 2002	Assess the relationship between DTR and ED admissions for COPD in Taiwan	Daily DTR expressed in %tile (40th, 60th, 80th and 90th %tiles)	ED admissions for COPD (ICD-9 codes 491-496), RR reported relative to lowest DTR	Univariate and multivariate Poisson regression model adjusting for DOW and air pollutant concentrations (O_3, PM_{10}, SO_2, CO, NO, NO_2)	-Significant inc. in COPD admission risk by ~14% when DTR ≥9.6°C relative to <6.6°C ($p < 0.05$) -COPD admissions were directly correlated with DTR by month ($r = 0.90$) and indirectly correlated with mean daily temp ($r = −0.95$)	-Did not adjust for SES, comorbidities for COPD, age or gender -Single monitoring station and single institution assessed
Tam et al., 2009	Time series/40,166 cases of CVD mortality in Hong	Examine relationship between DTR and	DTR as continuous variable	Mortality from CVD (ICD-9 390–	Generalized additive model using a Poisson distribution, regressing	RR of CVD mortality increased by 0.8%/1°C DTR inc. at Lag 1, with greatest	-Focused only on CVD mortality -Only addresses

Author/year*	Study design/ population	Objective	Exposure	Outcome	Models/Methods	Findings	Limitations
	Kong, China population >65yrs from 1997-2002	CVD mortality for >65yrs		459 or ICD-10 J00–I99)	for day of the week, daily mean temp and humidity, daily cone. of NO_2, SO_2, PM_{10} and O_3, smoothing for seasonal effects	cumulative RR at Lag 0-3 and 0-4, with 1.7%/1°C DTR inc. ($p < 0.05$)	population > 65yrs -Single geographic location DTR not representative
Cao et al., 2009	Time Series and Case Crossover/ 37,256 CVD-related deaths in the 9 urban districts of the Shanghai Municipal Center of Disease Control and Prevention (China) (SMCDCP) January 2001 to December 2004	Determine whether intra-day temp variability is an independent risk factor for acute heart disease death	DTR as a continuous variable	Mortality due to coronary heart disease (ICD-9: 390–398 and 410–429, and ICD-10: I00-I09 and I20-I52)	Time series: GAM smoothed for DOW, daily mean temp, relative humidity PM10, SO2, NO2, and O3 levels. Case-crossover: Unidirectional and bidirectional analyses with control periods 1-3 weeks before or after death with conditional logistic regression adjusting for same variables as time series	-all three analyses methods had significant increase in daily CHD mortality for each 1°C increase in DTR for lag 2-4, peaking on lag 3, Time series −2.63%/1°C, unidirectional case crossover − 3.62%/1°C, bidirectional case crossover − 2.22%/1°C	-Assessed only CHD mortality -Single geographical location
Magalhaes et al., 2011	Time Series/462 first-time stroke cases in the city of Porto, Portugal from October 1998 to September 2000	Determine the association between DTR, stroke and stroke subtypes	DTR as a continuous variable	Registry of all first-time stroke cases by active surveillance, based on WHO criteria, neurologist and radiological findings	Poisson GAM including daily maximum, minimum temperature, DTR, atmospheric pressure, relative humidity and total precipitation as continuous variables over 24hr, 7-day or 14-day periods prior to stroke	-GAM showed significant increase in primary intracerebral hemorrhage (PICH) risk of 11.8% per 1°C1C inc. in DTR 24hrs prior No significant increase for ischemic stroke, but significant decrease of ~8% risk of partial circulation infarct per 1°C1C DTR inc. 24hrs prior	-Single urban center assessed -Did not control or stratify analysis for SES or demographic factors
Sung et al. 2011	Retrospective Cohort/ 26,863 patients with schizophrenia inpatient admissions and 37,525 patients with non-schizophrenia inpatient admissions from 1996-2007 in 21 of 25 districts of Taiwan	Examine the association between DTR and schizophrenia admissions amongst psychiatric inpatients	DTR was divided into 10 %tile groups from <1% tile to ≥99%tile	Schizophrenia and Schizoaffective inpatient admission (ICD-9 codes: 295.0–295.9)	Generalized Linear Model to categorize admissions as schizophrenia and non-schizophrenia, co-variates were season, age, gender, region and hospital	-Observed consistently increasing risk of schizophrenia admission with increasing DTR, beginning at 10-24 percentile, and peaking at ≥99percentile (1.22, $p < 0.01$), dose-response -no significant relationship found for schizoaffective	-Did not control for SES, demographic info aside from age and gender
Lim et al., 2012	Time Series and Case-Crossover (CC)/ Hospital admissions for CVD or RD in four of the largest cities in South Korea from 2003 to 2006	Investigate the risk of hospital admission for CVD and RD in four metropolitan areas in Korea	DTR as a continuous variable	Hospital admissions for CVD (ICD-10: I00–I99, G45, G46, M30, M31, R58, excluding G45.3, I67.3, 168.0, 188, 197.8, I98.0) and	1) Poisson GLM with splines for time trend, DOW, mean daily temp and PM_{10}, using distributed lag of 0-9 days, two stage by city	-Time-Series showed significant inc. in admissions for total CVD (~1%/1°C), RD (−1%/1°C), cardiac failure (~3%/1°C), asthma (~1%/1°C) and COPD (~2%/1°C) -CC showed significant inc. in	-Did not control for SES variables or air pollutants aside from PM_{10} -Only included 4 cities covering ~37% of

