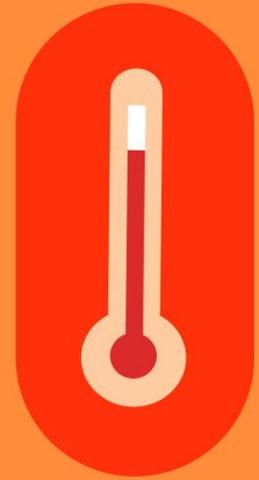




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Heat Morbidity and Mortality in Wales

A literature review of UK and International evidence to guide surveillance

13th November 2025



Key Findings

Heat affects health beyond heatwaves.

Moderate heat, hot nights, and cumulative exposure all contribute to increased risks of cardiovascular, respiratory, renal, and mental health conditions, even when heatwave thresholds are not met.

Vulnerable groups face disproportionate risks.

Older adults, children, people with chronic conditions, and those in socioeconomically deprived or urban areas are consistently shown to be more affected by heat-related health outcomes.

Wales needs tailored, routine heat-health surveillance.

Unlike England and other countries, Wales lacks systematic monitoring of heat-related morbidity and mortality. The review recommends adopting advanced modelling (DLNM), expanding exposure metrics, and establishing annual reporting to support climate adaptation.



Executive Summary

In Wales, the ten hottest years on record have all occurred since the early 2000s, with temperatures continuing to rise due to climate change ^[1]. Projections indicate that this warming trend will persist, leading to more frequent, intense, and prolonged heat events in the coming decades ^[2]. While the global burden of heat-related morbidity and mortality is increasingly recognised, the specific health impacts in Wales remain largely underexplored. The UK Climate Change Risk Assessment 2022 (CCRA3) has identified temperature-related health effects as a growing concern, particularly in relation to the risks of heat-related mortality and the resilience of health and social care systems ^[3]. However, in Wales there is a lack of tailored evidence and surveillance systems for heat morbidity and mortality.

This literature review identifies strong associations between various heat exposures - heatwaves, moderate heat, hot nights (diurnal temperature variation), and cumulative heat, and increased morbidity and mortality. Affected outcomes include cardiovascular, respiratory, renal, liver, and mental health conditions, as well as adverse pregnancy outcomes and direct heat-related illnesses such as heatstroke. Vulnerable groups include older adults, children, socioeconomically deprived populations, and some ethnic minorities. Confounding factors such as air pollution and humidity often amplify heat impacts.

The UK Health Security Agency (UKHSA) provides annual heat mortality reports, but Wales currently lacks equivalent routine monitoring. International models from France, the USA, and Australia offer more advanced surveillance systems. Most studies use time-series or case-crossover designs, with Distributed Lag Non-linear Models (DLNM) commonly applied to capture delayed and nonlinear effects.

Aim

This non-systematic literature review aims to identify the heat exposures that are most likely to lead to an increase in adverse health outcomes and to explore the health indicators that best capture the extent of heat-related morbidity and mortality. By synthesising existing international and UK-based evidence, this review seeks to highlight key risk factors and gaps in current understanding, while providing recommendations for improved public health surveillance to support climate adaptation efforts in Wales.

Key Recommendations

1. Apply DLNM to estimate heat-related health risks across Wales and provide descriptive statistics on the variation in both heat exposures and health outcomes by time, place, and person
2. Include diverse heat exposure types in analyses.
3. Focus on vulnerable populations by age, health status, and socio-demographics.



4. Establish annual heat-health reporting in Wales.
5. Define out-of-scope elements for future research.
6. Engage stakeholders early in the surveillance process.



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Methods

This review was led by the Integrated Climate and Environmental (ICE) Surveillance Team, within the Communicable Disease Surveillance Centre (CDSC), PHW. It was reviewed by the Climate Change Surveillance Subgroup (includes members from the following: PHW, Welsh Government, ONS and representatives of health board Directors of Public Health, local authority Environmental Health Officer representative, and the UK Health Protection Research Unit).

The review was conducted using a non-systematic, narrative approach with the aim of synthesising current knowledge on the relationship between heat exposure and health, with a focus on heat-related morbidity and mortality. While not exhaustive, the review sought to incorporate a wide range of relevant studies, reports, and policy documents to reflect the scope of the topic.

Data Sources

1. Scientific Databases: Searches were conducted in PubMed, Scopus, NHS E-library and Web of Science to identify peer-reviewed literature.
2. Government and Institutional Websites: UKHSA, PHW, UK Met Office, Santé Publique France, Australian Bureau of Meteorology and Department of Health, and the U.S. Centers for Disease Control and Prevention (CDC).

Policy Documents:

- UK Climate Change Risk Assessments (CCRA3).

Inclusion Criteria:

- Studies focused on heat health outcomes including morbidity and mortality.
- Meteorological information relevant to heat exposures, primarily from UK or comparable settings.
- Worldwide studies were included due to limited UK-specific evidence.

Exclusion Criteria:

- Studies focusing solely on cold weather impacts or climate-sensitive vector-borne diseases.
- Non-human studies.



Heat Exposures That Can Impact Health

In this review, a "heat event" is defined broadly to capture the different ways in which elevated temperatures impact health. Specifically, we consider four types of heat exposures: heatwaves, moderate heat, diurnal temperature and cumulative heat exposure.

Heatwaves

In the UK, the Met Office defines a heatwave as "three consecutive days in which the daily maximum temperature exceeds a heatwave threshold defined for recognised counties of the United Kingdom, ranging between 25 and 28°C" (figure 1) [4]. These thresholds are based on the 90th percentile of the climatological distribution of daily maximum temperatures for each region, reflecting local climatic norms. Regional variation in threshold temperatures accounts for geographical and environmental differences; for example, London's threshold is set at 28°C due to the urban heat island effect, whereas it is 25°C in parts of Wales, Scotland, and Northern Ireland. As acknowledged by the Met Office, not all heatwaves are the same, events can vary in magnitude, duration, geographic extent, and severity, with implications for population health risk and public health response.

