

RESEARCH ARTICLE

Extreme temperatures and morbidity in old age in Europe

Francesca Zanasi¹  and Risto Conte Keivabu² 

ABSTRACT Understanding the relationship between extreme temperatures and health among older adults is of paramount importance for public health in ageing societies. This study aims to enhance our understanding of the impact of extreme temperatures on morbidity, i.e. the risk of being hospitalised, using medications for heart conditions, and experiencing the onset of cardiovascular diseases (CVDs) among older adults in Europe (65+ years old) using five waves from the Survey of Health, Ageing and Retirement in Europe (SHARE, 2004–2015). It also explores heterogeneity in this impact depending on an array of factors that affect exposure and vulnerability to climate, including geographical location, gender, age, educational level, having a partner/child and living in an urban or a rural area. Results from individual fixed-effects models show that extremely cold temperatures increase the risk of being hospitalised and suffering from CVDs, while heat exposure has no noteworthy effect. Broken down by geographical location, the results indicate that one additional extremely cold day influences the risk of hospitalisation in the coldest and the warmest European regions, while extreme heat influences this risk in the warmest European regions. Finally, the oldest old and low educated individuals appear to be the most vulnerable social groups. The study concludes by discussing the advantages and the limitations of using survey data to study climate and health, and the strategies suggested by the relevant literature to prevent temperature-related illness.

KEYWORDS Old age • Extreme temperatures • Morbidity • Hospitalisation • European regions • Heterogeneity

Introduction

Over the past 50 years, Europe has experienced a significant increase in temperatures, with the average temperature rising by 1.7 °C since the pre-industrial era. According to the European State of the Climate 2020 report, the 2010s were the warmest decade on record in Europe, and there has been a global increase in the frequency of warm days and nights (Copernicus Climate Change Service, 2020). At the same time, Europe's population is ageing rapidly, with the percentage of those aged 65 and older projected to reach 27% by 2050. This demographic trend poses significant challenges for pension systems, healthcare services and long-term care. Understanding the relationship between extreme temperatures

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and health in the older population is crucial to public health in ageing societies (Kovats and Hajat, 2008). Climate change could increase future temperature-related mortality and morbidity, particularly among the older population (Bunker et al., 2016; Harper, 2019; Leyva et al., 2017; Schneider and Breitner, 2016).

Extreme temperatures put the body under stress, requiring it to exert extra effort to maintain a comfortable internal temperature of 37 °C (Cheshire, 2016). The weakening of the physiological response to the environment with age increases the likelihood of a failure in thermoregulation following exposure to heat and cold, which could lead to mortality and multiple morbidity from causes such as heat stroke and respiratory diseases (Ye et al., 2012).

Several studies have found that heat and cold increase mortality (e.g. Conte Keivabu, 2022; Gasparrini and Armstrong, 2011). A large multi-city study (Gasparrini et al., 2015) attributed roughly 8% of mortality to temperature, with most casualties following days colder than the optimum, and a much smaller number of casualties following days warmer than the optimum. Overall, however, the contribution of extreme temperature days to mortality appears to be comparatively low. Research on temperature-related morbidity is more outcome-, exposure- (Bhaskaran et al., 2009; Cicci et al., 2022; Phung et al., 2016; Ryti et al., 2016; Turner et al., 2012; Ye et al., 2012) and context-dependent (Michelozzi et al., 2009). A minority of these studies have focused specifically on the older population (see Åström et al., 2011; Bunker et al., 2016).

The objective of this study is to enhance our understanding of the impact of extreme temperatures on morbidity, particularly the risk of hospitalisation, medication usage for heart conditions, and experiencing the onset of cardiovascular diseases (CVDs) among older adults in Europe. We also account for how these effects differ depending on geographical location and climate conditions, given the tendency to adapt to the local climate (Kovats and Hajat, 2008); and depending on socio-demographic factors, including gender (Gifford et al., 2019), education (Gronlund, 2014), the urban-rural divide (e.g. Kovats and Hajat, 2008) and partnership and parenthood status (e.g. Conte Keivabu, 2022). These factors are known to influence individuals' exposure and vulnerability to climate.

Previous studies relied on vital statistics, census data and hospital records, which offer detailed information on health-related events. However, many of these data sources are not publicly accessible to researchers, do not provide extensive information on socio-economic characteristics or are limited to multiple cities (Michelozzi et al., 2009) or single cities/countries (e.g. Fonseca-Rodríguez et al., 2021; Linares and Díaz, 2008). In the present study, we use data from the Survey of Health, Ageing and Retirement in Europe (SHARE) (Börsch-Supan et al., 2013), which have, to the best of our knowledge, not been previously employed for research on this topic. In the European context, the SHARE data offer researchers a unique opportunity to compare older populations living in several European regions over the span of a decade based on a wide range of health and socio-economic characteristics.

Extreme temperature and morbidity in the older population

There is a vast body of literature on the relationship between temperature and health. The bodily stress caused by uncomfortable temperatures triggers physiological responses

designed to keep the body's internal temperature at about 37 °C, the human temperature of comfort. Failures in thermoregulation can lead to hypothermia in response to prolonged exposure to cold, and to hyperthermia in response to prolonged exposure to heat (Cheshire, 2016). Hypothermia occurs when, due to failed thermoregulation, the body temperature drops below 35 °C, leading to symptoms such as shivering, drowsiness and, ultimately, death if the condition is not addressed promptly (Osilla et al., 2023). Conversely, hyperthermia (i.e. abnormally high body temperature), which can result from excessive heat exposure, occurs when the core body temperature reaches 40 °C or higher. Some of the symptoms related to hyperthermia are sweating, rapid pulse, dizziness and nausea, which can progress to heatstroke, and then to death (Cheshire, 2016). In addition to triggering these acute conditions, uncomfortable temperatures can cause other illnesses affecting the cardiovascular and respiratory systems and mental health (Achebak et al., 2019; Mullins and White, 2019). Importantly, some socio-demographic groups are more vulnerable than others to the impact of extreme temperatures.

The older population is among the most vulnerable to elevated temperatures and cold spells (Cicci et al., 2022; Phung et al., 2016; Ryti et al., 2016; Ye et al., 2012). The factors that contribute to this vulnerability are both medical and socio-behavioural. Physiologically, the ageing process can lead to oxidative stress, inflammation and myocardial deterioration, which may increase the risk of developing health conditions such as high blood pressure, hypertension, coronary heart disease, arrhythmia (Rodgers et al., 2019) and diabetes (Wang et al., 2021). These conditions may be further exacerbated by extreme temperatures, which could trigger the onset of cardiovascular diseases or worsen pre-existing conditions (Ratter-Rieck et al., 2023). Furthermore, pre-existing health conditions can impair thermoregulation (Osilla et al., 2023), which may, in turn, increase susceptibility to temperature-related illnesses. In addition, socio-behavioural factors, such as having a mental disorder, living alone, feeling fatigued, being sleep deprived (Minor et al., 2022; Teyton et al., 2022) and being confined to bed, can alter coping strategies of heat and cold avoidance (Åström et al., 2011).

Most studies included in literature reviews and meta-analyses have reported a significant relationship between ambient temperature and all-cause and specific-cause morbidity. Hot spells usually have short-term effects lasting a few days, while the effects of cold spells can unfold over several weeks (Åström et al., 2011; Phung et al., 2016; Turner et al., 2012; Ye et al., 2012). Ryti et al. (2016) found that cold spells are associated with increased morbidity, particularly among people >65 years old. The authors observed that while the results of studies on causes of mortality are generally consistent, the substantial heterogeneity of the findings of morbidity studies makes it hard to quantitatively summarise the evidence. Bunker et al. (2016) found that a 1 °C reduction in temperature increases the risk of cold-induced pneumonia and respiratory morbidity, whereas a 1 °C increase in temperature increases the risk of cardiovascular disease, respiratory disease, diabetes mellitus, genitourinary conditions, infectious disease and heat-related morbidity. Bhaskaran et al. (2009) reported a short-term increase in the risk of myocardial infarction following exposure to low temperatures, and an increase in this risk at hot temperatures. Sun et al. (2018) found an immediate association between myocardial infarction and heat exposure and heatwaves, and a delayed association between myocardial infarction and cold exposure.

Morbidity causes related to heat and cold spells are usually measured via hospital records, which implies that individuals underwent (emergency) hospitalisation. In a study of European cities, Åström, Bertil and Joacim (2011) found that while respiratory admissions increased during hot days and heatwaves, there was no or a slightly negative association between cardiovascular and cerebrovascular admissions and high temperatures. Phung et al. (2016) reported an increase in cardiovascular hospitalisations related to cold exposure, heatwaves and increases in diurnal temperatures, but not to heat exposure. Similarly, Turner and colleagues (2012) found no association between increased ambient temperature and cardiovascular morbidity. Leyva et al. (2017) also reviewed the effects of cold and heat events on fluid and electrolyte disorders, ischemic heart diseases, and infectious diseases. In addition, Cicci and colleagues (2022) observed no association between high temperatures and ischemic heart disease (IHD), heart failure, dysrhythmia and some cerebrovascular-related hospital encounters. However, the authors also found evidence of a relationship between high temperatures and emergency department visits and hospitalisations related to total CVDs, hyper/hypotension, acute myocardial infarction (AMI) and ischemic stroke. Overall, the literature reviews and meta-analyses mentioned above highlight the importance of considering the whole spectrum of temperatures and morbidities, as well as the heterogeneity in the effects of temperatures on morbidity outcomes.

Socio-demographic and geographic differentials in the risk of temperature-related morbidity in Europe

In examining the relationship between extreme temperatures and morbidity, it is important to consider that this association may differ depending on climatic conditions. As the sensitivity of populations to cold and heat stress varies geographically, the effects of exposure in one area may diverge from those in another area. Consequently, it is important to analyse the impact of temperature in different climatic areas. Although multi-city studies on this topic exist, to our knowledge, only Michelozzi et al. (2009) has compared cities with very different latitudes and climates, namely, 12 European cities. The authors found that heat exposure increased the risk of respiratory admissions, but had no effect on CVD admissions. The results also indicated that the heat impact was greater in Mediterranean cities, which suggests that adaptation to the local climate (by both individuals and institutions such as healthcare providers) is not sufficient to avoid climate-induced morbidity.