Author/year*	Study design/ population	Objective	Exposure	Outcome	Models/Methods	Findings	Limitations
				RD (ICD-10: J00–J98), as well as subgroups of each.	and then metanalysis 2) Matched case-crossover with 28-day window and matching of controls by daily mean temp, adjusted by same variables as GLM	risk for total RD (~1%/1°C), cardiac failure (~5%/1C), and asthma (~2%/1°C) -Asthma admission risk significantly higher in >75 (4% vs 1%/1°C)	nation, did not include suburbs or rural
Ge et al., 2013	Time Series/11,017 ED visits from January 2008 through June 2009 from Huashan Hospital in Shanghai, China	Assess the association between RT1 morbidity and DTR	DTR as a continuous variable, expressed at single day lag (0-5) or cumulative lag (0-1 to 0-5)	RTI diagnosis on ED visit as resp virus, pharyngitis, laryngitis, croup, viral otitis, sinusitis, bronchitis, bronchiolitis, & pneumonia	GAM with log link and Poisson error with smoothing terms used for **trend** on days, temperature level, relative humidity, DOW and air pollutants (PM_{10},SO_2,and NO_2)	-Inc. in RTI ED visits were significant at lag0 and lag1, peaking at lag1 at 1.72%/1°C inc. in DTR ($p < 0.05$) -Cumulative lag significant at lag0-1 and lag0-5, peaking at lag0-1, 2.08%/1°C inc. in DTR ($p < 0.05$) -linear relationship between inc. DTR and RTI risk	-Data from single institution/ geographical region -Did not include SES or demographic data, such as age and gender
Luo et al., 2013	Time series/36,168 non-accidental deaths in Yue Xiu and Li Wan Districts of Guangzhou, China from January 1st, 2006, to December 31st, ,2008	Examine relationship between DTR and mortality due to CV, respiratory, cerebrovascular disease or total non-accidental	DTR categorized by percentile. >99%tile and <1%ile as extreme DTR	Mortality from CVD (ICD-10: I00–I99) and RD (ICD-10: J00–J99)	DLNM with log link and Poisson error, using linear regression for air pollution concentrations, and using time-smoothing to account for seasonal effects and day-of-week (DOW) signals	-Overall (lag 0-27) both CV and respiratory disease showed significantly inc. cumulative excessive risk (250% and 381%) with <1%tile DTR -<1%tile DTR causes significant Inc. risk of CVD mortality at shorter lags lag 0-13 and 0-20, and >99%tile with lag 0-6 and 0-13 significant inc. -<1%tile and >99%tile DTR show significant inc. of RD mortality at lag 0-20 and 0-27 for cold season	-Restricted to one geographic area -Coarse analysis of lag time (cumulative only) -Mortality only, rather than morbidity
Qui et al., 2013	Time Series/95,897 ED admissions for HF across Hong Kong, China from January 2000 to December 2007	Examine the association between HF and DTR, as well as effect modifiers age, sex and season	DTR as continuous variable, for daily lag0 to lag5 and cum lag0-5	ED admissions for heart failure (ICD-9: 487)	Poisson GAM with smoothing splines for seasonal effects, long-term trend, daily mean temp, relative humidity, DOW, holidays, influenza epidemics. Stratified analysis by warm or cool season, sex and age, sensitivity analysis for O_3, PM_{10}, SO_2, and NO_2	-Inc. in HF admissions was significant at all lags per 1°C DTR inc., peaking for lag1 at 0.89%/1°C (0.34-1.43), with lag0-5 = 3.76%/1°C (3.36-4.16) -Significant inc. effect for women relative to men at lag0 (1.31%) and lag0-5 (4.41%) -≥75 years had greatest inc. risk of HF admission with lag0-5 of 4.13%/1°C DTR, significantly higher than 65-74 or <65, peaking at lag1 -A significantly higher risk of HF admission seen in cool season for lag1, lag2 and lag0-5 (more than 6-fold higher at lag0-5)	-Limited to one urban center -could not separate first admission from readmission -Did not include SES-related variables

Author/year*	Study design/ population	Objective	Exposure	Outcome	Models/Methods	Findings	Limitations
Shaposhnikov et al. 2013	Time Series/2,833 MI and 1,096 stroke hospital admissions from two large hospitals Moscow, Russia from January 1992 to December 2005	Examine the association between DTR or TCN and MI or stroke hospitalizations	DTR and TCN as continuous variables for lag up to 7 days, selecting lag of peak effect	Daily counts of hospital admissions for MI or stroke	Poisson general linearized model with continuous predictors of mean temperature, DTR, TCN, mean barometric pressure, 24h-index of geomagnetic activity, and categorical variables for days with geomagnetic storms, heat/cold waves and DOW	-No significant relationship between MI or stroke and TCN -No significant relationship between DTR and MI -A 10°C increase in DTR from 4°C (minimum stroke risk) was associated with a 26% (2%-57%) increase in stroke admissions	-Limited to two hospitals in one urban center -Did not control for SES-related or demographic variables