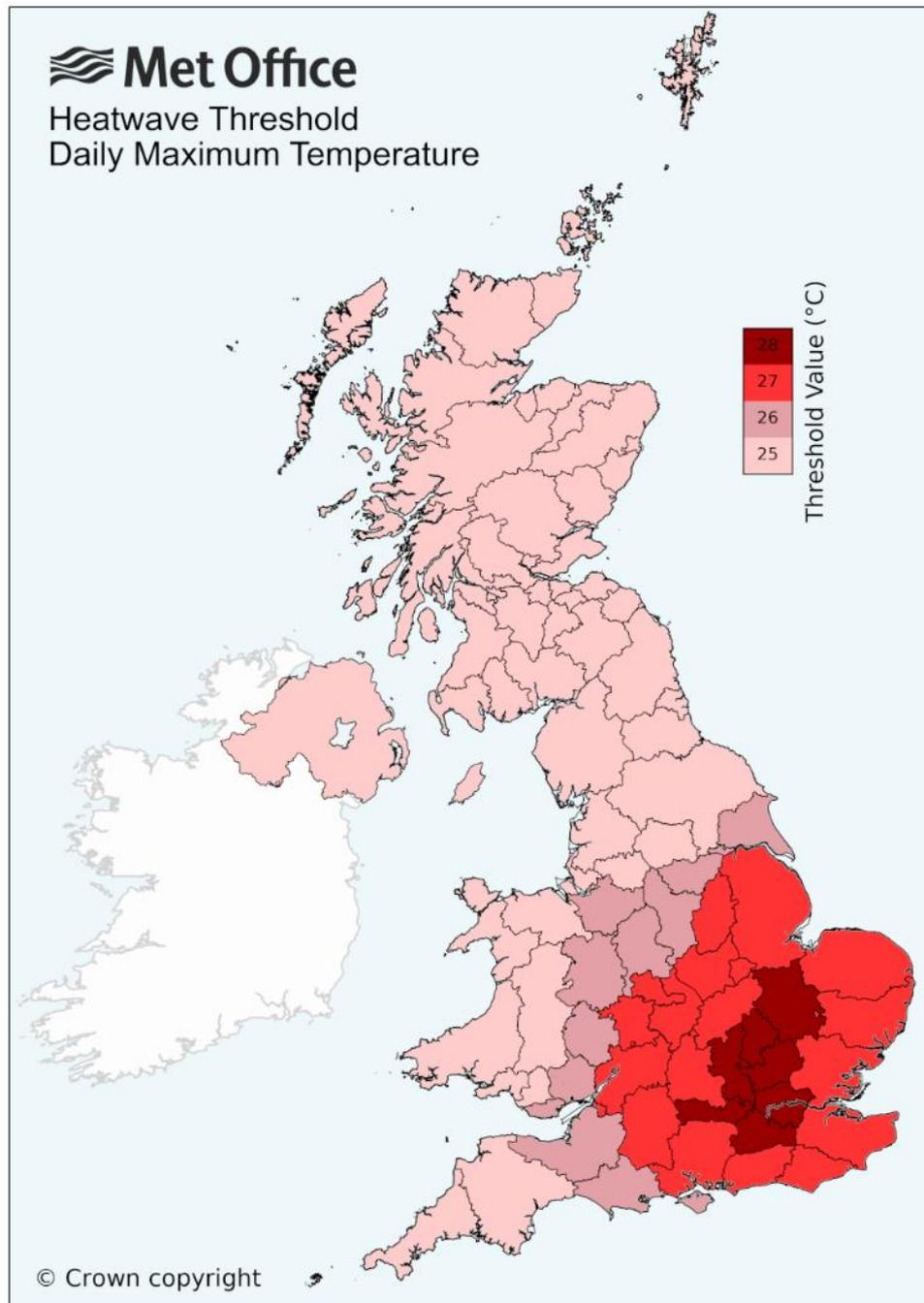


Figure 1. Met Office regional temperature thresholds for 3 consecutive days defining heatwaves in the UK

In the UK, heatwaves have been linked to measurable increases in mortality and healthcare demand. For instance, UKHSA reported approximately 2,500 excess deaths across England during the summer heatwaves of 2020, with the highest impacts seen during the August event [5]. Cardiovascular and respiratory illnesses are the most frequently recorded causes of heat-related deaths, particularly among older adults. London and other urban areas often experience more intense effects due to the urban heat island phenomenon, which can exacerbate high nighttime temperatures and reduce physiological recovery during sleep. While England has relatively consistent surveillance



of heatwave-related mortality, other UK nations, including Wales, have historically lacked systematic tracking making it more difficult to quantify region-specific risks. In addition to mortality, heatwaves in the UK are associated with increased healthcare use, including consultations for heat-related illnesses such as heat exhaustion and heatstroke. During the 2013 heatwave, syndromic surveillance systems recorded notable spikes in heat illness across emergency departments and GP services, especially among children and older adults [6]. However, morbidity data overall remain underreported and less consistently monitored. The effects of heatwaves are influenced not just by peak daytime temperatures, but also by the duration of heat, insufficient nighttime cooling, and population adaptation.

Diurnal Temperature

Diurnal temperature refers to the variation between daytime maximum and nighttime minimum temperatures within a 24-hour period. In the context of heat events, a reduced diurnal temperature range, where nighttime temperatures remain high after hot days can have important health implications. While nighttime temperatures are generally lower than daytime temperatures, they have nonetheless been shown to significantly impact heat-related mortality. During heat events, public health attention often focuses on high daytime temperatures; however, studies have demonstrated that elevated nighttime temperatures are also critical, particularly due to their effect on physiological recovery and sleep quality [7]. One study found that the relative risk of mortality was higher on hot nights following hot days compared to cool nights following hot days, especially for individuals with chronic ischaemia, stroke, infectious respiratory diseases, nervous system conditions, mental health disorders, cardiovascular and respiratory diseases [8].

Age-specific analysis further showed that mortality risk was particularly elevated among those aged 65–74 and 75+, when hot nights (defined in this analysis as minimum temperatures above 16°C following days with maximum temperatures above 25°C) followed hot days. In contrast, cooler nights appeared to mitigate mortality risks. Although these findings highlight the significance of high nighttime temperatures during heat events, it is important to note that the study was conducted in London, where the urban heat island effect may amplify both temperatures and their health impacts compared to rural or less densely populated areas.

Moderate Heat

Moderate heat, even when temperatures do not reach extreme thresholds, can significantly contribute to heat-related morbidity and mortality. A large multi-country observational study, which analysed over 74 million deaths across various climate zones, found most heat-attributable deaths were associated with moderately elevated temperatures rather than extreme heat events [9]. While the relative risk of mortality was higher during extreme heat, these events occurred less frequently. In contrast, moderate heat, though associated with lower daily risks, occurred more often and therefore contributed a greater share of the overall health burden.



Although there is no official definition of moderate heat for Wales, the study classified heat exposure based on the location-specific minimum mortality temperature (MMT) the temperature associated with the lowest mortality risk. Temperatures above the MMT were considered "heat" and divided into moderate (from MMT to the 97.5th percentile) and extreme (above the 97.5th percentile). For the UK, this would typically translate to daily mean temperatures between approximately 18°C and 25°C representing moderate heat, although exact thresholds would depend on local climate data.

Highlighting moderate heat deaths is important so as not to restricting public health responses to declared heatwaves alone. Sustained exposure to moderately high temperatures, especially outside of formal alert periods can still pose serious health risks, particularly to vulnerable groups such as older adults and those with chronic illnesses.

Cumulative Heat Exposure

Cumulative heat exposure has been shown to increase the risk of heat-related morbidity and mortality. Rather than a single hot day, it is the duration and persistence of heat over several consecutive days that can lead to a build-up of physiological stress. For example, a multi-community study from the U.S. found that mortality risk became significantly elevated only when heat persisted for four or more consecutive days, while shorter heatwaves (e.g., two days) had minimal additional impact ^[10]. Although specific thresholds for Wales are not defined, studies often classify cumulative exposure using three or more days above a location-specific high-temperature threshold, such as the 75th or 90th percentile of summer temperatures ^[9]. In a UK context, this may correspond to several days with daily mean temperatures exceeding ~20–22°C but would be location dependent. Understanding the cumulative effects of heat is essential, as repeated or sustained exposure may reduce individuals' ability to physiologically recover between hot days.



At Risk Populations

Scope Of Disease Outcomes Considered

This analysis focuses on the acute and subacute effects of heat exposure, that is, health outcomes that occur within hours to days of elevated temperatures, such as heat stroke, cardiovascular events, respiratory exacerbations, and emergency hospital admissions. The report prioritises outcomes that can be more directly and immediately linked to temperature changes, particularly those affecting vulnerable populations and/or those with preexisting comorbidities.

Cardiovascular Disease

In ambient temperatures, the vascular system can experience significant strain. Cardiac demand increases as the body regulates temperature through vasodilation, and a sustained need for oxygen can lead to ischaemia, infarction, and subsequent cardiac collapse ^[11].

A meta-analysis of studies examining the effects of high temperatures and heatwaves on heart-related diseases across different Köppen-Geiger climate zones (classification of climate regions; tropical, dry, temperate, continental and polar), found for every 1°C increase in temperature, mortality from cardiovascular diseases (cardiovascular disease, coronary heart disease, acute coronary heart disease, heart failure, stroke, cardiac arrest) significantly increased by 2.1% (RR 1.021 [95% CI: 1.020–1.023]), there was no statistically significant increase in mortality risk for hypertensive diseases (RR 1.032 [95% CI: 0.998–1.066] ^[12]). Those living in a tropical climate had higher cardiovascular related mortality, but this was not significantly higher than other climate zones. Additionally, those ≥ 65 years of age or living in low- and medium-income countries also had higher mortality ^[12].

For morbidity, the study found the pooled estimates to give a 0.5% increase in risk of cardiovascular disease for every 1°C temperature rise. The greatest effect was found for out-of-hospital cardiac arrest (RR 1.021 [95% CI: 1.010–1.032]), whilst a protective effect was noted for hypertensive diseases (RR 0.949 [95% CI: 0.928–0.970]). The analysis also highlighted the difference in heat cardiovascular mortality across categories of heatwaves; high (97th to 99th temperature percentile), medium (94th to 96th percentile), and low intensity (90th to 93rd percentile;). It found that individuals with heart conditions had a significantly increased risk across all categories: RR 1.189 [95% CI: 1.09–1.269] for high-intensity heatwaves, RR 1.088 [95% CI: 1.058–1.119] for medium-intensity, and RR 1.067 [95% CI: 1.056–1.078] for low-intensity heatwaves. The effect was lower and not significant for cardiovascular disease morbidity across the heatwave categories. Due the varying degree of climate zones analysed for the meta-analysis it is difficult to conclude how the risk would vary from one temperature threshold in one country to another, but the study provides strong evidence of worldwide associations of cardiovascular disease with increasing temperatures for all climates ^[12].

In the UK, analysis of cardiac deaths that occurred in 2020 was conducted over three heatwave events (categorised as Central England Temperature (CET) reaching 20 °C including a day preceding and the following day). When 20 °C was reached an increase in deaths was observed over these periods, with numbers below 100 people per heatwave



but notably there was a higher risk for those 65+, particularly when nighttime temperatures were $> 20^{\circ}\text{C}$ [13].