Literature reviews and meta-analyses have compared the effect sizes reported in research carried out in different climatic regions. Åström et al. (2011) found very heterogeneous results by geographical location, with respiratory admissions increasing for individuals aged 75+ in both Mediterranean and Northern-Continental cities, but not for individuals aged 65–74 in Mediterranean countries. Hajat and Kovats (2010) explained that populations who experience higher summertime temperatures (and are closer to the equator) have a higher heat threshold or minimum mortality temperature (MMT), defined as the temperature above which mortality/morbidity risks start to increase (see also Tobías et al., 2021). To cope with the local climate, individuals may implement multiple adaptation measures that can be classified as behavioural (e.g. avoiding outdoor leisure during hot periods of the day,

see [Fan et al., 2023](#)), cultural (e.g. painting buildings white) or institutional (e.g. placing healthcare systems on higher alert or providing cooling areas during hot days). In addition, individuals may experience long-term physiological adaptation to climate conditions ([Rai et al., 2022](#)). Similarly, [Turner et al. \(2012\)](#) found evidence of an association between increased heat exposure at higher latitudes (colder climates) and the risk of cardiovascular hospitalisation. This latitude effect in colder climates was attributed to the populations in these climates having a lower adaptive capacity, as they are often less acclimatised to high temperatures, live in houses that are not suitable for hot weather and lack adaptive measures such as air conditioning. [Bhaskaran et al. \(2009\)](#) also observed that locations with higher mean temperatures are more vulnerable to cold exposure. However, these results contradict those of [Phung et al. \(2016\)](#) and [Sun et al. \(2018\)](#). Phung and colleagues examined the relationship between exposure to temperatures and the risk of hospitalisation for CVDs at different latitudes, and found that in countries at higher latitudes (i.e. colder countries), the effect of diurnal temperatures on the risk of CVD hospitalisation is lower. Meanwhile, [Sun and colleagues \(2018\)](#) studied the effects of heat exposure and cold exposure on the risk of MI hospitalisation, and found that in countries at a higher latitude, the effects of both cold and heat exposure on MI hospitalisation are weaker. While the weaker impact of cold exposure can be due to adaptive capacities at both at the physiological and the behavioural level (e.g. adequate housing), the weaker impact of heat exposure can be related to the lower frequency and strength of extreme heat.

In addition, evidence on the effects of heat and cold on morbidity has been mixed depending on the socio-demographic characteristics of the populations studied. There are three main mechanisms to explain these differences: differential exposure, differential vulnerability (sensitivity and adaptive capacity) and differential access to good quality medical care and social support.

Beyond the previously mentioned relationship between temperature-related morbidity and age ([Åström et al., 2011](#)), heterogeneity by gender and socio-economic status (SES) has been widely studied. As gender differences in temperature-related morbidity are extremely outcome- and context-specific, they are very difficult to assess (see, for example, [Cicci et al., 2022](#); [Hajat and Kosatky, 2010](#); [Ye et al., 2012](#)). Some studies have highlighted physiological differences that are linked to differentials in sensitivity to temperatures. For example, compared to men, women may have a lower tolerance for heat because of their higher core temperature and the cyclical changes in oestrogen that affect their thermoregulation ([Cicci et al., 2022](#)). However, a meta-analysis on the topic showed that at all ages, men are at greater risk of heat illness than women. This may be due to sex-related behavioural differences in exposure. For example, compared to women, men may take fewer protective measures or engage in more risk-taking behaviours, and they might be more exposed to heat stress due to their work and outdoor leisure activities ([Gifford et al., 2019](#)).

In terms of socio-economic status, a review on heat-related health effects found that low SES and lower educated individuals are more vulnerable to heat ([Gronlund, 2014](#)). Single-country studies have also reported SES disparities in cold-related illnesses, e.g. for South Korea ([Min et al., 2021](#)). In terms of sensitivity to extreme temperatures, temperature vulnerability can be affected by pre-existing medical conditions and CVDs.

The existence of an educational gradient in health in later life, with low educated individuals being disadvantaged, is well-established (Cornia, 2013). In terms of exposure, low SES individuals tend to live in the hottest neighbourhoods of cities, whereas highly educated individuals tend to be more resourceful and able to afford better housing and thermally controlled indoor environments (Gronlund, 2014). In addition, individuals with lower SES or education are more likely to be employed in strenuous and outdoor occupations (e.g. miners, construction workers, farmers) (Gronlund, 2014). Lastly, access to good quality medical care and social support can protect individuals from the consequences of extreme temperatures (Leyva et al., 2017; Masiero et al., 2022). In Europe, social care programmes tend to be targeted to low SES individuals. However, low SES individuals may be less likely to have private health insurance, while high SES individuals might be able to access higher quality medical care.

A large number of studies have also explored the modifying effects of urbanicity, mainly on mortality. While there are only a handful of studies on these effects on morbidity, there is no reason to believe the mechanisms regarding mortality to be different from those at play for morbidity. Urban areas are at risk of becoming urban heat islands, as higher temperatures are likely to be found inside the city. Night-time temperatures are higher in cities than in the rural surroundings due to the retention of heat by concrete and asphalt and air pollutants, which can also intensify heat perception (Antal and Bhutani, 2022; Harper, 2019). The effects on morbidity and mortality of heat islands – and, in general, of living in an urban rather than in a rural context – are hard to assess, as they can vary depending on the housing conditions and socio-economic status of the population (Uejio et al., 2011), as well as on the city's ability to cope with high temperatures (e.g. it may be higher in Southern than in Northern Europe) (Kovats and Hajat, 2008). Nevertheless, compared to their urban counterparts, rural residents tend to have less access to healthcare services and facilities, less access to strong social networks for social support and more difficulties implementing strategies for temperature relief (especially in the case of extreme heat) due to a lack of transport options. These factors may lead to an increase in temperature-related health conditions among rural residents (Williams et al., 2013). In light of these competing dynamics, the existing empirical evidence on the urban-rural divide in mortality and morbidity is mixed. Some studies have reported a higher risk of heat-related mortality in urban areas, e.g. in densely populated areas of Berlin (Gabriel and Endlicher, 2011). By contrast, other studies have found no protective effect of vegetation or imperviousness in, for example, Philadelphia (Uejio et al., 2011) and Worcester (Madrigano et al., 2013); or differences between rural villages and the provincial capital (see, e.g. for Spain Martínez-Navarro, 2004; for the Czech Republic Urban et al., 2014) (for exhaustive reviews, see Kovats and Hajat, 2008; Gronlund, 2014). Moreover, no differences between rural and urban areas were found in a study of the effects of heat on morbidity in New York (Adeyeye et al., 2019) and Vienna (Wanka et al., 2014). Conversely, a study conducted in the Zhejiang province of China found that rural areas are the most vulnerable to heat and cold exposure (Hu et al., 2019). Interestingly, in South Korea, a U-shaped curve between urbanisation and temperature-related morbidity has been observed, with the highest risks being found in rural areas and in the most densely populated parts of the city, largely due to the lower availability of hospital beds (Lee et al., 2022).

Social networks could provide important help to individuals aged 65 and older during cold spells and heatwaves. There is long-standing evidence of a protective effect of marriage on health (by encouraging a healthier lifestyle and health monitoring, and by providing socio-emotional and material support) (Rendall et al., 2011). For example, widowed men and divorced women in Turin, Italy were found to have a higher risk of heat-related mortality (Ellena et al., 2020). Similar findings showing a higher risk of temperature-related mortality for unmarried individuals have been reported for the Czech Republic (Vésier and Urban, 2023), Scotland (Wan et al., 2022) and Spain (Conte Keivabu, 2022). In addition, social programmes providing support to individuals aged 75 and older have been shown to be effective in decreasing heatwave-related risks (Liotta et al., 2018). Notably, the strength of social networks during heatwaves has been found to be a major factor stratifying mortality risks in the Chicago Heatwave of 1995 (Klinenberg, 2002; Klinenberg et al., 2020). To the best of our knowledge, no previous study has explored the potential protective factor of older individuals having adult children as part of their support network during episodes of extreme temperatures.

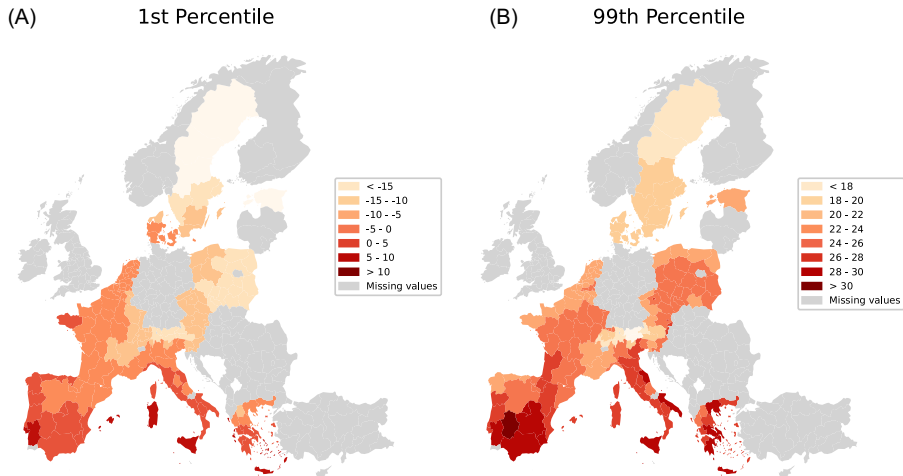
In conclusion, the present study will explore the effects of experiencing extreme temperatures on morbidity, while also taking into consideration subsequent mortality, among people aged 65 and older across a range of location-specific climates and socio-demographic individual characteristics, including gender, educational level, area of residence (urban/rural) and partnership and parenthood status.

Data, variables, and empirical strategy

Data and sample

For our study, we use data from the Survey of Health, Ageing and Retirement in Europe (SHARE), a biennial longitudinal survey that covers several key areas of life (health, socio-economic status, social and family networks, etc.) of roughly 140,000 people aged 50 and older from 28 European countries and Israel (Börsch-Supan et al., 2013). We pool together individuals from waves 1, 2, 4, 5 and 6 (2004–2015) (Börsch-Supan, 2022a, 2022b, 2022c, 2022d, 2022e).

We have selected individuals aged 65 and older, as they are more vulnerable to extreme temperatures. As a first inclusion criterion, respondents are selected if they report valid information on the region (NUTS-2) of residence. Since region of residence is surveyed at the baseline interview, in order to have a longitudinal sample, we could select only individuals who declared that they had not changed residence between two waves. As a consequence, wave 3 is not included in the sample, as it only includes retrospective information. Wave 7 and wave 8 do not report information on whether the individual had changed residence between the two waves (see below). Therefore, for these waves we could have retained only the baseline respondents, which is not suitable for a longitudinal approach. In any case, wave 8 does not include information on the NUTS-2 region. Second, and similarly, respondents are included if they had participated in at least two waves. This also affects the composition by country of our sample, as countries must have participated in the SHARE at least twice to be included.

Figure 1 Climatic differences in Europe by NUTS-2 regions

Note: The map reports the 1st (panel A) and the 99th percentile (panel B) in the temperature distribution, calculated using temperatures over the study period of January 2003 to December 2015. Temperatures are in ° Celsius. Source: E-OBS.

Our full analytical sample includes the following countries: Austria, Belgium, the Czech Republic, Denmark, Estonia, France, Greece, Italy, the Netherlands, Poland, Portugal, Slovenia, Spain, Sweden and Switzerland; corresponding to 155 NUTS-2 regions (see Figure 1). A complete list of the NUTS-2 regions included in the analysis is available in the online supplementary material, Tables S.1–S.3 (available at <https://doi.org/10.1553/p-8z36-6mmj>). The final number of respondents is 28,036, for whom we have 75,809 observations (Sample 1, S1).