Wang et al., 2013	Time Series/114,870 ED admissions of those >65 years from three large hospitals in Beijing, China from January 2009 to December 2021	Evaluate the short-term effect of DTR on ED admissions among elderly adults in Beijing.	DTR as a continuous variable, expressed at single day lag (0-7) or cumulative lag (0-1 to 0-7)	ED admission for CVD (ICD10:I00–I99), RD (ICD10:J00–J99), GI (ICD10:K00-K93)and GU disease (ICD10:N00–N99).	GAM with regression spline functions to control for long-term trend, seasonal patterns, DOW, public holidays, daily mean temp and relative humidity, and air pollutants (PM_{10}, SO_2,and NO_2); stratified analyses by age, gender and season	-CVD only significant inc. at lag0-1 and 0-2 (0.62% and 0.76%/1°C inc.) -RD significant inc. at lag0, lag3 and all cum. lag, peaking at lag0-7 (2.08%/1°C) -GU only significant inc. at cum. lag0-5, lag0-6 and lag0-7, peaking at lag0-5 (1.81%/1°C) -CVD has dec. risk at DTR <6°C, RD with inc. risk >11°C, linear non-significant trend for GU -CVD only significant in women and >75 years, RD significant in men and both age groups, GU only significant in men and >75	-Only used data from one weather station -Only assessed one urban area -did not include SES data
Xue et al., 2013	Time Series/13,324 ED admissions for asthma in children in Brisbane, Australia from January 2003 to December 2009	Examine the relationship between DTR and childhood asthma	DTR as continuous variable and as a 5°C increase in DTR above mean (10°C vs. 15°C)	ED admission for asthma (ICD-10: J45)	DLNM using cubic splines to control for mean daily temp, relative humidity, seasonal patterns, long-term trend, DOW, influenza epidemics and air pollutants (PM_{10}, SO_2, and NO_2)	-Significant inc. in asthma admission risk with DTR > 14°C, relative to mean of 10°C -RR at DTR 15C relative to 10C peaks for lag0-9 at 1.31 (1.11,1.58) -DTR effect only significant for children 5-9 years, at all lags, peaking at lag0-11 (RR 1.91) -Only significant for male children peaking at lag0-8 (RR 1.43)	-Assessed only one urban center -Did not adjust for SES
Hiltunen et al. 2014	Ecological/10, 802 suicides from 1974-2010 at six population centers within Finland	Determine association between ambient temperature, thermal season	DTR (ΔT_d), inter-day temp variability (from D0-D1, D0-D2, D0-D3, D0-D4 and D0-D5)	Daily suicide rate recorded in national database for each city	Poisson regression model, initially run with 21 variables (including 6 related to temp. variability), then 6 models generated to	-Significant inc. in suicide rate for men at two sites with decrease in daily mean temp. from previous day and 5 days prior, resp., and the latter for women at a third location	-Low absolute numbers of suicide by gender at some sites -Lack of SES data availability

Author/year*	Study design/ population	Objective	Exposure	Outcome	Models/Methods	Findings	Limitations
		timing and suicide in Finland			cover subsets of the 21 variables	-1.024 increase in rate ratio of suicide for women at one site with each degree of DTR increase	
Li et al., 2014	Time Series/8237 ED visits for RTI in those >65 years from January 2010 to December 2012 from Sun Yat-Sen University hospital in Guangzhou, China	Assess relationship between RTI and DTR in an elderly population	DTR as a continuous variable, expressed at single day lag (0-5) or cumulative lag (0-1 to 0-5)	RTI diagnosis on ED visit as resp virus, pharyngitis, laryngitis, croup, viral otitis, sinusitis, bronchitis, bronchiolitis, & pneumonia	Negative binomial model with sensitivity analysis for air pollutants (PM_{10}, SO_2, and NO_2)	-Inc. in RTI ED visits peaked at lag2 at 1.56%/1°C inc. in DTR ($p = 0.01$) -Cumulative lag peaked at lag0-2, 2.07%/1°C inc. in DTR ($p < 0.01$)	-Single institution -Did not report covariates included in model aside from air pollutants -Published as letter without peer review
Lim et al., 2015	Time Series/US residents included in the National Morbidity Mortality Air Pollution Study (NMMAPS) in one of 95 communities for which air pollution data available, from 1987-2000	Examine the effects of DTR on non-accidental mortality (NAM), as well as cardiovascular and respiratory mortality, in the US	DTR as a continuous variable	Mortality from non-accidental (ICD-9 < 800), CVD (ICD-91: 390–459)and RD (ICD-9, 490–496)	-Poisson generalized linear model, controlling for ambient temp, short and long term (seasonal) time trends -A generalized additive model was used to assess for non-linear relationships between DTR and mortality	−0.35% and 0.30% increase in mortality per 1°C increase in DTR for CVD and RD mortality, respectively ($p < 0.05$) -This increased mortality risk was seen largely for those >65yrs at death	-Assessed only mortality -Did not consider many demographic or SES factors in model and analysis -air pollution data not available at all sites