Stroke

Stroke, a major subtype of cardiovascular disease, has received growing attention in research exploring the health impacts of ambient temperature. A 2023 meta-analysis examining the association between ambient temperature and cerebrovascular outcomes reported an increased risk (RR 1.03 [95% CI: 0.95–1.27]) for mortality and (RR 1.04 [95% CI: 0.97–1.10]) for morbidity related to major adverse cerebrovascular events, although the increase wasn't significant and stroke-specific outcomes were not separately identified. Interestingly, the risk was higher in high-income countries, with an RR of 1.16 [95% CI: 1.00–1.34] for mortality and 1.14 [95% CI: 0.97–1.33] for morbidity, compared to lower estimates in low- and middle-income countries: RR of 1.05 [95% CI: 0.98–1.12] for mortality and 1.07 [95% CI: 1.00–1.16] [14].

Respiratory Diseases

The impact of heat on respiratory conditions has been widely studied, with heat events consistently linked to an increase in respiratory morbidity and mortality. The physiological stress induced by high temperatures, combined with air pollution, can exacerbate pre-existing respiratory conditions such as asthma, chronic obstructive pulmonary disease (COPD), and bronchitis. Exposure to extreme heat can also worsen respiratory symptoms, leading to higher rates of emergency department (ED) visits, hospitalisations and mortality, however, some research has highlighted a protective effect between heat and respiratory linked ED visits [15-19].

A US based study of 24.4 million Medicare beneficiaries aged ≥ 65 across 120 U.S. cities from 2000 to 2017 identified over 3.2 million hospitalisations with a primary respiratory diagnosis during the warm season (June–September) [20]. The leading causes were respiratory tract infections (RTIs), accounting for 39% of cases, and chronic respiratory disease or respiratory failure (CRD/RF).

The exposure–response relationship showed a monotonic increase in respiratory hospitalisations with temperatures above the 50th percentile of local warm-season distributions. Nationwide, a 7-day cumulative exposure to high temperatures (95th percentile vs. median) was associated with a 1.22% increase [95% CI: 0.42–2.03%] in all-cause respiratory hospitalisations, primarily driven by RTIs [1.84%; 95% CI: 0.70–3.01%] and CRD/RF [1.17%; 95% CI: –0.09 to 2.44%].

The strongest relative risk occurred on lag day 0, with a 2.1% increase [95% CI: 1.5–2.8%] in hospitalisations, followed by risk attenuation on subsequent days, consistent with short-term displacement effects (an acceleration of hospitalisations/deaths among already vulnerable individuals who would have been admitted soon regardless of heat exposure). Nationwide, an estimated 11,710 excess respiratory hospitalisations [95% CI: 8,290–14,670] were attributable to temperatures above the 50th percentile during the study period.

While no consistent effect modification by sex or race was observed at the national level, risk was most elevated among those aged 85 and older. Among Black beneficiaries, the heat-related risk persisted through lag days 0 and 1, unlike the general pattern of single-



day spikes. City specific variability in temperature exposure (0.1°C to 42.6°C across sites) explained some heterogeneity in effect estimates, with higher risks generally observed in warmer and more variable climates.

In terms of mortality, heat-related respiratory deaths also show a clear upward trend during periods of extreme heat. A study examining heat-related respiratory mortality in England, Wales, Germany, and Norway found significant associations between temperature increases and respiratory deaths [21]. In England and Wales, an increase in daily mean temperature from the 75th to the 99th percentile of the local temperature distribution was associated with a 27% increase in respiratory mortality (RR = 1.27 [95% CI: 1.19–1.3]). In Germany, the same temperature increase was linked to a 29% increase in respiratory mortality (RR = 1.29 [95% CI: 1.21–1.37]), while in Norway, the increase was 19% (RR = 1.19 [95% CI: 1.13–1.25]).

Chronic Obstructive Pulmonary Disease

Among respiratory conditions, COPD frequently shows higher mortality rates during extreme heat events. [16, 22-23]. A nationwide study in England between 2007 and 2018 found that for every 1°C increase above a threshold temperature of 23.2°C, the risk of COPD hospitalisation increased by 1.47% (95% Credible Interval (CrI): 1.19% to 1.73%) [16]. This association highlights the vulnerability of individuals with COPD to heat exposure, with approximately 1,851 COPD hospitalisations annually attributed to temperatures exceeding this threshold. Importantly, the study found spatial variations in risk, with regions in the Southeast of England exhibiting a higher hospitalisation risk compared to the Southwest, indicating that geographical and contextual factors influence vulnerability. Furthermore, there was evidence suggesting that age and sex may modify the effect, with men aged 65–74 years showing a slightly higher risk increase 1.75% [95% CrI: 1.13% to 2.41%] compared to younger or older individuals. Contextual characteristics such as green space coverage and urbanicity were associated with lower vulnerability, potentially due to heat-mitigating effects.

Asthma

There are several known environmental factors that increase the risk of exacerbating asthma such as air pollution, allergens, and cold air. However, the significance of the relationship warm temperatures and asthma isn't always clear, often with differences in methodologies and analysis making the extent of the link variable.

Studies from the US, China and South Korea found little to no association between higher ambient temperatures and asthma hospitalisations with other studies from the US, Hong Kong, Brazil, Japan and China finding an association [24-33].

A case-crossover study in England found that, for every 1°C increase in ambient summer temperature, there was an associated increased risk in asthma hospitalisations [17]. Age and sex were found to be significant effect modifiers, with males 16-64 being the most vulnerable and little association for those > 65 years old (Note ages < 5 were not used for the study). Additionally, temporal modifications were evident, with the strongest association between temperature and asthma hospitalisations occurring between 2002 and 2007, while the effects weakened in subsequent years (2008-2013 and 2014-2019). Spatial variations were also noted, with regions such as Yorkshire and the Humber and



East and West Midlands experiencing a higher risk, while populations in the Southwest appeared less vulnerable [17].

Mental Health

Recognising the growing burden of climate-related mental health issues, recent UK public health initiatives such as the UKHSA 2022 call for evidence on climate change and mental health have begun to prioritise this emerging area of concern [34]. A recent systematic review highlights a consistent international association between elevated temperatures and a range of adverse mental health outcomes [35]. The study found suicide is the most frequently reported outcome, with fifteen studies reporting a positive association between higher temperatures and suicide rates. In the UK, a time-series study found suicide risk to be lowest at 18 °C, with increased rates above that threshold [36]. RRs for suicide per 1 °C increase in temperature ranged from 1.01 to 1.37 ($P < 0.05$) with two out of seventeen articles not finding a positive relationship [35, 36-44].

Beyond suicide, the study noted temperature increases have also been associated with psychiatric hospital admissions for mood and psychotic disorders. For bipolar disorder, one study reported that the risk of hospital admission rose sharply above 30.7 °C (RR = 1.51 [95% CI: 1.16-1.97]), and others found positive correlations between admissions and temperature (β coefficient = 0.0022-0.0044, $P < 0.001$) [34, 45-47]. In contrast, evidence for mania and depression was mixed, with some studies showing no statistically significant associations [48-49]. Schizophrenia was another frequently studied condition, with temperature increases linked to symptom exacerbation ($r = 0.52$ - 0.64 , $P < 0.0002$) and hospital admissions ($r = 0.35$, $P < 0.001$) [50-51]. One study found mortality risk among individuals with schizophrenia more than doubled on heatwave days (RR = 2.08 [95% CI: 1.05-4.14]) [52].

Organic mental disorders, including dementia, were also significantly impacted. Admissions for dementia rose during heatwaves, with RRs ranging from 1.21 [95% CI: 1.091-1.349] for heatwaves lasting over three days to 3.62 [95% CI: 1-1.90] for heatwaves lasting over seven days [52-53]. One study reported that mortality among individuals with dementia increased significantly above 18 °C (RR = 1.03 per 1 °C [95% CI: 1.00-1.07]), and another found a dramatic rise during heatwaves (RR = 5.06 [95% CI: 1.20-21.232]) [52,54]. For individuals with substance use disorders, hospitalisation risk did not rise significantly, but mortality did increase, particularly among women aged 15-64 years old (IRR = 3.21 [95% CI: 1.297-7.948]) [52].

In addition to diagnostic-specific outcomes, several studies found an increase in psychiatric emergency visits and general psychological distress during high temperature periods. One Australian study showed that each 1 °C increase in temperature was associated with a significant rise in reported high distress in adults over 45, and another found a linear relationship between psychiatric emergencies and increasing heat [55-56].