Prospective surveys are expected to suffer from non-response attrition. One of the main causes of this attrition is mortality, especially for surveys focusing on older people. This must be considered in our study, since there is a well-established link between temperature and mortality (e.g. Gasparrini et al., 2015). Thus, analyses that only focus on the hospitalisation of longitudinal respondents (i.e. living individuals) can be downwardly biased. To tackle this problem, we also construct a second analytical sample (Sample 2, S2) using the so-called “end-of-life” interviews. When a SHARE longitudinal respondent died, a follow-up interview was conducted with a proxy respondent (a family or household member, a neighbour, or another person in the closer social network of the deceased respondent). Therefore, we also retain observations for deceased individuals. This second analytical sample (Sample 2, S2) contains 82,017 observations.

We perform separate analyses for the two samples because S2 has an important limitation: given that the end-of-life interviews do not report information on the respondent’s residence, we can only assume it remained unchanged since the previous wave.

Therefore, we offer the reader the option to compare two sets of analyses, with the second further supporting the evidence from the first.

Finally, we use temperature data that are provided by the E-OBS and are available from the Copernicus Data Store (CDS). The meteorological information, which is available from 1950 to 2022, is gridded at a resolution of 0.1°. We extract data on the average temperatures from January 2003 to December 2015 to cover the full period of analysis. The temperature data are linked to the individual-level SHARE observations according to the interview month and year and the NUTS-2 region of residence.

Variables

Our first dependent variable measures whether the respondent had been hospitalised in the last 12 months before the interview (S1), based on the answer to the following question: “During the last 12 months, have you been in a hospital overnight? Please consider stays in medical, surgical, psychiatric or in any other specialised wards”. The variable takes a value of 1 if the respondent answers positively, and of 0 otherwise. In the sample including deceased individuals (S2), we are able to measure whether the respondent was hospitalised during the 12 months before death. Therefore, as a robustness check, hospitalisation takes a value of (1) if the respondent was hospitalised either one year before the interview or one year before dying, and of (0) otherwise.

The second dependent variable broadly measures CVDs. In the main analytical sample (S1), we use a proxy measure for heart conditions. Specifically, we measure whether the respondent takes medication for heart problems, including cardiovascular and cerebrovascular problems. The variable takes a value of (1) if the respondent takes medications for heart problems, and of (0) otherwise.

Directly measuring CVDs in SHARE presents a few problems, and we include the direct CVDs variable only in the S2 sample. Living respondents are asked whether a doctor has told them that they suffered a stroke or a heart attack between the current and the previous interviews, and therefore over a two-year time span, without precise information on the timing. Proxy respondents for deceased individuals are asked about the respondent’s cause of death, including about whether it was a heart attack, a stroke or another CVD. We code a variable that takes a value of (1) if the respondent suffered a stroke or a heart attack between the two waves, or suffered from such a condition and died as a consequence. This variable presents an additional problem related to the timing of exposure to temperature, which we discuss in relation to [Figure 1](#).

We create our exposure to temperature in the 12 months prior to the interview in three steps. First, we calculate the average of the daily grid values falling within the NUTS-2 administrative boundaries. Second, we construct monthly temperature bins based on the NUTS-2-specific temperature distributions calculated using the temperatures in our study period of 2003–2015. Respectively, the temperature bins are < 1st; 1st to 5th; 5th to 10th; 10th to 25th; 25th to 75th (comfort zone); 75th to 90th; 90th to 95th; 95th to 99th; and >99th percentile. We count the number of days in which the daily temperature falls within these ranges per each NUTS-2 region. Third, we sum the number of days of

exposure to the temperature bins in the preceding 12 months, starting from the month of the interview for living individuals, or from the month of death for deceased individuals (included in S2). Alternative measures that capture the impact of extreme temperatures exist and have been found to be comparable (Barnett et al., 2010). For example, some studies have relied on the number of days falling within temperature bins based on absolute temperature ranges, while other studies have investigated the impact of heatwave exposure as measured by the number of consecutive days in which the temperature was above a specific threshold (e.g.: > 99th percentile of the local temperature distribution). Here, we rely on temperature percentiles based on the local temperature to better capture the location-specific adaptation to the climate (Masiero et al., 2022), and we use the total number of days in these temperature ranges, as this better captures the cumulative exposure to heat and cold in the previous year. The use of this approach is also supported by a prominent study (Gasparrini et al., 2015) that found a sizable contribution of moderately cold and moderately high temperatures to mortality, which highlights the importance of considering the full spectrum of temperatures, rather than only extreme events. Beyond the conceptual appropriateness of this measure of temperature, it also has the operational advantage of allowing us to have a more sustained number of observations within each temperature bin across NUTS-2 regions. Indeed, as our multi-country study covers a very diverse range of climates, extreme temperatures (e.g. hot days above 30 °C) only occur in a few of the analysed regions, which leads to problems of statistical power. A robustness check with absolute temperatures is reported in the supplementary material, Table S.4.

We have chosen to measure exposure to temperature in the previous 12 months for survey design reasons. Across waves and countries, individuals were interviewed in different months. Therefore, measuring the exposure to extreme temperatures in the previous year ensures that all the included individuals have lived through the same seasons. Moreover, the 12-month span is in line with the information on hospitalisation, which is related to the year before the interview.

We employ a few additional variables for the heterogeneity analysis. First, the median temperature of each region is used as an indicator of the location-specific climate. This indicator is based on the location-specific 50th percentile identified between 2003 to 2015, and ranges from 0.5 °C in Norrbottens län in northern Sweden to 18 °C in Las Palmas in Spain. To simplify the analysis, we recode it in categories (0/5.99 °C, 6/8.99 °C, 9/11.99 °C, 12/14.99 °C, 15/16.99 °C, 17+ °C). Previous studies focusing on cities often employed latitude to capture the local climate (Curriero et al., 2002). However, we prefer the use of the median temperature, as it better captures variation in climate that could occur within the same latitude, and it better proxies the climate of the whole administrative unit analysed. Second, we explore differences by gender and age. Age, given its time-varying nature, is also used as a control variable in the individual fixed-effects models. Third, we employ a set of socio-demographic variables related to the respondent's access to resources and social support, which can enable or hinder his/her ability to cope with extreme temperatures. We measure socio-economic status by the respondent's level of education. Education is measured in SHARE using the International Standard Classification of Education (ISCED-1997). However, given the very different distribution of education across

countries, we compute a measure of “relative” education using a strategy similar to that of Reardon (2011). We consider education as a latent characteristic in a population having a country-specific cumulative distribution (rank) that we can only observe with a measurement; in this case, with ISCED-97. For each ISCED category, we compute the average percentile of the country-specific educational distribution, and assign it to each individual. By doing so, we create the rank (the percentile) of each observation in the country-specific educational distribution. We consider individuals in the bottom 20th percentile of the country-specific educational distribution to be low educated, and individuals in the top 80th percentile to be high educated. Individuals who are primary educated according to the ISCED and those who are low educated in “relative” terms coincide; but, for example, high educated individuals are considered secondary educated in Italy and tertiary educated in Sweden. Moreover, we measure whether the respondent has a partner (from a question on marital status: whether the respondent is married or in a civil partnership); whether the respondent has living children; and whether the respondent lives in a rural or an urban area.

Empirical strategy

In the analysis, we use a Linear Probability Model (LPM) with three binary outcomes: Y (hospitalisation, use of medication for heart problems, and onset of CVDs) for the individual i in interview year t , and NUTS-2 region n . Our exposure variable of interest is $TEMP_m$, which measures the number of days in a certain temperature bin in the year prior to the interview $t - 1$ and NUTS-2 region n .

We employ fixed effects (FE) at the individual level μ_i and month of interview δ_m (see equation 1). This longitudinal approach allows us to measure the impact of temperature exposure on the dependent variables net of confounding at the individual level, and location-specific seasonality. First, the individual-level FE μ_i allow us to account for time-invariant differences in factors such as healthcare use, medication use, housing conditions and socio-economic status; additionally, as the respondents in our sample do not change residence between waves, individual FE also account for time-invariant characteristics of the context of residence, such as neighbourhood conditions or availability of healthcare services. Second, interview month FE δ_m is added to account for seasonal differences in the reporting of hospitalisations, medication use and CVDs Y_{it} that could be due to recall bias and might determine a seasonal pattern in the incidence of certain conditions. Finally, we add βX , which represents the age of individual i in year t as a time-varying control variable to account for ageing, and is thus strongly related to health deterioration, and, in turn, to morbidity and mortality. Based on our modelling strategy, the results should be interpreted as the impact of an extra day in a specific temperature bin on the outcomes relative to a day in the comfort zone (25th to 75th percentile).

$$Y_{it} = \sum_j \Theta_j TEMP_{t-1,n} + \beta X_{it} + \delta_m + \mu_i + \varepsilon_{it} \quad (1)$$

Regardless, we test the sensitivity of our results to different modelling strategies, reported in [Tables S.5–S.8](#) in the supplementary material.

In the second part of the analysis, as depicted in [equation 2](#), we interact the temperature-exposure variables with the variable measuring location-specific climate $CLIMA_n$ (location-specific median temperature).

$$Y_{it} = \sum_j \Theta_j TEMP_{t-1,n} \times CLIMA_n + \beta X_{it} + \delta_m + \mu_i + \varepsilon_{it} \quad (2)$$

Similarly, in [equation 3](#), we test interactions between the nine temperature bin variables and individuals' socio-demographic characteristics (simultaneously); a few of these characteristics are time-constant (gender, educational level, having children, $SOCIODEM_i$), while having a partner or children and living in a rural or an urban area could change between waves ($SOCIODEM_{it}$).

$$Y_{it} = \sum_j \Theta_j TEMP_{t-1,n} \times SOCIODEM_{it} + \beta X_{it} + \delta_m + \mu_i + \varepsilon_{it} \quad (3)$$

In all the models, standard errors are clustered at the level of the NUTS-2 region of residence.

Results

Descriptive results

In [Table 1](#), we report summary statistics for the main variables used in the analysis. Approximately 18% of our sample had been hospitalised and 26% had taken medications for heart problems in the previous 12 months. Hospitalisation increases to 21% when deceased individuals are also included, which means that several respondents had been hospitalised before dying. An estimated 5% of S2 suffered or died from a stroke, a heart attack or another CVD. Descriptive statistics by NUTS-2 region and wave are reported in the supplementary material, [Tables S1–S3](#). As for the temperature exposure variables, we observe a higher prevalence of days in the comfort zone (25th to 75th percentile) than of days in the most extreme temperature bins, which respectively show an average of approximately three days of exposure for days in the < 1st percentile and four days of exposure for days in the >99th percentile. The 50th percentile temperature distribution is the median and is used as a proxy for location-specific climate. It is employed in the heterogeneity analysis and has a range of 1–19 degrees.