Zheng et al., 2016	Time series/22,069 ED admissions in people >65 years from three large hospitals in the Haidian district of Beijing from January 2009 to December 2011	Examine the modifying effect of age, gender and season on the relationship between DTR and ED admission for CVD	DTR as a continuous variable	ED admissions associated with all CVD (ICD-10: I00-I99, G45-G46)	Poisson generalized additive model controlling for long term trends, seasonality, DOW, public holiday, relative humidity and mean daily temp, including PM_{10}, SO2 and NO2 as confounders. Separate analyses performed by gender, and age >75 or <75yrs	-Larger magnitude effects on all CVD admissions seen for women, except for cerebrovascular disease, with 1.46%/1°C DTR increase for women at lag 0-1 and 0-2 ->75 years category had larger effects for all CVD types -larger cerebrovascular disease effects seen in warm season -women >75 show larger effect on all CVD admissions/1°C DTR in cold season, but men less	-Only covers one narrow geographical area -Weather data from one station -No SES data included
Zhao et al., 2016	Time series/36,607 ED admissions for schizophrenia from **January** 1, 2005 to November 30, 2014, in Anhui province, China	Examine association of DTR and schizophrenia ED admissions, how this relationship is influenced by age, gender, marital status	75th and 95th %tile of DTR relative to 50th %tile	ED admission for schizophrenia (ICD-10 codes: F20-F29)	Poisson generalized linear regression combined with DLNM with mean temp, relative humidity, seasonality, long-term trend, DOW and public holiday included as confounders	-95%tile DTR exposure with significant 2.7% inc. risk of schizophrenia admission at lag 0 (max. effect), with cumulative effect peaking at lag 0-11 days (RR = 1.187) -authors found greater risk in those aged 15-29, 50-64, born in spring or autumn, male or married	-Data obtained from single city -SES and air pollution data not included as potential confounders
Zhao et al., 2017	Time series/18,417 ED admissions for schizophrenia from	Examine association of DTR and temp change	DTR and TCN at 75%tile, 95%tile and 99%tile	ED admission for schizophrenia	Poisson generalized linear regression combined with DLNM	-Significant inc. in RR for lag 2, 3, and 4 days in those born in Spring and exposed to DTR	-Data obtained from single city -SES and air pollution

Author/year*	Study design/ population	Objective	Exposure	Outcome	Models/Methods	Findings	Limitations
	January 1, 2005 to November 30, 2014, in Anhui province, China	btw neighboring days (TCN) with schizophrenia ED admissions and by birth season		(ICD-10 codes: F20-F29)	with mean temp, relative humidity, seasonality, and long-term trend controlled for using natural cubic splines	at 95%tile and 99%tile -Significant inc. in RR for lag 3, and 4 days in those born in Spring and exposed to TCN at 99%tile (inc. in temp)	data not included as potential confounders
Lee et al., 2018	Time Series/ 39,943,041 deaths from 1972 to 2015, inclusive, in all 47 prefectures of Japan	Determine whether temperature is an effect modifier on relationship between DTR and mortality	DTR and mean temp. over 3-day moving average, segregated into 5 %tile groups, or expressed as IQR (overall = 4.6C)	Mortality divided into twelve categories, including total CVD (ICD-8: 390-458, ICD-9: 390-459, ICD-10: I00-I99), total RD (ICD-8: 460-519, ICD-9: 460-519, ICD-10: J00-J99) and renal disease (ICD-8: 580-599, ICD-9: 580-599, ICD-10: N00-N39)	Two-stage model with 1st stage using distributed lag for time-series regression for each prefecture and then metanalysis of all prefectures, adjusting for relative humidity and DOW	-~2% inc. in total CVD, ~4% inc. in RD and ~4% inc. in renal disease mortality per IQR increase in DTR -CVD mortality % inc. per DTR IQR significantly inc. at higher relative mean daily temp, but no such relationship for RD mortality -CVD and RD mortality inc. with DTR inc. peaks at lag2 days for extremely hot days, but on extremely cold days only significant at 10-12 days for CVD and >8 days for RD	-only one weather monitoring station available per prefecture -air pollution, demographic, SES and other weather indicator data not included in analysis -temperature range studied not representative globally