Diabetes

Another disease recognised to be associated with heat events is diabetes mellitus [57-64]. Extreme heat can exacerbate diabetes complications by affecting glucose metabolism, insulin sensitivity, and increasing dehydration risk, particularly in vulnerable populations. However, the effects of heat may differ between type 1 and type 2 diabetes due to



variations in insulin dependence, thermoregulation, and metabolic responses [65]. While type 1 diabetes requires strict insulin management, which heat exposure can disrupt, type 2 diabetes is often associated with obesity and cardiovascular comorbidities, which may heighten susceptibility to heat-related stress [66]. However, differences between the two types of diabetes aren't often distinguished when evaluating the impact of high temperatures on these diseases.

In a meta-analysis of forty studies conducted across multiple regions, including Australia, Brazil, Canada, China, Thailand, and the United States, an overall positive association was observed between excessive heat and diabetes-related hospital emergency department admissions [67]. The pooled effect of all associations examined was 1.045 [95% CI: 1.024–1.066], with half (twenty out of forty studies) showing statistical significance. Among studies categorising exposures by different percentile thresholds, significant pooled effects were observed for extreme heat defined as the 95th (RR = 1.096 [95% CI: 1.017–1.182]) and 99th (RR = 1.083 [95% CI: 1.010–1.161]) percentiles for at least two consecutive days, but not for the 90th, 97th, or 98th percentiles. Studies using a case-crossover study design consistently demonstrated significant associations (RR = 1.056 [95% CI: 1.032–1.080]), while time-series studies showed borderline significance (RR = 1.036 [95% CI: 0.996–1.077]). Regionally, pooled effects were strongest in Australia, Brazil, Canada, China, and the United States, but not in Thailand.

Demographic analyses highlight that older adults are particularly vulnerable to heat-related diabetes complications. Several studies reported that individuals aged ≥ 65 years old had a higher risk of diabetes-related hospitalisations compared to younger age groups [68-71]. Among the ten associations examined in older adults, the pooled effect was 1.100 [95% CI: 1.067–1.135], indicating a significant increase in risk. However, studies on racial and ethnic disparities yielded mixed results. While some studies observed higher risks among Asian individuals compared to non-Hispanic White individuals, other studies found no significant racial or ethnic differences [68, 72-73].

For diabetes-specific mortality a meta-analysis examining associations between extreme temperatures and diabetes outcomes, including 32 studies revealed that heat exposure had a more pronounced effect on diabetes mortality (RR = 1.139, [95% CI 1.089-1.192]) than for diabetes morbidity (RR = 1.012 [95% CI: 1.004-1.019]) [74]. Subgroup analysis found a stronger relationship between heat exposure and diabetes outcomes in the elderly population (≥ 60 years) (RR = 1.040 [95% CI: 1.017–1.064]), indicating that older adults are particularly vulnerable to the adverse effects of heat.

Overall, the existing literature provides strong evidence that increasing ambient temperatures contribute to a rise in diabetes-related hospital admissions and emergency department visits, with older adults being particularly vulnerable. While the effects of heat exposure on type 1 and type 2 diabetes may vary, the overall impact on morbidity and mortality is evident.

Pregnancy and Birth

Maternal and newborn health are frequently overlooked when it comes to heat exposure. This could be partially due to the complex physiological and social factors influencing both mother and baby, as well as a lack of sufficient evidence on the impact of heat and



heatwaves on this vulnerable group. During pregnancy, physiological factors such as an increased body mass, reduced ability to thermoregulate, and increased circulatory stress can make pregnant women more susceptible to heat. Additionally, social vulnerabilities, such as lower incomes and unsuitable working conditions, can further exacerbate risks.

Preterm Births, Low Birthweight And Stillbirth

Results from a meta-analysis that include 47 studies, 40 documented an association between high temperatures and an increased risk of preterm birth [75]. Six studies showed the odds of preterm birth during a heatwave were 1.16 times higher compared to non-heatwave days [95% CI: 1.10 to 1.23]. Studies that looked at gradual increases in temperature had a 5% higher increase in odds of preterm birth (OR 1.05 [95% CI: 1.03 to 1.07]) for every rise in 1°C temperature. When considering temperature exposure across an entire trimester or the whole pregnancy, the OR for preterm birth was 1.14 [95% CI: 1.11 to 1.16].

The studies analysed showed the odds of preterm birth are most significantly affected by heat exposure during the final weeks of pregnancy, though positive associations were observed in all lag windows, including during the month of conception or preconception [75]. In low- and middle-income countries, heat exposure was associated with preterm birth in the first and second trimesters, while in the European Union and Central Asia, associations were primarily found in the last week of pregnancy.

In the same analysis the authors reviewed studies linking low birthweight to high temperatures and found that 10 of 16 studies reported an increased risk of low birth weight at higher temperatures with 1 study finding the opposite effect and 5 with no significant findings [75]. Due to variations in study methodologies, there were no meta-analysis performed but it was concluded that weight changes in newborns were minimal, but the greatest observations were seen in younger mothers (≤ 22 years) and older mothers (≥ 40 years), as well as individuals from marginalised groups, including Black, Indigenous, and Hispanic populations, and those of lower socioeconomic status.

For all eight studies that reviewed still births, the meta-analysis found an increased risk at higher temperatures with the strongest association observed in the final week or month of pregnancy. For every 1°C rise in temperature, still birth risk increased by RR 1.05 [95% CI: 1.01-1.08].

These studies have further reinforced the link between heat exposure and adverse pregnancy outcomes, with these effects appearing more pronounced among vulnerable populations, including younger and older mothers, racial minorities, individuals with lower socioeconomic status, and those with preexisting health conditions.

Renal Disease

Exposure to elevated temperatures often results in dehydration, which can precipitate the onset of renal disease.

In a UK case-crossover study, researchers found a significant increase in the risk of acute kidney injury (AKI) with rising temperatures. The study revealed a 62% higher likelihood of AKI on days when the maximum temperature reached 32°C compared to 17°C [76].



Additionally, the study observed a 28.6% increase in AKI cases during a 7-day heatwave in July 2021.

Liver Disease

Similar to renal disease, high ambient temperatures can lead to exacerbation of liver damage, particularly in individuals experiencing heatstroke, which can lead to acute liver injury and failure. The Acute Liver Failure Study Group (2007) highlighted the association between heatstroke and acute liver injury, revealing that patients suffering from severe hyperthermia during heatwaves often developed significant liver dysfunction [77]. This case series demonstrated that the rapid increase in body temperature, combined with dehydration and the systemic inflammatory response, contributed to hepatic cell injury. In severe cases, heatstroke led to fulminant hepatic failure, requiring intensive care.

Heatstroke

Heatstroke represents an acute but severe form of heat-related illness and occurs when the body's thermoregulatory mechanisms fail, typically when core temperatures exceed 40°C. It is a life-threatening condition characterised by central nervous system dysfunction, including altered mental status, seizures, and potentially coma. Heat stroke is broadly categorised into two types: classic (non-exertional), which predominantly affects vulnerable (higher likelihood of exposure or reduced ability to respond.) and susceptible (higher biological sensitivity to heat once exposed) populations such as the elderly during heat waves, and exertional, which occurs in younger, healthier individuals during intense physical activity in hot environments [78].

Owing to the relatively small series of patients admitted to hospital care and the rapid onset of disease in cases of heatstroke, it can be challenging to collect comprehensive data during heat events. However, one study that analysed a large cohort of patients during the European heatwaves of 2003, found that in France, a total of 345 patients were admitted to 80 ICUs with heatstroke, representing 81.9% of all heatstroke ICU admissions nationwide during that period [79]. The study revealed a high mortality rate, with 56.5% of patients dying in the ICU, and an overall 62.6% in-hospital mortality rate. The study also highlighted that air conditioning in the ICU was associated with improved survival outcomes.

Population Vulnerabilities

Socio-Economic Deprivation

The health impacts of socioeconomic factors during heat events are multifactorial and location specific making them difficult to quantify and have been under reported. There are many factors that contribute to the deprivation of a community, for instance, income, housing, education, health etc. In Wales, 8 domains are considered for the Welsh Index of Multiple Deprivation (WIMD): income, employment, health, education, access to services, housing, community safety and physical environment. These interconnected factors can influence both exposure and vulnerability to heat, highlighting the need for context-specific analyses that incorporate deprivation indices like the WIMD to better understand and address heat-health inequalities.