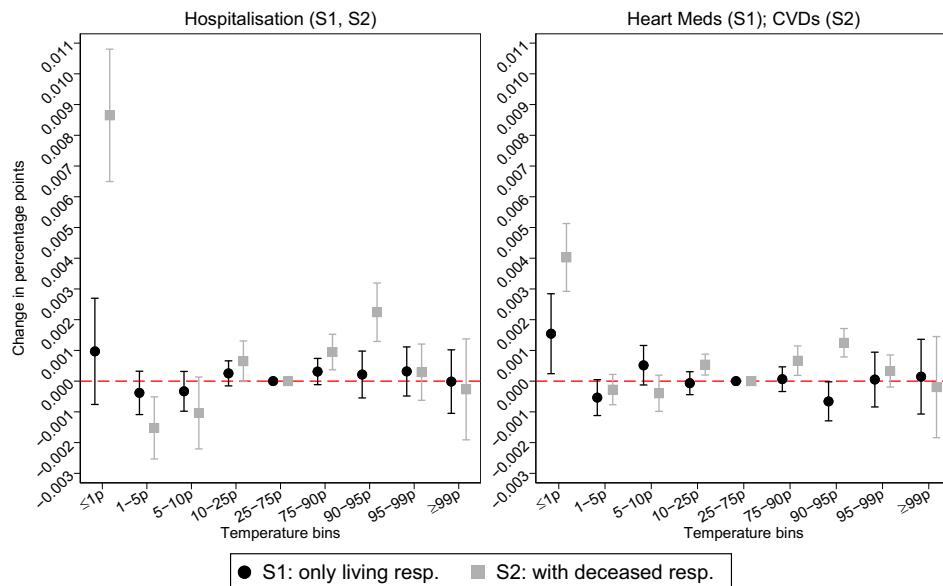
In [Figure 1](#), we report the 1st percentile and the 99th percentile in the temperature distribution in the NUTS-2 regions. The mean temperature in the 1st percentile bin is -6 degrees, while the mean temperature in the 99th percentile 24 degrees (not shown). The 1st percentile varies from -23 °C in Upper Norrland (Sweden) to 12 °C in the Canary Islands (Spain), and the 99th percentile varies from 17 °C in Tyrol (Austria) to 30 °C in Extremadura (Spain).

Table 1 Summary statistics for the main sample (S1) and the sample including deceased respondents' observations (S2)

	Sample 1 (S1)			Sample 2 (S2)		
	Mean/%	Max	Min	Mean/%	Max	Min
<i>Outcome variables</i>						
Hospitalisation (%)	18	1	0	21	1	0
Use of medications for heart problems (%)	26	1	0	26	1	0
CVDs (%)	4	1	0	5	1	0
<i>Exposure variables</i>						
Days <1 st percentile	2.85	17	0	2.95	26	0
Days 1 st to 5 th percentile	16.43	39	0	16.41	55	0
Days 5 th to 10 th percentile	20.52	45	1	20.45	46	1
Days 10 th to 25 th percentile	55.05	81	23	54.95	91	19
Days 25 th to 75 th percentile	179.74	239	118	179.85	249	118
Days 75 th to 90 th percentile	54.42	98	24	54.36	98	24
Days 90 th to 95 th percentile	16.83	36	3	16.86	36	3
Days 95 th to 99 th percentile	15.06	39	0	15.07	39	0
Days above 99 th percentile	4.18	24	0	4.19	24	0
<i>Heterogeneity</i>						
Age	74.41	105	65	74.89	105	65
Education: Low (%)	16	1	0	16	1	0
Education: Medium (%)	64	1	0	64	1	0
Education: High (%)	20	1	0	20	1	0
Female (%)	56	1	0	56	1	0
Has children (Yes) (%)	90	1	0	90	1	0
Lives in rural area (vs. urban) (%)	32	1	0	32	1	0
Has a partner (Yes) (%)	67	1	0	66	1	0
Median (50 th percentile)	10.04	18.64	0.79	10.03	18.64	0.79
Median: 0–5.99 degrees (%)	5	1	0	5	1	0
Median: 6–8.99 degrees (%)	30	1	0	30	1	0
Median: 9–11.99 degrees (%)	43	1	0	43	1	0
Median: 12–14.99 degrees (%)	14	1	0	14	1	0
Median: 15–16.99 degrees (%)	6	1	0	6	1	0
Median: 17+ (%)	2	1	0	2	1	0
<i>Total NUTS-2 regions</i>	155			155		
<i>Total individuals</i>	28,036			30,382		
<i>Total observations</i>	75,809			82,017		

Note: We report descriptive statistics (mean, %, minimum and maximum) for the variables of interest and the total number of unique individuals, observations, and NUTS-2 regions. Source: SHARE (2004–2015).

Figure 2 Effects of exposure to percentiles of temperature in the 12 months before the interview (S1, black dots, only living respondents) or death (S2, grey squares, including observations from deceased respondents) on the risk of being hospitalised (left panel), using medications for heart problems (only S1) and experiencing the onset of CVDs (only S2) (right panel)



Note: Figure 2 shows the percentage-point change in the probability of being hospitalised (left panel), taking medications for heart problems and experiencing CVDs (right panel) in the previous 12 months (Y-axis), given exposure to an additional day in a certain temperature bin according to the region's temperature distribution (X-axis), for two samples of respondents: a sample that only includes living respondents (S1) and a sample that also includes observations for deceased individuals (S2). LPMs with individual and interview month FE; standard errors are clustered at the NUTS-2 level. 95% CI. Source: SHARE (2004–2015).

Temperature-related morbidity: fixed-effects models

In Figure 2, we show the results for the probability of being hospitalised, taking medications for heart problems and experiencing CVDs. The black dots show estimates for S1 (only living respondents), while the grey squares show estimates for S2, which includes deceased respondents. The coefficients indicate the percentage-point change in the probability of experiencing the outcome for each additional day of exposure to a certain temperature compared to remaining in the comfort zone. Importantly, the percentage point reflects the effect at the individual level net of confounders related to ageing and month-specific trends in the reporting of hospitalisation, medication use and CVDs.

Starting from the black dots (S1), we hardly detect any effects, other than a slight increase in the intake of heart medications following exposure to cold temperatures (<1st percentile, left panel), and a decrease (barely statistically significant) in this intake following exposure to moderate-to-extreme heat (90–90th percentile). This latter result

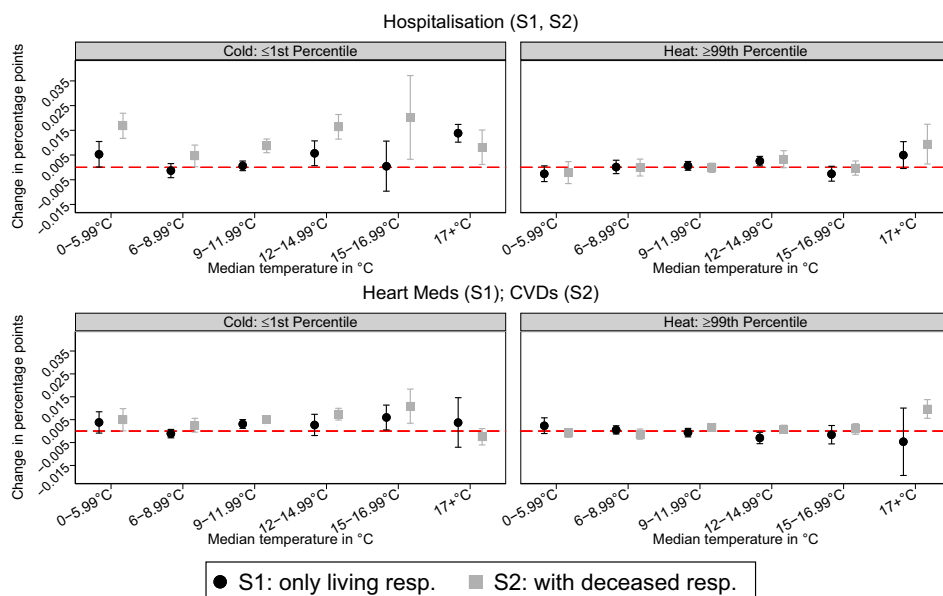
may have occurred because heart medications can accentuate the risk of dehydration and heat-related illness, such as changed thermoregulation, reduced sweat production, hypotension and reduced cardiac output, especially in older people taking multiple medicines (Westaway et al., 2015). However, these figures only include individuals who have been hospitalised and have returned home. Extreme temperatures could have impacted hospitalisation and led to mortality, which makes the consideration of deceased respondents important (S2, grey squares).

Results from S2 confirm the presence of a mortality bias: the risk of hospitalisation (left panel) strongly increases following cold exposure, up to around 1 percentage point, if deceased individuals' observations are also included. It slightly decreases with exposure to moderate cold, and it increases again following exposure to temperatures above the comfort zone (between the 75th and the 95th percentile). The relationship between temperature exposure and the risk of suffering from CVDs (right panel), or of dying from them, follows a very similar pattern, even though the coefficients are smaller in size. In both cases, surprisingly, we do not detect an effect of extreme temperatures (above the 95th percentile); this could be due to the diversity of the prevalence of extreme temperatures across the NUTS-2 regions.

The results for S2 must be interpreted with caution, as we have no information on the region of residence of each respondent when s/he died, and can only assume it remained unchanged from the previous wave (when the respondent was alive). Moreover, in our analysis of the role of CVDs, we face problems in establishing the timing of events. In follow-up interviews, the respondents are asked whether they had suffered a stroke or a heart attack between the current and the previous wave. As SHARE waves are conducted every two years, a stroke or a heart attack could have occurred at any point over a two-year time frame. However, we measure exposure to temperatures in the year before the interview. Therefore, we cannot be sure that the stroke or the heart attack happened within the window during which we measure temperature exposure. The alternative of measuring exposure to temperature in the previous two years, rather than over one year, would be too long to enable us to detect a meaningful effect.

Full models are included in Tables S.5–S.8, column (5). We also compare different model specifications with the inclusion of different combinations of FE to test the sensitivity of our results. Interestingly, models that do not add individual FE (column 1 in Tables S.5–S.8: the models consider each individual observation as independent, ignoring the longitudinal component of the data) show a positive effect of extreme cold (<1st percentile) on health outcomes, consistent with Figure 2; but a negative effect of extreme heat (>99th percentile) on health outcomes. This hints at the existence of confounding factors related to the individual and/or to the context in which s/he resides, which make people who have lived through extreme heat in the previous year less likely overall to be hospitalised, take medications for heart problems or experience CVDs. In column (2) of Tables S.5–S.8, we also include FE for the wave to account for possible period effects. However, this term is highly correlated with age, which changes signs, showing an odd negative relationship with health outcomes. We therefore omit the wave FE term. Finally, columns (4) and (5), which display the inclusion or exclusion of month FE together with individual FE, do not alter our results.