Sun et al., 2018	Prospective cohort/ 66,820 Hong Kong residents >65 years enrolled from 1998 to 2001 and followed until 2010	Assess association of seasonal temperature variability with respiratory disease	Seasonal temp variability defined as standard deviation of daily mean temp in summer (June-Aug) or winter (Dec-Feb)	Emergency hospital admissions for respiratory diseases (ICD-9: 460:519)	Cox proportional hazards model controlling for age, sex, marital status, BMI, physical activity, housing type, educational attainment, smoking status, and medication. Sensitivity analysis controlling for average daily temp, pre-existing resp disease and $PM_{2.5}$	-Hazard ratios (HRs) of 1.20 (95% CI 1.08-1.32), 1.15 (1.01-1.31) and 1.41 (1.15-1.71) for total respiratory diseases, pneumonia and COPD, respectively, per 1°C increase in TV during the winter -HR for summer were not significant	-No data on hospital admissions prior to enrollment -Enrollment was voluntary (selection bias) -Did not adjust for humidity and wind chill
Tian et al., 2019	Time series/8 million hospital admission for CVD in 184 Chinese cities from 2014 to 2017	Examine short-term associations between temperature variability and hospital admissions for CVD in urban China	Standard deviation of max and min daily temp for each day included in exposure interval from TV_{0-1} to TV_{0-7} (combined intra- and inter-day variability)	CVD admissions, including ischemic heart disease (ICD-10: I20-I25), heart failure (ICD-10: I50), arrhythmias (ICD-10: I47-I49) and ischemic stroke (ICD-10: I63)	DLNM model used for each TV time range, with two stage analysis, first for each city, and then a metanalysis combining cities into regions and national, considering DOW, public holidays and long-term trend. Stratified analysis for age, sex and geographic region. $PM_{2.5}$, NO_2, and SO_2 also added as confounders	-There was a 0.44% increase in CVD admissions per 1°C of TV_{0-1}, the greatest for any lag interval, with ischemic stroke showing the greatest effect of subgroups at 0.82%/1°C -Greater effects for CVD were seen for male gender (0.51%/1°C), for the elderly (0.81%/1°C for >75), and for warmer regions (0.58%/1°C)	-Did not include children -Only included urban areas -Exposure metric does not distinguish between intra- and inter-day temp variability -did not incorporate relative humidity

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Xue at al., 2019	Longitudinal study, Difference-in-difference/21,543 adults from 25 Chinese provinces who filled out the China Family Panel Studies (CFPS) questionnaire in both 2010 and 2014	Estimate associations between environmental factors and self-assessed mental health	Standard deviation of mean daily temperature within one calendar year	Significant change in mental health score (MHS)	Logistic regression model adjusting for covariates $PM_{2.5}$, mean temperature and Normalized Difference Vegetation Index (NDVI)	− 15% decrease in MHS associated with 1°C inc. in temp variability - Inc. in temp variability associated with inc. in feeling nervous, upset, hopelessness and meaninglessness	-High risk of misclassification -low time-resolution of exposure
Phosri et al., 2020	Time Series/255,333 hospitalizations due to CVD, and 247,872 due to RD, from 2006 to 2014 in Bangkok, Thailand	Examine the relationship between short-term DTR exposure and hospital admissions for CVD and RD in Bangkok, Thailand	DTR derived as average from three monitoring sites in Bangkok, continuous variable and 99%tile relative to mean	Hospital admissions due to CVD or RD (ICD-10: I00-I99, and J00-J00)	Quasi-Poisson generalized Linear Regression combined with DLNM controlling for daily mean temp, relative humidity, DOW, public holiday, seasonal trend, long-term trend, ozone and PM_{10}.	-Overall (lag 0-21) RR was significantly increased for CVD admissions at 99%tile DTR at 1.206 -No significant association for RD admissions at any lag -CVD admissions show strong relationship to DTR in winter season, none in summer or rainy season	-Only one small geographical location considered -Admissions data did not include patient residence, so misclassification of exposure may occur for those living outside Bangkok -SES, air pollutants aside from ozone and PM_{10} not considered
Pedder et al., 2021	Time Series/ 4062 Pneumonia hospitalizations from October 2007 to December 2015 in the Mopani district of South Africa	Investigate the delayed effects of different temperature indicators and relative humidity on pneumonia hospital admissions	Mean daily temperature, daily relative humidity and DTR as continuous variables	Hospital admission for pneumonia, based on recorded reason for admission (not ICD code)	DLNM model adjusting for seasonality and DOW, as well as mean daily temp and relative humidity when assessing DTR	-Significant association between DTR and pneumonia admissions occurred only when DTR > 21°C, which was a rare event only occurring ~12 days/year at this location	-Pneumonia not confirmed radiologically or microbiologically -Did not include demographic data or air pollution into model -Single geographic location of weather data -Admission data not geocoded to ensure exposure was not misclassified