For studies in the UK on heat morbidity and mortality, there have been inconsistent links between deprivation and heat events^[80-81]. A small-area analysis of cardiorespiratory diseases during periods of warm temperatures in England and Wales found that while the proportional effects of heat on mortality were similar across rural and urban areas, deprived districts experienced a larger absolute impact^[82]. While the effects of temperature did not differ substantially by deprivation at a proportional level, the larger number of deaths in more deprived areas led to a higher absolute increase in mortality. Women, especially those aged ≥ 85 years, were found to be more vulnerable to the effects of heat, with the most deprived areas seeing the highest absolute mortality increases^[82]. Another England and Wales study focusing on all-cause heat mortality recorded a clear association between socioeconomic deprivation and heat-related excess mortality, with higher standardised mortality rates observed in more deprived areas^[83]. Although cold-related impacts were generally greater in magnitude, heat-related mortality was still elevated in socioeconomically disadvantaged communities, indicating that deprivation is a consistent modifier of vulnerability to temperature extremes, even when accounting for demographic differences^[83].

Ethnicity

Classifying people by race or ethnicity in epidemiological research is complex and often subjective, as these identities are multifaceted and ideally self-reported. While physiological differences do not appear to account for disparities in heat-related health outcomes, factors like cultural adaptation, social inequalities, and systemic discrimination play a significant role^[84]. As such, modifiable social and environmental factors likely contribute more to observed ethnic disparities in heat vulnerability than inherent biological differences.

Several studies have highlighted the role of ethnicity in shaping vulnerability to heat-related morbidity and mortality in both the UK and internationally. Research has identified certain cities such as Birmingham, Nottingham, Leicester, and London boroughs like Newham, Tower Hamlets, and Hackney as having communities most vulnerable to heat, with a large representation of ethnic minorities^[85]. The increased vulnerability is attributed to socioeconomic factors, including lower-quality housing and reduced access to green spaces, which can amplify heat exposure. Internationally, evidence from countries such as the USA and Australia has shown elevated heat-related risks among ethnic minorities, including African American, Hispanic, and Indigenous populations, who often face structural inequalities in housing, healthcare access, and occupational exposure^[86-89]. Ethnicity often overlaps with socioeconomic and environmental inequalities, which can compound vulnerability to heat. These intersecting factors stress the importance of considering ethnicity not in isolation, but as part of broader social determinants of health in climate-related health risk assessments.

Age

Most research on age-related heat-health impacts tends to focus on adults, with fewer studies investigating the effects on adolescents and children. Physiologically, children are vulnerable to heat-related health issues due to their smaller surface-to-mass ratios, rapid growth, and lower capacity to regulate core body temperature. These factors make them particularly susceptible to heat stress and related disorders.



A scoping review examining the impacts of heat on child morbidity in the US, Canada, and the UK found positive associations between elevated temperatures and several health issues in children, including dehydration, electrolyte imbalance, general symptoms, digestive disorders, asthma, wheezing, and injuries ^[15]. The review noted that the effects were more pronounced and statistically significant during heat events, defined by maximum daily temperatures (T_{max}) and mean daily temperatures (T_{mean}) of heatwave days, as compared to lag days following heat events. Interestingly, the review also identified a protective effect for ED visits related to respiratory diseases on hotter days, although this was less consistent across studies.

Regarding mental health, studies on heat and children's psychological well-being yielded mixed results. One study observed a higher number of ED visits for self-inflicted injuries and suicides on days with elevated daily mean temperatures (T_{mean}) among children aged 8–18 years, indicating that heat exposure may exacerbate mental health crises in vulnerable populations.

Heat-related mortality studies in children are more limited, often aggregating data into larger age groups due to the small number of child deaths. However, in regions with warmer climates, such as parts of Africa, the effects of extreme heat on child mortality can be more pronounced. For example, across three regions in Africa, child mortality (ages 0–5 years) during heat events was recorded at 6.65 deaths per 1,000 children, underscoring the significant impact of heatwaves on younger populations in such regions ^[90].

Older adults are particularly vulnerable to the health impacts of extreme heat, with risk increasing significantly with age. A pan-European study examining summer 2022 estimated a steep rise in heat-related mortality with advancing age ^[91]. The study identified an optimum temperature range (17–19°C) at which mortality risk was lowest and found that RR of death increased both above and below this range, with steeper slopes observed in older populations.

During the summer of 2022 alone, heat exposure was associated with 36,848 deaths in individuals aged 80+, compared to 9,226 in those aged 65–79 and 4,822 in those under 65. Mortality rates also scaled dramatically with age, reaching 1,684 deaths per million in the 80+ age group, versus 160 per million (65–79) and 16 per million (0–64) ^[91]. Women in older age groups, particularly those 80+, exhibited substantially higher heat-related mortality than men, suggesting both biological and social vulnerabilities.

Geographically, Southern European countries (such as Italy, Greece, and Spain) experienced the highest mortality rates, aligning with the strongest temperature anomalies, which peaked between mid-July and mid-August ^[91]. Notably, these weeks alone accounted for over 60% of the entire summer's heat-related deaths, illustrating how short, intense heat periods disproportionately affect the most vulnerable.

Sex

Sex differences in heat-related morbidity and mortality have been explored in various studies, revealing important distinctions in how men and women are impacted by heat exposure.



A meta-analysis examining heat illness (HI) incidence found that men had a significantly higher rate of HI compared to women. The incidence rate ratio (IRR) for men was notably elevated across different age groups, levels of severity, and occupational environments [92]. This higher risk for men may be attributed to behavioural and psychological factors, rather than just physiological differences, as men tend to engage in outdoor or physically demanding work more frequently, which increases their exposure to extreme heat.

On the other hand, a separate analysis focusing on mortality during heatwaves indicated that women have a slightly higher risk of death compared to men. The RR for women during heat events was found to be higher, suggesting that gender differences may influence heatwave-related mortality [21]. The increased risk in women could be linked to physiological factors such as hormonal differences, comorbidities that disproportionately affect older women, or social factors like caregiving roles that may lead to limited access to cooling resources.



Confounders And Effect Modifiers

When examining the health impacts of extreme heat, it is essential to account for a range of potential confounders and effect modifiers that can influence observed associations. Confounders are variables that are associated with both temperature exposure and the health outcome of interest but are not on the causal pathway, and thus must be adjusted for to avoid biased estimates. Common confounders in heat–health studies include air pollution (e.g., PM_{2.5}, ozone), day of the week, long-term and seasonal trends, and relative humidity. These are often incorporated into time-series or case-crossover designs using flexible functions, such as splines, particularly within distributed lag non-linear models (DLNMs). In contrast, effect modifiers are variables that alter the strength or direction of the association between temperature and health outcomes. These may include age, sex, deprivation, or baseline health conditions. Effect modifiers help highlight patterns of susceptibility (biological sensitivity) and vulnerability (contextual risk), but fully identifying at-risk populations also requires additional data, such as differential exposure levels, housing conditions and cooling resources.

Recognising and appropriately adjusting for both confounders and effect modifiers is vital for accurately estimating the true effects of heat on morbidity and mortality.

Air Pollution

Often in environmental epidemiological studies, air pollution serves a dual role, as both a confounder and an effect modifier. As a confounder, it is associated with both temperature and health outcomes, potentially distorting the observed relationship if not properly adjusted for. Simultaneously, it acts as an effect modifier, altering the strength or direction of the association between heat and health outcomes. This dual role emphasises the importance of accounting for air pollution in studies assessing the health impacts of extreme heat, particularly in urban areas where pollution levels are typically higher.

As an effect modifier air pollution can further exacerbate respiratory and cardiovascular conditions during periods of high ambient temperature. Heat events often coincide with elevated levels of ground-level ozone and particulate matter (PM₁₀ and PM_{2.5}), both of which are known to worsen respiratory health. Evidence from an Australian study examining the interactive effects of heatwaves and particulate matter (PM₁₀) on cardiovascular emergency hospital admissions demonstrated that air pollution can significantly modify the health impact of extreme heat ^[93]. The analysis assessed six cardiovascular outcomes at different PM₁₀ concentrations (high: ≥90th percentile; low: <90th percentile) and at multiple lags days (lag 0, lag 1, lag 2) across all ages and by age group. A statistically significant positive interaction between heatwaves and high PM₁₀ levels was observed for hypertensive diseases at lag1 and for cardiac arrest in the older age group at 1 and 2 lagged days. These findings indicate that the adverse effects of heatwaves on cardiovascular emergency hospital admissions were amplified on days with elevated PM₁₀, particularly among older adults. For heart failure and conduction disorders, stronger heatwave effects were consistently observed on high PM₁₀ days across definitions and lags, although interaction terms were not always statistically significant



[93]. Additionally, a negative association was reported for ischaemic heart disease (lag 2) and heart arrhythmia (lag 1) in younger individuals, suggesting complex and outcome-specific modifying effects of air pollution.