Figure 3 Effects of exposure to extreme temperatures (1st and 99th percentile bins) in the 12 months before the interview (S1, black dots, only living respondents) or death (S2, grey squares, including observations from deceased respondents) on the risk of being hospitalised (top panels), using medications for heart problems (only S1), and experiencing the onset of CVDs (only S2) (bottom panels); by location-specific climate (median, in categories)



Note: Figure 3 shows the percentage-point increase in the probability of being hospitalised (upper panel), taking medications for heart problems and experiencing CVDs (bottom panels) in the previous 12 months (Y-axis), given exposure to an additional cold day (1st percentile bin, left panels) and to an additional warm day (99th percentile bin, right panels) compared to the comfort zone, according to the location-specific climate as measured by categories of the median regional temperature (X-axis), for two samples of respondents: a sample that only includes living respondents (S1) and a sample that also includes observations for deceased individuals (S2). LPMs with individual and interview month FE; augmented with interaction terms between the nine exposure variables and the median temperature. Standard errors are clustered at the NUTS-2 level. 95% CI. Source: SHARE (2004–2015).

Heterogeneity by local climate

In Figure 3, we report the results of the interaction between the exposure to days in the <1st percentile and in the >99th percentile with the median temperature in the NUTS-2 regions, which we use to measure location-specific climate. The median temperature range varies from roughly 1 to 19 degrees (see Table 1). Please note that the results are consistent with also considering exposure to temperatures in the 90–95th and 95–99th percentiles (not shown).

The black dots show estimates for S1 (only living respondents), while the grey squares show estimates for S2, which includes deceased respondents. If we look at the estimates for the risk of hospitalisation in S1, we see that the estimates are very small in size. If there is

any increase in the risk of hospitalisation, it is observed in regions with a very low (0–5.99 °C) and a very high median temperature (17+ °C) following exposure to cold (one additional day below the 1st percentile bin, compared to the comfort zone, top-left panel). For exposure to heat (one additional day above the 99th percentile bin, top-right panel), we find that in regions with a median temperature of 17+ °C, one additional warm day slightly increases the risk of hospitalisation. When looking at S2 (including deceased respondents' observations, grey squares), we observe that the patterns are virtually unchanged, but the estimates are larger in size. In this sample, we find that exposure to extreme cold (<1st percentile, top-left panel) leads to hospitalisation in almost all location-specific climates, while exposure to extreme heat (>99th percentile, top-right panel) increases the risk of hospitalisation in the regions with the highest (17+ °C) median temperatures.

For the risk of taking medications for heart problems and of suffering from CVDs (bottom panels), we find similar patterns in S1 and S2, with the second sample having estimates that are larger in size. Exposure to cold temperatures (<1st percentile, bottom-left panel) increases the risk of taking medications for heart problems across almost all regions apart from those with a median temperature higher than 17+ °C, possibly due to the contraindications of taking heart medications during hot weather. By contrast, exposure to high temperatures (>99th percentile, bottom-right panel) does not seem related to medication intake in S1, but it increases the probability of experiencing CVDs in the warmest regions in S2.

Our finding of a heat effect only in the warmest regions supports the claim that the lack of evidence of a detrimental effect of temperatures above the 95th percentile (see [Figure 2](#)) could be due to the heterogeneity of climates across European regions.

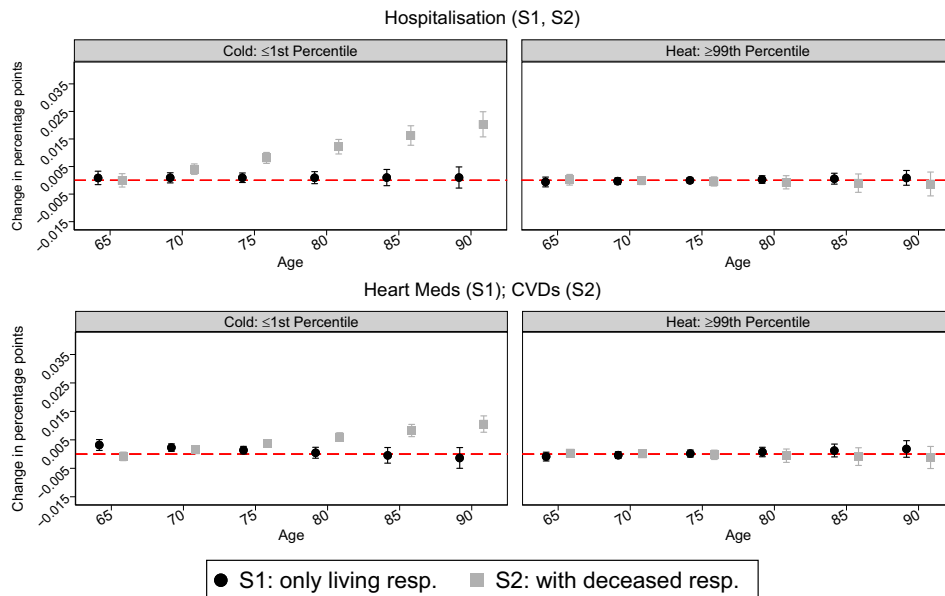
Heterogeneity by socio-demographic variables

We further explore heterogeneities using information on the socio-demographic characteristics of the individuals in our study, including age, gender, educational level, partnership status (having a partner), having children and area of residence (rural or urban). These variables are included as interaction terms with the temperature bins in the LPMs. Given space constraints, we show in the present section only the results we deem the most interesting: namely, those for age, educational level and having a partner. The results for gender, having children and area of residence are reported in the appendix ([Figure S.1–S.3](#)).

As shown in [Figure 4](#), older age is a strong predictor of being hospitalised or experiencing CVDs following exposure to very cold temperatures (<1st percentile) in S2. While the probability of being hospitalised or of suffering from (and subsequently dying from) CVDs at age 65 does not increase with exposure to extreme temperatures, it increases until reaching 2 percentage points for hospitalisation and 1 percentage point for CVDs by age 90.

When looking at educational level ([Figure 5](#)), heterogeneity emerges for exposure to very cold temperatures (<1st percentile) (left panels) in S2, with low educated individuals being at greater risk than their highly educated counterparts of both being hospitalised and taking heart medications. We do not detect any heterogeneity by educational level for exposure to very hot temperatures (>99th percentile, right panels). It should be mentioned that if we

Figure 4 Effects of exposure to extreme temperatures (1st and 99th percentile bins) in the 12 months before the interview (S1, black dots, only living respondents) or death (S2, grey squares, including observations from deceased respondents) on the risk of being hospitalised (top panels), using medications for heart problems (only S1) and experiencing the onset of CVDs (only S2) (bottom panels); by age



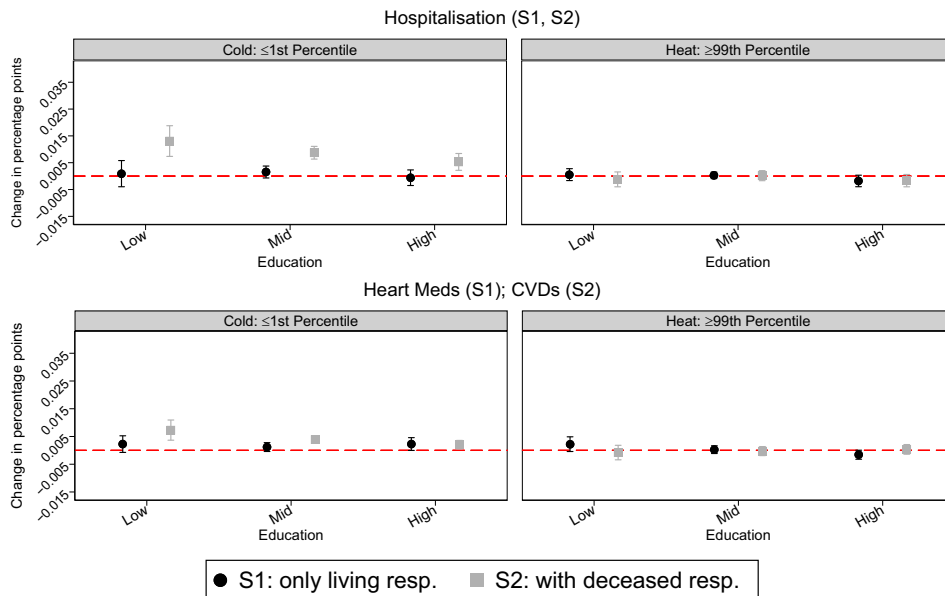
Note: Figure 4 shows the percentage-point increase in the probability of being hospitalised (upper panel), taking medications for heart problems and experiencing CVDs (bottom panels) in the previous 12 months (Y-axis), given exposure to an additional cold day (1st percentile bin, left panels) and to an additional warm day (99th percentile bin, right panels) compared to the comfort zone, according to age (X-axis), for two samples of respondents: a sample that only includes living respondents (S1) and a sample that also includes observations for deceased individuals (S2). LPMs with individual and interview month FE; augmented with interaction terms between the nine exposure variables and age. Standard errors are clustered at the NUTS-2 level. 95% CI. Source: SHARE (2004–2015).

showed the results for the interaction with temperatures in the 90–95th percentile, a gradient similar to that for cold would emerge, but would be extremely limited in size.

When looking at whether the respondent has a partner (Figure 6), we do not detect meaningful differences. Indeed, if there are any differences, it would appear that not having a partner slightly increases the probability of being hospitalised when experiencing very cold temperatures (<1st percentile, top-left panel).

Results on the remaining moderating variables we consider (gender, living in a rural or an urban area, parenthood) are shown in the appendix (Figures S.1–S.3). Men are more likely than women to be hospitalised following exposure to very cold temperatures. For the remaining variables, no noteworthy differences emerge in terms of either size or statistical significance. If there are any differences, it would appear that childless men living in rural areas are at slightly greater risk of being hospitalised following exposure to extreme cold.

Figure 5 Effects of exposure to extreme temperatures (1st and 99th percentile bins) in the 12 months before the interview (S1, black dots, only living respondents) or death (S2, grey squares, including observations from deceased respondents) on the risk of being hospitalised (top panels), using medications for heart problems (only S1) and experiencing the onset of CVDs (only S2) (bottom panels); by education level



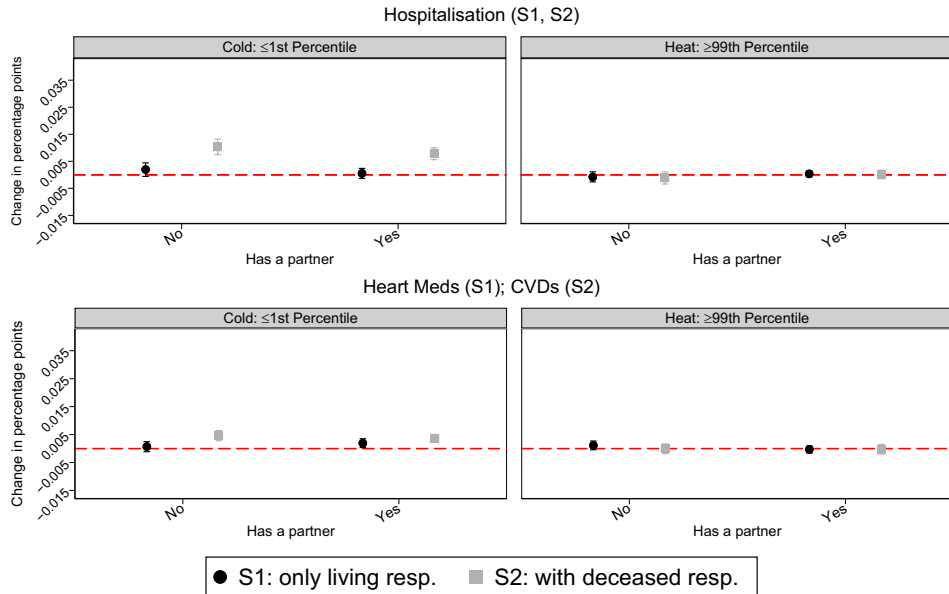
Note: Figure 5 shows the percentage-point increase in the probability of being hospitalised (upper panel), taking medications for heart problems and experiencing CVDs (bottom panels) in the previous 12 months (Y-axis), given exposure to an additional cold day (1st percentile bin, left panels) and to an additional warm day (99th percentile bin, right panels) compared to the comfort zone, according to educational level (X-axis), for two samples of respondents: a sample that only includes living respondents (S1) and a sample that also includes observations for deceased individuals (S2). LPMs with individual and interview month FE; augmented with interaction terms between the nine exposure variables and educational level. Standard errors are clustered at the NUTS-2 level. 95% CI. Source: SHARE (2004–2015).