Kang et al., 2021	Prospective cohort study/30,036 subjects selected at random from Chinese Hypertension Survey participants from 16 cities and 17 counties in China and followed from 2017 to 2019, with 23,721 retained in final analysis	Estimate the effect of long-term temperature variability on cardiovascular disease in China	TV defined as standard deviation of daily mean temperatures for survey years derived from ERA5 global forecasting models	CVD incidence obtained from interviews and health records including '**coronary** heart disease (CHD), stroke, chronic heart failure, and death due to other CVD"	Cox proportional hazards model used to measure association between TV and CVD incidence/mortality, adjusting for sex, age, BMI, alcohol, smoking use, education level, urbanity, hypertension, diabetes, dyslipidemia and annual mean temp	-For a 1C increase in long-term TV, there was a 6% increase in CVD incidence -Exposure to the highest tertile of TV reduced disease-free years for those 35-65yrs by 2.11yrs, with a 72% higher risk of CVD for those in the highest tertile relative to lowest	-Did not incorporate relative humidity

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Yu et al., 2021	Time series/2120 patients diagnosed with Acute Aortic Dissection (AAD) at Tongju hospital in Wuhan China from 2011 to 2018	Examine the relationship between AAD, daily mean temp and temp variability, as well as lag from exposures to outcomes	Standard deviation of max and min daily temp for each day included in exposure interval from $TV_{0\text{-}1}$ to $TV_{0\text{-}7}$ (combined intra- and inter-day variability)	AAD defined as dissection onset within 14 days of presentation and confirmed by review of medical records (not ICD code)	DLNM following quasi-Poisson regression, with relative humidity, atmospheric pressure, public holidays and DOW as confounders and including considering PM_{10}, NO_2 and SO_2	-Overall cold exposure (0.5°C) or less was found to produce significant increase in AAD at lag 0 or 1 day -TV only found to have a protective effect with −11% RR per 1°C TV increase at 0-2 and 0-3 exposure days, respectively for females only	-Single geographical location -Outcomes data not linked to residence of patients -TV metric does not differentiate between inter and intraday variability -Only one-fifth of patients were female, limiting subgroup sample analysis
Zha et al., 2021	Time series/Sub-urban farmers who were admitted for CVD in Qingyang, China from 2011 to 2015, recruited through New Rural Cooperative Medical Scheme (NRCMS)	Examine relationship between DTR and CVD morbidity in suburban populations, identifying vulnerable subpopulations	DTR calculated from daily mean and maximum temp data obtained for district from China Meteorological Science Data Sharing Service	Hospital admission for coronary heart disease (ICD-10: I25.101), arrhythmia, myocardial infarction (ICD-10: I20.052), coronary atherosclerotic heart disease (ICD-10: I25.103), hypertension (ICD-10: I10.x00).	DLNM combined with quasi-Poisson GAM including terms for **relative** humidity, mean temperature, air velocity, sunshine, precipitation, and pressure, long-term trend, seasonality, DOW and public holidays	-Bi-modal peak seen in DTR effect on RR of CVD overall, with low DTR effect peaking at 6.1°C (RR 2.95) and high DTR at 19.1°C (RR 2.60), relative to mean DTR of 13°C -adults <65yrs and males were found more sensitive to DTR than women or the elderly	-Single geographical location -Does not include data on air pollution -Only considers inpatient data -Narrow outcome definition by ICD-10 code, does not encompass all CVD
Zhai et al., 2021	Time series/24,940 hospital admission for CVD from 2015 to 2019 from Dingxi city through **New** Rural Cooperative Medical Insurance of Gansu Province (NRCMI)'s health database	Examine relationship between DTR and CVD morbidity in rural China	DTR calculated from daily mean and maximum temp data obtained for district from China Meteorological Science Data Sharing Service	Hospital admission for: chronic rheumatic heart disease (ICD-10: I05–I09), hypertension (ICD-10: I10–I15), ischemic heart disease (ICD-10: I20–I25) and other types of heart disease (ICD-10: I30–I52)	DLNM model including relative humidity, windspeed, mean daily temp, sunshine hours, long-term trend, DOW and public holidays as covariates	-Bimodal peak observed for increased RR with both low (6°C) and high (17°C) DTR, with high DTR peak significant (1.78) -Both RR peaks higher and significant in men, 1.55 for low DTR and 1.94 for high DTR -Lower DTR peak greater in >65yrs (2.55) and high DTR peak greater in <65 (2.23) -extremely low DTR had greater effect on women and >65yrs, while extremely high DTR led to higher risk in men and <65 years	-Single geographical area studied (cannot generalize) -Did not include data on SES or comorbidities -Did not include air pollution data in model analysis