Some studies in the UK have chosen not to adjust for air pollution or relative humidity, citing earlier evidence suggesting these factors exert minimal confounding influence in the context of heat-health analyses [94-95].

Humidity

Humidity plays a complex role in shaping the health impacts of high temperatures, acting both as a potential effect modifier and confounder in heat health. Elevated humidity can impair the body's ability to dissipate heat through sweating, thereby intensifying the physiological stress of high temperatures and increasing the risk of heat-related illness. Several studies have noted that the combined effect of high temperature and high humidity often captured through Heat Index or Wet Bulb Globe Temperature (WBGT) is more strongly associated with adverse health outcomes than temperature alone [96-98]. However, the direction and magnitude of humidity's modifying effect can vary depending on the health outcome, climate zone, and population vulnerability. For instance, in some temperate regions, the added moisture may enhance heat stress, whereas in arid regions, the relationship may be less pronounced or even inverse [99].

Seasonality

In temperate regions like the UK, mortality typically follows a seasonal cycle, with peaks in winter due to cold and in summer due to heat. These broader seasonal trends can obscure or exaggerate the specific health impacts of short-term temperature fluctuations if not properly considered. Several studies have recognised this and incorporated seasonal adjustment in their analyses. For example, research from England and Wales has shown that elevated temperatures are associated with increased mortality, even after accounting for underlying seasonal patterns [95]. Accurately accounting for seasonality ensures that observed associations reflect the acute effects of heat exposure, rather than general seasonal trends or unrelated causes of illness and death that also vary throughout the year.



UK and International Reporting on Heat-Related Morbidity and Mortality

UK reporting

In the UK, each devolved nation takes a slightly different approach to reporting the health impacts of heat. Wales does not currently produce routine surveillance reports on heat-related morbidity or mortality, but public health adaptation is a priority. The Welsh Government's Climate Change Adaptation Plan (2020–2025) highlights rising temperatures as a public health concern, with PHW contributing to evidence generation through initiatives like the Health Impact Assessment of Climate Change in Wales, and to the third UK Climate Change Risk Assessment (CCRA3), specifically addressing climate-driven risks to health and wellbeing ^[100-101].

In England, UKHSA publishes detailed annual Heat Mortality Monitoring Reports, which estimate the excess mortality observed during heatwave periods, using baseline comparisons with historical mortality data ^[102]. These reports also include modelled estimates of heat-attributable deaths across the summer period and Years of Life Lost (YLL) to reflect the impact beyond crude mortality counts. The surveillance system is underpinned by temperature thresholds set in the Heat-Health Alert system, which are used to trigger public health interventions. These reports form part of the Adverse Weather and Health Plan, England's overarching policy for climate-related health threats.

In Scotland, the Scottish Climate Change Adaptation Programme (SCCAP) acknowledges heat-related health risks, but the country does not currently produce specific surveillance reports on heat-related mortality ^[103]. Northern Ireland similarly addresses climate-health links through its adaptation policies but lacks targeted monitoring of heat morbidity or mortality ^[104].

Together, these approaches illustrate a fragmented landscape of heat-health surveillance across the UK, with England leading in quantitative monitoring, and the devolved nations incorporating climate-health risks more broadly within strategic adaptation planning. A more harmonised, UK-wide surveillance effort could enhance public health preparedness as extreme heat events become more frequent and severe under climate change.

International Reporting

At the international level, several countries have established formal systems for tracking heat-related morbidity and mortality. France, through Santé Publique France, operates a national Heat and Health Watch Warning System which includes real-time surveillance of excess mortality and hospital activity during heatwaves ^[105]. During the summer months, this system produces weekly bulletins that combine meteorological data with health indicators, including emergency department visits, urgent doctor consultations and mortality figures. The reports provide both national and regional surveillance. For example, the national 2023 summer report identified four major heatwave episodes affecting over 70% of the population, with approximately 1,500 heat-attributable deaths



and over 5,000 excess deaths recorded across the season^[106]. Regional analyses from the Auvergne-Rhône-Alpes region analysed emergency department data between 2015 and 2022, focusing on conditions not routinely monitored: acute renal failure, cardiac decompensation, and myocardial ischemia. The findings showed a 47% increase in emergency visits for acute renal failure [95% CI: 39–56%] during periods exceeding heatwave thresholds, with no significant associations observed for the other conditions.

In the United States, heat-related health outcomes are captured through both formal reporting mechanisms and real-time surveillance systems ^[107-108]. The United States Centers for Disease Control and Prevention (CDC) include heat-related mortality figures in their annual National Vital Statistics Reports, derived from death certificate data across the country. This provides consistent national estimates of deaths attributable to heat exposure. Complementing these formal reports, the CDC's National Environmental Public Health Tracking Program offers an interactive online platform that monitors a broader range of heat-related health indicators. These include emergency department visits, hospital admissions, and deaths, allowing for seasonal surveillance and long-term trend analyses. Data are disaggregated by geographic region, time period, and demographic groups, supporting targeted public health responses. State-level participation varies, but the system enables timely, evidence-based interventions during periods of extreme heat.

In Australia, monitoring of heat-related morbidity and mortality is primarily conducted at the state level, with systems tailored to regional thresholds of risk. In Victoria, the Department of Health operates a localised Heat Health Warning System and publishes detailed post-event reports assessing the health impacts of extreme heat events. These reports include data on hospital admissions, emergency department visits, and mortality, with excess deaths estimated by comparing observed deaths during heatwave periods to expected values based on historical averages for the same season. This approach accounts for confounders such as day of the week, population changes, and long-term trends. For example, during the 2009 heatwave, Victoria recorded 374 excess deaths, a 62% increase above expected levels, while the 2014 heatwave resulted in 167 excess deaths ^[109].

These international systems are notable for their multi-source data integration, including meteorological, mortality, and morbidity indicators. However, limitations remain in underreporting, inconsistent attribution of heat as a cause of death, and the lack of standardised international definitions for heat-related health outcomes. Despite the downfalls, these countries demonstrate systematic monitoring of heat-health impacts, offering models that could inform enhanced public health surveillance in Wales.



Topics Out of Scope

Urban Heat Island

When analysing regional effects of heat on populations, the Urban Heat Island (UHI) effect is a key factor that can not be overlooked, as it significantly raises temperatures in urban areas compared to their rural surroundings. This effect occurs when urban environments, with their concentration of heat-absorbing surfaces like concrete, asphalt, and limited green spaces, trap heat and result in higher ambient temperatures. Research has consistently shown that urban populations are particularly vulnerable to heat-related health impacts, especially in cities with pronounced UHI effects.

A study based in Birmingham, UK, sought to quantify the impacts of UHI on the number of heat related deaths during the heatwave of 2003. The study found that the UHI effect contributed to around 50% of the total heat-related mortality during this period. The researchers also highlighted that when using a geographical mean temperature rather than a population-weighted mean, there was an underestimation of population exposure to heat by approximately 1°C, which translated to a 20% underestimation in mortality^[110].

However, while the UHI effect is a significant contributor to urban heat risks, it will not be incorporated into the analysis for Wales that will focus on broader regional temperature trends and their impact on health outcomes, whereas the UHI effect is more localised and varies considerably across different cities and urban settings. The role of the UHI effect is critical for understanding urban heat risks, but due to its complexity and localised nature, it is not the primary focus of immediate heat morbidity and mortality analysis for Wales.

Future Heat Health Impact Projections

Projected increases in extreme heat are expected to significantly raise the health burden across multiple regions, with mounting evidence quantifying future impacts on morbidity and mortality. In a UK focused modelling study, projected heat-related mortality under different climate and adaptation scenarios using temperature–mortality relationships based on historical time-series data^[111]. Without further adaptation, annual heat-related deaths in England and Wales could rise from approximately 2,000 per year to over 7,000 by the 2050s under a medium-emissions scenario (RCP4.5). The elderly (65+) were identified as the most vulnerable group, particularly in densely populated urban areas such as London and the West Midlands. The study also highlighted that even with moderate adaptation measures, the growing burden of heat would continue to strain health systems.

Another comprehensive study assessed the future impact of climate change on heat-related mortality in high income countries, with a particular focus on the UK and Australia^[112]. The analysis used temperature mortality exposure–response relationships based on historical data, combined with national population and climate projections under a high-emissions scenario (SRES A2). The findings projected that, without substantial intervention, the UK could face approximately 38,000 additional heat-related deaths per year by 2030, increasing to as many as 95,000 annually by 2080. The burden was expected



to be especially severe in cities such as London, where the urban heat island effect amplifies ambient temperatures. Vulnerability was found to be highest among older adults (65+), particularly in densely populated and socio-economically deprived regions, including parts of Wales and the West Midlands ^[112].