Conclusions

In this article, we investigated how exposure to extreme temperatures affects morbidity, i.e. the risk of being hospitalised and of using medications for heart problems, in individuals aged 65 and older living in several European regions; and whether this relationship is moderated by the local climate and individual level socio-demographic characteristics. We made use of SHARE data (2004–2015), the only publicly available survey data in Europe that allow us to take into consideration the health outcomes of the older population across a variety of climatic contexts, along with their socio-demographic characteristics.

Our results show that exposure to extreme temperatures below the 1st percentile of the regional temperature distribution slightly increases the risk of being hospitalised and of using heart medications. Conversely, we do not observe any substantive effect of heat

Figure 6 Effects of exposure to extreme temperatures (1st and 99th percentile bins) in the 12 months before the interview (S1, black dots, only living respondents) or death (S2, grey squares, including observations from deceased respondents) on the risk of being hospitalised (top panels), using medications for heart problems (only S1) and experiencing the onset of CVDs (only S2) (bottom panels); by partnership status



Note: Figure 6 shows the percentage-point increase in the probability of being hospitalised (upper panel), taking medications for heart problems and experiencing CVDs (bottom panels) in the previous 12 months (Y-axis), given exposure to an additional cold day (1st percentile bin, left panels) and to an additional warm day (99th percentile bin, right panels) compared to the comfort zone, according to partnership status (X-axis), for two samples of respondents: a sample that only includes living respondents (S1) and a sample that also includes observations for deceased individuals (S2). LPMs with individual and interview month FE; augmented with interaction terms between the nine exposure variables and partnership status. Standard errors are clustered at the NUTS-2 level. 95% CI. Source: SHARE (2004–2015).

exposure on health outcomes. These results align with those of some studies on cause-specific hospitalisation and the health effects of heat exposure (Åström et al., 2011; Cicci et al., 2022; Phung et al., 2016; Turner et al., 2012), but contradict those of several others (Bhaskaran et al., 2009; Bunker et al., 2016; Ye et al., 2012), which highlights the importance of the outcome that is considered as well as the measure of exposure that is employed.

When looking at climate-specific heterogeneity, we find that extremely cold days affect the risk of hospitalisation in both the coldest and the warmest European regions, while extremely hot days affect the risk of hospitalisation (but just slightly) in the warmest regions only (as was found by Michelozzi et al., 2009). The effects of extreme cold in both the coldest and the warmest regions may be attributable to two different mechanisms: on the one hand, despite their higher preparedness, one additional cold day strikes more populations living in very cold environments because of the strength and the

frequency of these events. This also holds for the effects of one additional hot day in the warmest regions. On the other hand, one additional cold day in the warmest regions could affect the risk of hospitalisation because of the lower adaptive capacity of populations who are not used to and are not well equipped for below-zero temperatures.

The effects for taking medications for heart problems follow the same pattern as for cold days, with the effects being much reduced in size and not statistically significant. No noteworthy relationship is found between exposure to heat and the risk of taking heart medications.

Since we employed a prospective longitudinal survey, our results could be affected by mortality bias. The relationship between temperature and mortality is well-established in the literature (Gasparrini et al., 2015; Gasparrini and Armstrong, 2011; Tobias et al., 2021). Individuals can report on their health problems and hospitalisations only if they are still alive. By contrast, if individuals were hospitalised or developed a heart condition following exposure to extreme temperatures and subsequently died, they would not be present in the survey. This could greatly reduce our effect size. SHARE includes end-of-life interviews that we employed in a complementary analysis, despite the difficulties of assessing the region of residence and the timing of the onset of cardiovascular diseases for deceased individuals. These limitations notwithstanding, our results including deceased respondents show a much larger effect of exposure to extreme cold on the risk of both being hospitalised and experiencing CVDs (even though the effects remain limited in size). There also appears to be an effect on health outcomes of moderate-to-extreme heat, namely, of temperatures between the 75th and the 95th percentile. The lack of evidence for exposure to extremely hot temperatures (above the 95th percentile) could be due to the diversity of temperatures across the NUTS-2 regions (e.g. the 99th percentile ranges from 17 °C in Tyrol, Austria to 30 °C in Extremadura, Spain). Indeed, the interaction between temperature exposure and location-specific climate (i.e. as measured by the median temperature) indicates that any detrimental effects of exposure to extremely hot temperatures on morbidity and mortality are limited to the warmest regions.

The effects of exposure to heat on the risk of both being hospitalised and suffering from CVDs appear to be stronger in Europe's warmest regions (with median temperatures above 17 degrees). This could suggest that the greatest mortality bias lies in heat-related morbidity. Interestingly, albeit to a different extent, the effects of exposure to cold on the risk of both being hospitalised and experiencing CVDs are observed across European regions.

In terms of heterogeneous impacts, we observe age differences in the risks related to cold (but not heat) exposure, with older individuals being at higher risk of being hospitalised and of suffering (and subsequently dying) from CVDs. A similar pattern is found for men compared to women in relation to the risk of hospitalisation. Moreover, for these two outcomes, we find that lower educated individuals are at greater risk than their highly educated counterparts following exposure to extreme cold. No sizeable differences emerge regarding the other socio-demographic characteristics considered. Indeed, if any, there seems to be a relationship between social vulnerability and vulnerability to temperatures, with individuals who have no partner and no children and who live in a rural area being at slightly higher risk of being hospitalised following exposure to extreme cold. Again, these differences are very limited in size.

This study has several limitations. First, the respondents were surveyed at different months, and not at regular intervals. Our decision to measure temperature exposure in the 12 months before the interviews ensures that all the respondents have experienced the same seasons. Moreover, this time span matches that for the morbidity outcomes (hospitalisation and heart medications intake in the previous 12 months; and CVDs experienced since the last wave). The drawback of this approach is that it cannot detect the short-term effects of temperature exposure. Second, as the hospitalisation variable includes all causes, we cannot distinguish between hospitalisations for respiratory diseases and for CVDs. Including all-cause hospitalisation could have offset the evidence on the effects of temperature exposure. Still, the results employing the measure of the onset of CVDs are in line with the results on hospitalisation, even though they are measured over a two-year time span, making the timing issue described above more problematic. Third, in terms of our research design, the NUTS-2 region of residence is reported only at survey entry. Thus, to adopt a longitudinal approach, we are forced to retain only individuals who did not change residence between two waves. Changing residence could be a coping strategy to escape extreme temperatures; following this reasoning, individuals who stay may be worse-off, with fewer resources to deal with extreme temperatures, than those who left, making our estimates upwardly biased. To check for this potential bias, we have compared the group of movers (deleted from the analytical sample) with the group of non-movers (included in the analytical sample) in terms of their socio-economic background (education, income) and family network (having a partner, number of children). Small differences by educational level emerge, with the group of movers being slightly more likely to be tertiary educated than the group of non-movers. This gives us confidence that if this bias exists, it is small in size.

Despite its limitations, SHARE remains the only survey that allows us to compare older individuals' health outcomes at the European level with an adequate sample size across several climates, and in a longitudinal perspective. At the same time, SHARE allows to explore the heterogeneity of these outcomes based on socio-demographic and economic factors. Recently, the SHARE survey has been expanded with the creation of SHARE-ENV dataset (Midões et al., 2024), which was not yet available at the time of the present analysis. SHARE-ENV complements the information on SHARE respondents' life conditions, health histories, healthcare use and working lives with indicators of respondents' cumulative exposures to different environmental hazards. This harmonised source of data will be crucial for gaining new knowledge about the health hazards of climate change for the older population.

In conclusion, several best practices have been identified, and have often been implemented, to mitigate the effects of climate change on older people's health (Schifano et al., 2012). For example, healthcare providers have been developing the competencies of GPs and nurses to identify health problems related to climatic events, adjusting and monitoring the care plans of older people (changing diet, adjusting medications) and implementing educational interventions aimed at encouraging preventive behaviours (Montoro-Ramírez et al., 2022). Nevertheless, the success of these strategies may be complicated by individuals with social disadvantage facing difficulties in accessing these interventions, even though people with fewer socio-economic and cultural resources are at greatest risk of experiencing social isolation (no children, no partner) and of suffering from temperature-related illness.

Therefore, the ageing-climate change nexus must be addressed in more structural terms, as it will be among the defining relationships of the coming decades. For example, the prevention of temperature-related illness should be included in policies, such as those aimed at promoting active, healthy and successful ageing (Sowa et al., 2016; Urtamo et al., 2019; World Health Organization, 2002). While there are several different definitions of healthy ageing, they all point to the need to sustain older people's health and well-being via an active and healthy lifestyle, and through engagement with others and society at large. These frameworks can find a place in the movement for age-friendly cities, which seeks to make urban environments supportive and inclusive for older people (e.g. services are easily accessible and reachable), especially in light of the growing share of older people living in urban areas (Antal and Bhutani, 2022).

Research has recently shown the importance of what has been called "social infrastructure" during disasters and episodes of extreme temperatures (Klinenberg, 2002, 2018; Klinenberg et al., 2020). Social infrastructure comprises "the physical places and organisations that shape the way people interact" (Klinenberg, 2018, p.12); e.g. accessible gathering places such as libraries, community gardens and parks, restaurants and bars, and beauty parlours and barbershops. These places affect the formation of social capital in everyday life. When public spaces offer people the opportunity to engage in casual but sustained and recurrent interactions, particularly during activities they enjoy, they develop bonds and social cohesion. Strong interpersonal relationships and networks foster contact, mutual support and collaboration. This social infrastructure can lead to people caring for and checking in on each other, which is particularly crucial when the weather is very hot or very cold, especially for vulnerable individuals such as the oldest old (*ibidem*).