Li et al., 2022	Time series/132,698 outpatient visits for urinary diseases in the three main cities of Ganshu province, China, from January 2014 to December 2016	Analyze the effects of meteorological factors, including DTR, on urinary health in arid regions of western China	Short-term DTR expressed as continuous variable and as extremely low (<5% percentile) high DTR (>95%tile)	Outpatient visits for urinary disease (ICD-10: N00-N39)	DLNM with quasi-Poisson distribution including average temp, relative humidity, $PM_{2.5}$, long-term trend, DOW and public holidays, sensitivity analyses accounted for	-Overall, there were no significant effects of DTR on urinary disease RR at any lag -In Zhangye, both <5%tile and >95%tile produced significant increases in RR at 7, 14 and 21d lag, increasing to lag 21 (low 6.96, high 5.96)	-Focused only on outpatients -Did not include age, SES or medical history -One climactic region included

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					effects of PM_{10}, NO_2, SO_2, CO, O_3		
Rahman et al., 2022	Time series/340,758 cardiovascular and 38,233 respiratory disease ED visits in Dhaka City, Bangladesh from January 2014 to December 2017	Assess the effect of short-term TV on cardiovascular and respiratory disease ED visits	TV was calculated as standard deviation of min and max temperature on each exposure day, from 2-8 exposure days ($TV_{0\text{-}1}$ to $TV_{0\text{-}7}$)	Cardiovascular or respiratory disease listed as reason for ED visit during initial screening (not by ICD code)	quasi-Poisson time-series generalized regression model with a DLNM model used for non-linear components, including long-term trend, seasonality, DOW with stratified analysis for age > or <50yrs, season, as well as sensitivity analysis to measure effect of relative humidity and warm/cold waves	-There were significant increases in CVD risk (1.0%/1°C) for $TV_{0\text{-}1}$ only, but for both $TV_{0\text{-}1}$ (2.1%/1°C) an $TV_{0\text{-}7}$ there were significant inc. in RD risk -Larger effects were seen at 0-1 and 0-2 lags CVD by age stratification at 50 years, largest effect for <50 years in monsoon season -RD showed greater effect in >50yr group for all lags, particularly in hot/dry season and monsoon season	-Lack of SES data, smoking data, medications or comorbid conditions -single geographic location -unable to distinguish intra- from inter-day TV
Tang et al., 2022	Prospective Cohort study/Baseline population of 22,702 recruited from China Hypertension Survey from 2012-2015 across 14 provinces and followed from 2018-2019	Assess the longitudinal association of DTR with all-cause and CVD mortality in a nationwide prospective cohort, and predict future climate-change related DTR changes	Long-term DTR calculated as annual mean difference from daily min to max temp, interpolated from 2419 weather stations to 1km resolution	All-cause mortality, CVD diagnosis and mortality (ICD-10: I00–I25, I27–I88, and I95-99), stroke diagnosis and mortality (ICD codes not listed)	Multivariate Cox proportional hazards regression model, with 3 model levels including different covariates, model one including demographic and substance use, model 2 including co-morbidities related to CVD, model 3 adding $PM_{2.5}$, NO_2 and ambient temp, while model 4 included education and GDP	-CVD and stroke mortality risk increased by 12% and 9%/1°C inc. in DTR, respectively (model 4) -Stroke mortality had U-shaped curve with exponential increase at DTR >10°C, while CVD showed more linear response	-Length of follow-up only ~5 years -Only looked at mortality rather than morbidity effect
Wang et al., 2022	Time series/4.3 million ED visits from 2014 to 2018 at 20 sites spanning all 11 geo-meteorological regions of China	Evaluate association between DTR or TCN and specific ED visit types, considering seasonal variation and vulnerable populations	DTR and TCN (mean temperature change on neighboring days) as continuous variables	RD (ICD–10: J), circulatory disease (ICD–10: I), GU (ICD–10: N) or mental health ED visits ((ICD–10: F)	Quasi-Poisson regression with DLNM adjusting for mean temp., relative humidity, $PM_{2.5}$, O_3, atmospheric pressure, seasonal, DOW and long-term time trends	-Mental illness EDV inc. 11.8%/1°C inc. in TCN in Spring only -No significant association for CVD disease -GU disease increased 8.25%/1°C inc. in TCN in summer and 4.03%/1°C inc. in TCN overall -RD disease inc. 4.79%/1°C TCN in winter, 1.91%/1°C in TCN overall, and inc. 1.46%/1°C DTR for autumn,	-Did not report associations over different lag periods -Did not include metrics of SES or medical history