The study also considered the role of adaptation and highlighted that, although moderate measures could reduce some of the projected burden, they would be insufficient to fully offset the rising health risks. Adaptation strategies examined included strengthening public health infrastructure, implementing timely heat-health warning systems, expanding access to air-conditioned public spaces, and promoting urban design interventions such as increased green space and reflective surfaces. Even with these interventions, the projections indicated that the scale of demographic change, rising temperatures, and structural inequalities would likely outpace the benefits of moderate adaptation alone.

In addition, a study evaluating heat related mortality risk across several European cities found that, under a high-emissions scenario (RCP8.5), heat-related mortality could increase five- to ten-fold by 2100 in southern and central European regions, with summer average temperatures exceeding historical baselines by 4–6°C ^[94]. Cities such as Rome, Madrid, and Paris were identified as particularly at risk due to both climatic exposure and aging populations.



Analysis Methods for Heat Morbidity and Mortality

All key topics examined in this literature review, including various forms of heat exposure (e.g. heatwaves, diurnal temperature range, and moderate heat), lagged and cumulative effects, vulnerable population groups, and health outcomes will inform the analytical approach used to assess heat-related health risks in Wales. The primary method selected for this investigation is the distributed lag non-linear model (DLNM), which allows for flexible modelling of the non-linear and delayed effects of temperature on health ^[113]. This approach is particularly suited to heat-health research due to its ability to capture complex exposure-response relationships across varying temperature ranges and time lags and has been widely applied in UK based studies.

DLNMs will be used to analyse time-series data on daily temperature, hospital admissions, and mortality in Wales, adjusting for confounding factors such as air pollution, humidity, seasonality, and day-of-week effects. This methodology enables the estimation of both immediate and delayed health impacts of heat, while accounting for population-level vulnerability factors and regional climate variation. While alternative models, such as time-stratified case-crossover analyses or linear regressions, are commonly used due to their simplicity and clear interpretability, they may inadequately address the non-linear and time-dependent nature of temperature-health associations. By contrast, DLNMs provide a robust and sophisticated framework for quantifying heat-related risks, making them highly suitable for generating policy-relevant evidence in the Welsh context.



Discussion

This non-systematic review highlights that heat-related health impacts are a growing concern for Wales, especially as climate change is expected to increase the frequency and intensity of hot weather. The evidence shows that risks extend beyond heatwaves to include moderate heat, high nighttime temperatures, and cumulative exposure, which are often overlooked in traditional surveillance systems.

Vulnerable groups, such as older adults and people with chronic illnesses, are consistently shown to be at greater risk. This underlines the importance of disaggregated data in future analysis to enable targeted interventions.

The review also supports the use of distributed lag non-linear models to capture the delayed and non-linear effects of temperature on health outcomes. Despite this strong evidence base, Wales currently lacks a routine surveillance system for heat-related morbidity and mortality, limiting our ability to respond effectively.

To address this, a tailored, multi-dimensional surveillance approach is needed, one that includes broader heat exposures, multiple health outcomes, and population vulnerabilities, supported by regular reporting and stakeholder engagement.



Recommendations

With the overarching aim of this review to aid and develop the best method to conduct heat morbidity and mortality surveillance, we have identified six recommendations to further the analysis. We have not set out specific public health actions as we will recommend these based on the findings. Note that not all recommendations may be feasible to implement immediately; some may be more suitable for inclusion in future iterations of the reports.

Recommendation 1: Implement a distributed lag non-linear model (DLNM) to estimate the relative risk (RR; likelihood) and attributable fraction (AF; proportion of cases that can be attributed to heat exposure) of heat-related morbidity and mortality across Wales and by health board.

A DLNM approach is well-supported in the literature and allows for the quantification of both immediate and lagged effects of temperature on health outcomes. This model is especially useful given the temporal nature of heat exposure and health events. Estimating the AF of morbidity and mortality due to heat at national and sub-national levels would provide a robust evidence base for targeted public health planning.

Recommendation 2: Define and include multiple types of heat exposures in the analysis.

The literature highlights that health risks are not limited to officially declared heatwaves. Moderate but sustained heat, reduced diurnal temperature variation, and cumulative heat exposure have all been associated with adverse health outcomes. Including these different exposure types allows for a more comprehensive and sensitive analysis of heat-health risks.

Recommendation 3: Incorporate analysis of vulnerable population groups, including age, pre-existing conditions, and socio-demographic factors.

As shown throughout the literature, populations such as the elderly, those with chronic conditions (e.g., cardiovascular conditions, renal disease) can face higher risks. Including these subgroups in the analysis will enable more targeted public health actions.

Recommendation 4: Establish routine annual reporting of heat-related morbidity and mortality in Wales, informed by international and UK models.

Wales currently lacks a formal system for reporting the health impacts of heat. Drawing from the examples from countries with established systems, we recommend developing annual surveillance reports for both heat-related mortality and morbidity, to produce consistent and evidence-based monitoring.

These reports should:

- Provide descriptive statistics on the variation in both heat exposures and health outcomes by time, place, and person.



- Estimate RR of heat-related morbidity and mortality for key health outcomes (e.g., cardiovascular, respiratory, renal, maternity-related) using a DLNM applied to a rolling 10-year dataset.
- Calculate AFs and absolute numbers of heat-attributable cases and deaths based on the RR estimates and the daily temperature distribution for the reporting summer season.
- Disaggregate findings by Health Board, age group, sex, deprivation, and clinical risk groups, where data permit.
- Include a broad range of health indicators, such as hospital admissions, emergency department (ED) visits, emergency service calls (999, 111), maternity outcomes, alongside mortality data from the Office for National Statistics (ONS).
- Compare AFs using rolling 10-year periods (e.g., 2014–2023 vs. 2015–2024) to monitor trends and assess whether heat-related health impacts are increasing over time.

This reporting approach aims to strengthen Wales' public health preparedness and align with commitments in the Climate Change Adaptation Plan. It also offers a mechanism for consistent evaluation of emerging trends and population vulnerabilities and could eventually contribute to a more harmonised UK wide heat-health surveillance framework.

Recommendation 5: Clearly define elements considered out of scope for this analysis (e.g., the urban heat island effect), but identify them for future research or parallel studies.

Explicitly stating which factors are outside the scope of this analysis such as the urban heat island effect or long-term projections helps maintain analytical focus. At the same time, highlighting these areas as priorities for future research or parallel studies can guide future iterations, support strategic planning, and help identify key partners for collaboration, particularly in academia.

Recommendation 6: Engage with stakeholders early in the surveillance process.

Early and ongoing engagement with stakeholders helps ensure that the resulting outputs are relevant, interpretable, and actionable. This approach also aligns with Agile project management principles supporting iterative development, responsiveness to feedback, and greater likelihood of uptake and impact.



References

1. Met Office. (2024). *2023 was second warmest year on record for UK*. <https://www.metoffice.gov.uk/about-us/news-and-media/media-centre/weather-and-climate-news/2023/2023-was-second-warmest-year-on-record-for-uk/>
2. Met Office. (2018). *UK climate projections: Headline findings*. <https://www.metoffice.gov.uk/pub/data/weather/uk/ukcp18/science-reports/ukcp-infographic-headline-findings.pdf>
3. HM Government. (2022). *UK climate change risk assessment 2022*. <https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-2022>
4. Met Office. (2023). *Heatwave*. <https://weather.metoffice.gov.uk/learn-about/weather/types-of-weather/temperature/heatwave>
5. Public Health England. (2020). *PHE heatwave mortality monitoring: Summer 2020*. <https://www.gov.uk/government/publications/phe-heatwave-mortality-monitoring>
6. Smith, S., Elliot, A. J., Hajat, S., Bone, A., Smith, G. E., & Kovats, S. (2016). Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance. *Journal of Epidemiology and Community Health*, 70(5), 459–465. <https://doi.org/10.1136/jech-2015-206079>
7. Obradovich, N., Migliorini, R., Mednick, S. C., & Fowler, J. H. (2017). Nighttime temperature and human sleep loss in a changing climate. *Science Advances*, 3(5), e1601555. <https://doi.org/10.1126/sciadv.1601555>
8. Murage, P., Hajat, S., & Kovats, R. S. (2017). Effect of night-time temperatures on cause and age-specific mortality in London. *Environmental Epidemiology*, 1(2), e005. <https://doi.org/10.1097/EE9.000000000000005>
9. Gasparrini, A., Guo, Y., Hashizume, M., Kinney, P. L., Petkova, E. P., Lavigne, E., Zanobetti, A., Schwartz, J. D., Tobias, A., Leone, M., Tong, S., Honda, Y., Kim, H., Armstrong, B. G., & Bell, M. L. (2015). Mortality risk attributable to high and low ambient temperature: A multicountry observational study. *The Lancet*, 386(9991), 369–375. [https://doi.org/10.1016/S0140-6736\(14\)62114-0](https://doi.org/10.1016/S0140-6736(14)62114-0)
10. Anderson, G. B., & Bell, M. L. (2011). Heat waves in the United States: Mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environmental Health Perspectives*, 119(2), 210–218. <https://doi.org/10.1289/ehp.1002313>
11. Boyette, L. C., & Manna, B. (2019). Physiology, myocardial oxygen demand. In StatPearls. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK499897/>
12. Liu, J., Varghese, B. M., Hansen, A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A., & Bi, P. (2022). Heat exposure and cardiovascular health