In conclusion, the design of age-friendly cities with a healthy social infrastructure takes on particular importance in a world that is increasingly affected by extremely hot temperatures due to climate change. Conceiving of ageing and climate change as related challenges could greatly benefit European societies. For example, the creation of more green outdoor spaces can be seen as supporting older people's health and social life, while also mitigating heat perception (van Hoof et al., 2021).

Supplementary material

Available online at <https://doi.org/10.1553/p-8z36-6mmj>

Supplementary file 1. Tables S.1–S.8, Figures S.1–S.3.



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GA N°870628, SERISS: GA N°654221, SSHOC: GA N°823782, SHARE-COVID19: GA N°101015924) and by DG Employment, Social Affairs & Inclusion through VS 2015/0195, VS 2016/0135, VS 2018/0285, VS 2019/0332, and VS 2020/0313. Additional funding from the German Ministry of Education and Research, the Max Planck Society for the Advancement of Science, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064, HHSN271201300071C, RAG052527A) and from various national funding sources is gratefully acknowledged (see www.share-project.org).

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References

- Achebak, H., Devolder, D., and Ballester, J. (2019). Trends in temperature-related age-specific and sex-specific mortality from cardiovascular diseases in Spain: a national time-series analysis. *The Lancet Planetary Health*, 3(7), e297–e306. [https://doi.org/10.1016/S2542-5196\(19\)30090-7](https://doi.org/10.1016/S2542-5196(19)30090-7)
- Adeyeye, T. E., Insaf, T. Z., Al-Hamdan, M. Z., Nayak, S. G., Stuart, N., DiRienzo, S., and Crosson, W. L. (2019). Estimating policy-relevant health effects of ambient heat exposures using spatially contiguous reanalysis data. *Environmental health*, 18(1), 1–13. <https://doi.org/10.1186/s12940-019-0467-5>
- Antal, H., and Bhutani, S. (2022). Identifying Linkages Between Climate Change, Urbanisation, and Population Ageing for Understanding Vulnerability and Risk to Older People: A Review. *Ageing International*, 48, 816–839. <https://doi.org/10.1007/s12126-022-09504-7>
- Åström, D. O., Bertil, F., and Joacim, R. (2011). Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies. *Maturitas*, 69(2), 99–105. <https://doi.org/10.1016/j.maturitas.2011.03.008>
- Barnett, A. G., Tong, S., and Clements, A. C. A. (2010). What measure of temperature is the best predictor of mortality? *Environmental Research*, 110(6), 604–611. <https://doi.org/10.1016/j.envres.2010.05.006>
- Bhaskaran, K., Hajat, S., Haines, A., Herrett, E., Wilkinson, P., and Smeeth, L. (2009). Effects of ambient temperature on the incidence of myocardial infarction. *Heart*, 95(21), 1760–1769. <https://doi.org/10.1136/hrt.2009.175000>
- Börsch-Supan, A., Brandt, M., Hunkler, C., Kneip, T., Korbmacher, J., Malter, F., Schaaf, B., Stuck, S., Zuber, S., on behalf of the SHARE Central Coordination Team (2013). Data Resource Profile: The Survey of Health, Ageing and Retirement in Europe (SHARE). *International Journal of Epidemiology*, 42(4), 992–1001. <https://doi.org/10.1093/ije/dyt088>
- Börsch-Supan, A. (2022a). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 1. Release version: 8.0.0. SHARE-ERIC. Data set. <https://doi.org/10.6103/SHARE.w1.800>
- Börsch-Supan, A. (2022b). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 2. Release version: 8.0.0. SHARE-ERIC. Data set. <https://doi.org/10.6103/SHARE.w2.800>
- Börsch-Supan, A. (2022c). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 4. Release version: 8.0.0. SHARE-ERIC. Data set. <https://doi.org/10.6103/SHARE.w4.800>
- Börsch-Supan, A. (2022d). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 5. Release version: 8.0.0. SHARE-ERIC. Data set. <https://doi.org/10.6103/SHARE.w5.800>
- Börsch-Supan, A. (2022e). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 6. Release version: 8.0.0. SHARE-ERIC. Data set. <https://doi.org/10.6103/SHARE.w6.800>
- Bunker, A., Wildenhain, J., Vandenberghe, A., Henschke, N., Rocklöv, J., Hajat, S., and Sauerborn, R. (2016). Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence. *EBioMedicine*, 6, 258–268. <https://doi.org/10.1016/j.ebiom.2016.02.034>
- Cheshire, W. P. (2016). Thermoregulatory disorders and illness related to heat and cold stress. *Autonomic Neuroscience: Basic and Clinical*, 196, 91–104. <https://doi.org/10.1016/j.autneu.2016.01.001>

- Cicci, K. R., Maltby, A., Clemens, K. K., Vicedo-Cabrera, A. M., Gunz, A. C., Lavigne, É., and Wilk, P. (2022). High temperatures and cardiovascular-related morbidity: A scoping review. *International Journal of Environmental Research and Public Health*, 19(18), 11243. <https://doi.org/10.3390/ijerph191811243>
- Conte Keivabu, R. (2022). Extreme Temperature and Mortality by Educational Attainment in Spain, 2012–2018. *European Journal of Population*, 38(5), 1145–1182. <https://doi.org/10.1007/s10680-022-09641-4>
- Corna, L. M. (2013). A life course perspective on socioeconomic inequalities in health: A critical review of conceptual frameworks. *Advances in Life Course Research*, 18(2), 150–159. <https://doi.org/10.1016/j.alcr.2013.01.002>
- Copernicus Climate Change Service (2020). *European State of the Climate 2020*. <https://climate.copernicus.eu/ESOTC/2020>
- Curriero, F. C., Heiner, K. S., Samet, J. M., Zeger, S. L., Strug, L., and Patz, J. A. (2002). Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology*, 155(1), 80–87. <https://doi.org/10.1093/aje/155.1.80>
- Ellena, M., Ballester, J., Mercogliano, P., Ferracin, E., Barbato, G., Costa, G., and Ingole, V. (2020). Social inequalities in heat-attributable mortality in the city of Turin, northwest of Italy: A time series analysis from 1982 to 2018. *Environmental Health*, 19, 116. <https://doi.org/10.1186/s12940-020-00667-x>
- Fan, Y., Wang, J., Obradovich, N., and Zheng, S. (2023). Intraday adaptation to extreme temperatures in outdoor activity. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-022-26928-y>
- Fonseca-Rodríguez, O., Sheridan, S. C., Lundevall, E. H., and Schumann, B. (2021). Effect of extreme hot and cold weather on cause-specific hospitalizations in Sweden: A time series analysis. *Environmental Research*, 193. <https://doi.org/10.1016/j.envres.2020.110535>
- Gabriel, K. M. A., and Endlicher, W. R. (2011). Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. *Environmental Pollution*, 159(8), 2044–2050. <https://doi.org/10.1016/j.envpol.2011.01.016>
- Gasparini, A., and Armstrong, B. (2011). The impact of heat waves on mortality. *Epidemiology*, 22(1), 68–73. <https://doi.org/10.1097/EDE.0b013e3181fdcd99>
- Gasparini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., De Sario, M., Bell, M. L., Leon Guo, Y.-L., Wu, C., Kan, H., Yi, S.-M., de Sousa Zanotti Stagliorio Coelho, M., Nascimento Saldiva, P. H., ... Armstrong, B. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet*, 369–375. [https://doi.org/10.1016/S0140-6736\(14\)62114-0](https://doi.org/10.1016/S0140-6736(14)62114-0)
- Gifford, R. M., Todisco, T., Stacey, M., Fujisawa, T., Allerhand, M., Woods, D. R., and Reynolds, R. M. (2019). Risk of heat illness in men and women: A systematic review and meta-analysis. *Environmental Research*, 171, 24–35. <https://doi.org/10.1016/j.envres.2018.10.020>
- Gronlund, C. J. (2014). Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: a Review. *Current Epidemiology Reports*, 1(3), 165–173. <https://doi.org/10.1007/s40471-014-0014-4>
- Hajat, S., and Kosatky, T. (2010). Heat-related mortality: A review and exploration of heterogeneity. *Journal of Epidemiology and Community Health*, 64(9), 753–760. <https://doi.org/10.1136/jech.2009.087999>
- Harper, S. (2019). The convergence of population ageing with climate change. *Journal of Population Ageing*, 12(4), 401–403. <https://doi.org/10.1007/s12062-019-09255-5>
- Hu, K., Guo, Y., Hochrainer-Stigler, S., Liu, W., See, L., Yang, X., Zhong, J., Fei, F., Chen, F., Zhang, Y., Zhao, Q., Chen, G., Chen, Q., Zhang, Y., Ye, T., Ma, L., Li, S., and Qi, J. (2019). Evidence for urban–rural disparity in temperature–mortality relationships in Zhejiang province, China. *Environmental Health Perspectives*, 127(3), 037001. <https://doi.org/10.1289/EHP3556>
- Klinenberg, E. (2002). *Heat Wave: A Social Autopsy of Disaster in Chicago*. University of Chicago Press. <https://doi.org/10.7208/chicago/9780226026718.001.0001>
- Klinenberg, E., Araos, M., and Koslov, L. (2020). Sociology and the climate crisis. *Annual Review of Sociology*, 46(1). <https://doi.org/10.1146/annurev-soc-121919-054750>
- Klinenberg, E. (2018). *Palaces for the people: How social infrastructure can help fight inequality, polarization, and the decline of civic life*. New York: Broadway books.
- Kovats, R. S., and Hajat, S. (2008). Heat stress and public health: A critical review. *Annual Review of Public Health*, 29, 41–55. <https://doi.org/10.1146/annurev.publhealth.29.020907.090843>