Zhai et al., 2022	Time series/32,567 hospital admissions for CVD across 30 hospitals in Qingyang City, Gansu, China	Compare the effects of ambient temp and DTR on CVD incidence in rural China	DTR calculated from mean daily max and min temp obtained from China	Hospital admission for: chronic rheumatic heart disease (ICD-10: I05–	Poisson generalized linear regression modeling combined with distributed lag nonlinear modeling	-DTR had larger magnitude and more significant effect over 30-day lag period, with bimodal peaks at low DTR (6°C) and high DTR (20°C)	-Single geographic site -Did not include metrics of SES or medical history -Did not include

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	from January 2014 to March 2017		Meteorological Science Data Sharing Service	I09), hypertension (ICD-10: I10–I15), ischemic heart disease (ICD-10: I20–I25) and other types of heart disease (ICD-10: I30–I52)	(DLNM) including mean temp, atmospheric pressure, relative humidity, wind speed, long-term trend, DOW and public holidays. Sensitivity analysis with $PM_{2.5}$, PM_{10} and SO_2 found no difference	with greater overall RR as low DTR (2.24) -Women had a more pronounced peak RR at low DTR (2.49), but greater RR for men at high DTR peak (2.06) -Both >65yrs and <65 years had more pronounced RR at high DTR than whole pop., and low DTR RR peaked at ≤lag 7	episodes of CVD not resulting in hospitalization
Gong et al., 2023	Time Series/364 counties from 5 Chinese provinces over 2013 to 2017 for which mortality data available from provincial Centers for Disease Control and Prevention	Investigate association between temp variability and years of life lost (YLL) in China	Temp variability (TV) as standard deviation of the max and min temperature from preceding two days (combines intra and inter-day variability)	YLL/100,000 population and years of life lost per death (LLD) calculated from province-specific mortality and life-expectancy data based on WHO methods; CVD (ICD-10: I00-I99), RD (ICD-10: J00-J98)	Two-stage analysis: 1st with DLNM controlling for daily temp, relative humidity, DOW, long-term trend and PM_{10} for each county, then 2nd a metanalysis pooling the county data. Demographic and geographic subgroup analyses also performed	-The minimum YLL was at TV 2.5°C nationally, with a U-shaped curve -Most LLD attributable to TV was from TV greater than 2.5°C (96.6%), LLD was greater in those <65, and for CVD (0.65y) relative to RD (0.54y) -Increased LLD from TV was found for warmer, more humid, lower latitude, high altitude areas and for those with low education	-Data not evenly distributed across all regions of China -Weather indicator did not distinguish between intra- and inter-day variability
Qi et al., 2023	Time Series/Cause-specific mortality from 266 cities in the Disease Surveillance Points system across China from 2013 to 2017	Examine the association between DTR and cause-specific morality to predict future changes in mortality due to DTR changes	Annually averaged DTR calculated from daily max and minimum temp for each city from data obtained through China Meteorological Data Service Center	Cause specific mortality by ICD-10 code: Non-accidental, CVD (ICD-10: I00-I99), RD (ICD-10: J00-J98), including subgroups of coronary artery disease (I20–I25), stroke (I60–I69) and COPD (J41-J44)	Two stage Poisson linear regression model including seasonal trend, long term trend, DOW, relative humidity, mean temp with a 14 day lag and stratified analysis for altitude, season, four regions of China, age, gender and education status	-Approx 3% increase in CVD mortality per 10°C increase in long term DTR, with slight increase at lower elevation (<500m), and only significant below 1500m -RD with far greater variation by altitude, with only significant inc. at 4% for <500m	-Temperature data averaged over entire city -SES, medical history, air pollution data not included -Did not assess morbidity, only mortality

ACS – acute coronary syndrome, cum. -cumulative DTR – diurnal Temperature Range, COPD – Chronic Obstructive Pulmonary Disease, CVD – cardiovascular disease, DLNM – distributed lag non-linear model, DOW – day of the week, ED – emergency department, GAM – generalized additive model, GLM – generalized linear model, GU – genitourinary, HF – heart failure, ICD – International Classification of Disease, inc. – increase, LLD – lives lost per death, MH – mental health, RD – respiratory disease, RTI – respiratory tract infection, SES – socioeconomic status, TV – temperature variability, YLL – years of life lost.

* Red = CVD outcome, yellow = RD outcome, orange = CVD and RD outcomes included, light gold = renal or GU outcomes included, dark gold = CVD, RD and renal/GU outcomes included, light blue = mental health outcome, dark blue = CVD, RD, renal/GU and MH outcomes included.