- Leyva, E. W. A., Beaman, A., and Davidson, P. M. (2017). Health impact of climate change in older people: An integrative review and implications for nursing. *Journal of Nursing Scholarship*, 49(6), 670–678. <https://doi.org/10.1111/jnu.12346>
- Lee, W., Choi, M., Bell, M. L., Kang, C., Jang, J., Song, I., Kim, Y.-O., Ebi, K., and Kim, H. (2022). Effects of urbanization on vulnerability to heat-related mortality in urban and rural areas in South Korea: A nationwide district-level time-series study. *International Journal of Epidemiology*, 51(1), 111–121. <https://doi.org/10.1093/ije/dyab148>
- Linares, C., and Díaz, J. (2008). Impact of high temperatures on hospital admissions: Comparative analysis with previous studies about mortality (Madrid). *European Journal of Public Health*, 18(3), 317–322. <https://doi.org/10.1093/eurpub/ckm108>
- Liotta, G., Inzerilli, M. C., Palombi, L., Madaro, O., Orlando, S., Scarcella, P., Betti, D., and Marazzi, M. C. (2018). Social interventions to prevent heat-related mortality in the older adult in Rome, Italy: A quasi-experimental study. *International Journal of Environmental Research and Public Health*, 15(4), 715. <https://doi.org/10.3390/ijerph15040715>
- Madrigano, J., Mittleman, M. A., Baccarelli, A., Goldberg, R., Melly, S., von Klot, S., and Schwartz, J. (2013). Temperature, myocardial infarction, and mortality: effect modification by individual- and area-level characteristics. *Epidemiology*, 24(3), 439–446. <https://doi.org/10.1097/EDE.0b013e3182878397>
- Martínez Navarro, F., Simón-Soria, F., and López-Abente, G. (2004). Valoración del impacto de la ola de calor del verano de 2003 sobre la mortalidad. *Gaceta Sanitaria*, 18(1), 250–258.
- Masiero, G., Mazzonna, F., and Santarossa, M. (2022). The effect of absolute versus relative temperature on health and the role of social care. *Health Economics (United Kingdom)*, 31(6), 1228–1248. <https://doi.org/10.1002/hec.4507>
- Midões, C., De Cian, E., Pasini, G., Pesenti, S., and Mistry, M. N. (2024). SHARE-ENV: A data set to advance our knowledge of the environment–wellbeing relationship. *Environment and Health*, online first. <https://doi.org/10.1021/envhealth.3c00065>
- Michelozzi, P., Accetta, G., De Sario, M., D’Ippoliti, D., Marino, C., Baccini, M., Biggeri, A., Anderson, H. R., Katsouyanni, K., Ballester, F., Bisanti, L., Cadum, E., Forsberg, B., Forastiere, F., Goodman, P. G., Hojs, A., Kirchmayer, U., Medina, S., Paldy, A., . . . Perucci, C. A. (2009). High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. *American Journal of Respiratory and Critical Care Medicine*, 179(5), 383–389. <https://doi.org/10.1164/rccm.200802-217OC>
- Min, J.-young, Lee, H.-S., Choi, Y.-S., and Min, K.-bok. (2021). Association between income levels and prevalence of heat- and cold-related illnesses in Korean adults. *BMC Public Health*, 21(1). <https://doi.org/10.1186/s12889-021-11227-4>
- Minor, K., Bjerre-Nielsen, A., Jonasdottir, S. S., Lehmann, S., and Obradovich, N. (2022). Rising temperatures erode human sleep globally. *One Earth*, 5(5), 534–549. <https://doi.org/10.1016/j.oneear.2022.04.008>
- Montoro-Ramírez, E. M., Parra-Anguita, L., Álvarez-Nieto, C., Parra, G., and López-Medina, I. (2022). Effects of climate change in the elderly’s health: a scoping review protocol. *BMJ Open*, 12(4), e058063. <https://doi.org/10.1136/bmjopen-2021-058063>
- Mullins, J. T., and White, C. (2019). Temperature and mental health: Evidence from the spectrum of mental health outcomes. *Journal of Health Economics*, 68. <https://doi.org/10.1016/j.jhealeco.2019.102240>
- Osilla, E. V., Marsidi, J. L., and Sharma, S. (2023). Physiology, Temperature Regulation. In *StatPearls Internet*. StatPearls Publishing
- Phung, D., Thai, P. K., Guo, Y., Morawska, L., Rutherford, S., and Chu, C. (2016). Ambient temperature and risk of cardiovascular hospitalization: An updated systematic review and meta-analysis. *Science of the Total Environment*, 550, 1084–1102. <https://doi.org/10.1016/j.scitotenv.2016.01.154>
- Rai, M., Breitner, S., Wolf, K., Peters, A., Schneider, A., and Chen, K. (2022). Future temperature-related mortality considering physiological and socioeconomic adaptation: a modelling framework. *The Lancet Planetary Health*, 6(10), e784–e792. [https://doi.org/10.1016/S2542-5196\(22\)00195-4](https://doi.org/10.1016/S2542-5196(22)00195-4)
- Ratter-Rieck, J. M., Roden, M., and Herder, C. (2023). Diabetes and climate change: Current evidence and implications for people with diabetes, clinicians and policy stakeholders. *Diabetologia*, 66(6), 1003–1015. <https://doi.org/10.1007/s00125-023-05901-y>

- Reardon, S. F. (2011). The widening academic achievement gap between the rich and the poor: new evidence and possible explanations. In Duncan, G. J., and Murnane, R. J. (Eds.). (2011). *Whither opportunity? Rising inequality, schools, and children's life chances* (pp. 91–116). Russell Sage Foundation.
- Rendall, M. S., Weden, M. M., Favreault, M. M., and Waldron, H. (2011). The protective effect of marriage for survival: a review and update. *Demography*, 48(2), 481–506. <https://doi.org/10.1007/s13524-011-0032-5>
- Rodgers, J. L., Jones, J., Bolleddu, S. I., Vanthenapalli, S., Rodgers, L. E., Shah, K., Karia, K., and Panguluri, S. K. (2019). Cardiovascular risks associated with gender and aging. *Journal of Cardiovascular Development and Disease*, 6(22). <https://doi.org/10.3390/jcdd6020019>
- Ryti, N. R. I., Guo, Y., and Jaakkola, J. J. K. (2016). Global association of cold spells and adverse health effects: A systematic review and meta-analysis. *Environmental Health Perspectives*, 124(1), 12–22. <https://doi.org/10.1289/ehp.1408104>
- Schifano, P., Leone, M., De Sario, M., Dedonato, F., Bargagli, A. M., Dippoliti, D., Marino, C., and Michelozzi, P. (2012). Changes in the effects of heat on mortality among the elderly from 1998-2010: Results from a multi-center time series study in Italy. *Environmental Health: A Global Access Science Source*, 11(1). <https://doi.org/10.1186/1476-069X-11-58>
- Schneider, A., and Breitner, S. (2016). Temperature effects on health – current findings and future implications. *EBioMedicine*, 6, 29–30. <https://doi.org/10.1016/j.ebiom.2016.04.003>
- Sowa, A., Tobiasz-Adamczyk, B., Topór-M dry, R., Poscia, A., and La Milia, D. I. (2016). Predictors of healthy ageing: Public health policy targets. *BMC Health Services Research*, 16(5). <https://doi.org/10.1186/s12913-016-1520-5>
- Sun, Z., Chen, C., Xu, D., and Li, T. (2018). Effects of ambient temperature on myocardial infarction: A systematic review and meta-analysis. *Environmental Pollution*, 241, 1106–1114. <https://doi.org/10.1016/j.envpol.2018.06.045>
- Teyton, A., Tremblay, M., Tardif, I., Lemieux, M. A., Nour, K., and Benmarhnia, T. (2022). A longitudinal study on the impact of indoor temperature on heat-related symptoms in older adults living in non-air-conditioned households. *Environmental Health Perspectives*, 130(7). <https://doi.org/10.1289/EHP10291>
- Tobías, A., Hashizume, M., Honda, Y., Sera, F., Ng, C. F. S., Kim, Y., Roye, D., Chung, Y., Dang, T. N., Kim, H., Lee, W., Íñiguez, C., Vicedo-Cabrera, A., Abrutzky, R., Guo, Y., Tong, S., de Sousa Zanotti Stagliorio Coelho, M., Saldiva, P. H. N., Lavigne, E., . . . Gasparrini, A. (2021). Geographical variations of the minimum mortality temperature at a global scale. *Environmental Epidemiology*, 5(5), E169. <https://doi.org/10.1097/EE9.000000000000169>
- Turner, L. R., Barnett, A. G., Connell, D., and Tong, S. (2012). Ambient temperature and cardiorespiratory morbidity: A systematic review and meta-analysis. *Epidemiology*, 23(4), 594–606. <https://doi.org/10.1097/EDE.0b013e3182572795>
- Uejio, C. K., Wilhelm, O. V., Golden, J. S., Mills, D. M., Gulino, S. P., and Samenow, J. P. (2011). Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health and place*, 17(2), 498–507. <https://doi.org/10.1016/j.healthplace.2010.12.005>
- Urban, A., Davidkiová, H., and Kyselý, J. (2014). Heat- and cold-stress effects on cardiovascular mortality and morbidity among urban and rural populations in the Czech Republic. *International journal of biometeorology*, 58(6), 1057–1068. <https://doi.org/10.1007/s00484-013-0693-4>
- Urtamo, A., Jyväkorpi, S. K., and Strandberg, T. E. (2019). Definitions of successful ageing: A brief review of a multidimensional concept. *Acta Biomedica*, 90(2), 359–363. <https://doi.org/10.23750/abm.v90i2.8376>
- van Hoof, J., Marston, H. R., Kazak, J. K., and Buffel, T. (2021). Ten questions concerning age-friendly cities and communities and the built environment. *Building and Environment*, 199. <https://doi.org/10.1016/j.buildenv.2021.107922>
- Vésier, C., and Urban, A. (2023). Gender inequalities in heat-related mortality in the Czech Republic. *International Journal of Biometeorology*, 67(8), 1373–1385. <https://doi.org/10.1007/s00484-023-02507-2>
- Wan, K., Feng, Z., Hajat, S., and Doherty, R. M. (2022). Temperature-related mortality and associated vulnerabilities: Evidence from Scotland using extended time-series datasets. *Environmental Health*, 21(1), 99. <https://doi.org/10.1186/s12940-022-00912-5>
- Wang, T., Zhao, Z., Wang, G., Li, Q., Xu, Y., Li, M., Hu, R., Chen, G., Su, Q., Mu, Y., Tang, X., Yan, L., Qin, G., Wan, Q., Gao, Z., Yu, X., Shen, F., Luo, Z., Qin, Y., . . . Wang, W. (2021). Age-related disparities in diabetes

- risk attributable to modifiable risk factor profiles in Chinese adults: a nationwide, population-based, cohort study. *The Lancet Healthy Longevity*, 2(10), e618–e628. [https://doi.org/10.1016/S2666-7568\(21\)00177-X](https://doi.org/10.1016/S2666-7568(21)00177-X)
- Wanka, A., Arnberger, A., Allex, B., Eder, R., Hutter, H. P., and Wallner, P. (2014). The challenges posed by climate change to successful ageing. *Zeitschrift für Gerontologie und Geriatrie*, 47(6), 468–474. <https://doi.org/10.1007/s00391-014-0674-1>
- Westaway, K., Frank, O., Husband, A., McClure, A., Shute, R., Edwards, S., Curtis, J., and Rowett, D. (2015). Medicines can affect thermoregulation and accentuate the risk of dehydration and heat-related illness during hot weather. *Journal of Clinical Pharmacy and Therapeutics*, 40(4), 363–367. <https://doi.org/10.1111/jcpt.12294>
- Williams, S., Bi, P., Newbury, J., Robinson, G., Pisaniello, D., Saniotis, A., and Hansen, A. (2013). Extreme heat and health: Perspectives from health service providers in rural and remote communities in South Australia. *International Journal of Environmental Research and Public Health*, 10(11), 5565–5583. <https://doi.org/10.3390/ijerph10115565>
- World Health Organization. (2002). Active ageing: a policy framework. *The Aging Male* 5(1), 1–37. <https://doi.org/10.1080/tam.5.1.1.37>
- Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., and Tong, S. (2012). Ambient temperature and morbidity: A review of epidemiological evidence. *Environmental Health Perspectives*, 120(1), 19–28. <https://doi.org/10.1289/ehp.1003198>