- outcomes: A systematic review and meta-analysis. *The Lancet Planetary Health*, 6(6), e484–e495. [https://doi.org/10.1016/S2542-5196\(22\)00117-6](https://doi.org/10.1016/S2542-5196(22)00117-6)
13. Thompson, R., Landeg, O., Kar-Purkayastha, I., Hajat, S., Kovats, S., & O’Connell, E. (2022). Heatwave mortality in summer 2020 in England: An observational study. *International Journal of Environmental Research and Public Health*, 19(19), 6123. <https://doi.org/10.3390/ijerph19106123>
 14. Wen, J., Zou, L., Jiang, Z., Li, Y., Tao, J., Liu, Y., Fu, W., Bai, X., & Mao, J. (2023). Association between ambient temperature and risk of stroke morbidity and mortality: A systematic review and meta-analysis. *Brain and Behavior*, 13(7), e3078. <https://doi.org/10.1002/brb3.3078>
 15. Uibel, D., Sharma, R., Piontkowski, D., Sheffield, P. E., & Clougherty, J. E. (2022). Association of ambient extreme heat with pediatric morbidity: A scoping review. *International Journal of Biometeorology*, 66(8), 1683–1698. <https://doi.org/10.1007/s00484-022-02310-5>
 16. Zhao, Q., Li, S., Coelho, M. de S. Z. S., et al. (2019). Ambient heat and hospitalization for COPD in Brazil: A nationwide case-crossover study. *Thorax*, 74(11), 1031–1036. <https://doi.org/10.1136/thoraxjnl-2019-213926>
 17. Konstantinoudis, G., Minelli, C., Lam, H. C. Y., Fuertes, E., Ballester, J., Davies, B., Vicedo-Cabrera, A. M., Gasparrini, A., & Blangiardo, M. (2023). Asthma hospitalizations and heat exposure in England: A case-crossover study during 2002–2019. *Thorax*, 78(9), 875–881. <https://doi.org/10.1136/thorax-2022-219901>
 18. GBD Chronic Respiratory Disease Collaborators. (2020). Prevalence and attributable health burden of chronic respiratory diseases, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. *The Lancet Respiratory Medicine*, 8(6), 585–596. [https://doi.org/10.1016/S2213-2600\(20\)30105-3](https://doi.org/10.1016/S2213-2600(20)30105-3)
 19. Konstantinoudis, G., Minelli, C., Vicedo-Cabrera, A. M., et al. (2022). Ambient heat exposure and COPD hospitalizations in England: A nationwide case-crossover study during 2007–2018. *Thorax*, 77(12), 1098–1104. <https://doi.org/10.1136/thoraxjnl-2022-219402>
 20. O’Lenick, C., Cleland, S. E., Neas, L. M., Turner, M. W., McInroe, E. M., Hill, K. L., Ghio, A. J., Rebuli, M. E., Jaspers, I., & Rappold, A. G. (2025). Impact of heat on respiratory hospitalizations among older adults in 120 large U.S. urban areas. *Annals of the American Thoracic Society*, 22(3), 367–377. <https://doi.org/10.1513/AnnalsATS.202405-470OC>
 21. Zafeiratou, S., Samoli, E., Analitis, A., Gasparrini, A., Stafoggia, M., de’ Donato, F. K. C., Rao, S., Zhang, S., Breitner, S., Masselot, P., Aunan, K., Schneider, A., & Katsouyanni, K. (2023). Assessing heat effects on respiratory mortality and location characteristics as modifiers of heat effects at a small area scale in Central-Northern Europe. *Environmental Epidemiology*, 7(5), e269. <https://doi.org/10.1097/EE9.0000000000000269>



22. Pinho-Gomes, A., McIntosh, A., & Woodward, M. (2024). Sex differences in mortality associated with heatwaves: A systematic review and meta-analysis. *European Journal of Public Health*, 34(Suppl 3), ckae144.283. <https://doi.org/10.1093/eurpub/ckae144.283>
23. Anderson, G. B., Dominici, F., Wang, Y., et al. (2013). Heat-related emergency hospitalizations for respiratory diseases in the Medicare population. *American Journal of Respiratory and Critical Care Medicine*, 187(10), 1098–1103. <https://doi.org/10.1164/rccm.201210-1861OC>
24. Son, J.-Y., Bell, M. L., & Lee, J.-T. (2014). The impact of heat, cold, and heat waves on hospital admissions in eight cities in Korea. *International Journal of Biometeorology*, 58(10), 1893–1903. <https://doi.org/10.1007/s00484-014-0791-y>
25. Zhang, Y., Peng, L., Kan, H., et al. (2014). Effects of meteorological factors on daily hospital admissions for asthma in adults: A time-series analysis. *PLoS ONE*, 9(6), e102475. <https://doi.org/10.1371/journal.pone.0102475>
26. Delamater, P. L., Finley, A. O., & Banerjee, S. (2012). An analysis of asthma hospitalizations, air pollution, and weather conditions in Los Angeles County, California. *Science of the Total Environment*, 425, 110–118. <https://doi.org/10.1016/j.scitotenv.2012.02.01>
27. Wang, Y.-C., & Lin, Y.-K. (2015). Temperature effects on outpatient visits of respiratory diseases, asthma, and chronic airway obstruction in Taiwan. *International Journal of Biometeorology*, 59(7), 815–825. <https://doi.org/10.1007/s00484-014-0866-3>
28. Yamazaki, S., Shima, M., Yoda, Y., et al. (2013). Association of ambient air pollution and meteorological factors with primary care visits at night due to asthma attack. *Environmental Health and Preventive Medicine*, 18(5), 401–406. <https://doi.org/10.1007/s12199-013-0339-5>
29. Lam, H. C.-Y., Li, A. M., Chan, E. Y.-Y., et al. (2016). The short-term association between asthma hospitalisations, ambient temperature, other meteorological factors and air pollutants in Hong Kong: A time-series study. *Thorax*, 71(12), 1097–1109. <https://doi.org/10.1136/thoraxjnl-2015-208054>
30. Wu, Y., Xu, R., Wen, B., et al. (2021). Temperature variability and asthma hospitalisation in Brazil, 2000–2015: A nationwide case-crossover study. *Thorax*, 76(10), 962–969. <https://doi.org/10.1136/thoraxjnl-2020-216549>
31. Soneja, S., Jiang, C., Fisher, J., et al. (2016). Exposure to extreme heat and precipitation events associated with increased risk of hospitalization for asthma in Maryland, U.S.A. *Environmental Health*, 15, 57. <https://doi.org/10.1186/s12940-016-0142-z>
32. Lin, S., Luo, M., Walker, R. J., et al. (2009). Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. *Epidemiology*, 20(5), 738–746. <https://doi.org/10.1097/EDE.0b013e3181ad5522>



33. Chen, Y., Kong, D., Fu, J., et al. (2022). Associations between ambient temperature and adult asthma hospitalizations in Beijing, China: A time-stratified case-crossover study. *Respiratory Research*, 23, 38. <https://doi.org/10.1186/s12931-022-01960-8>
34. UK Health Security Agency. (2024). *Mental health and climate change in the UK: Call for evidence*. <https://www.gov.uk/government/calls-for-evidence/mental-health-and-climate-change-in-the-uk-call-for-evidence>
35. Thompson, R., Hornigold, R., Page, L., & Waite, T. (2018). Associations between high ambient temperatures and heat waves with mental health outcomes: A systematic review. *Public Health*, 161, 171–191. <https://doi.org/10.1016/j.puhe.2018.06.008>
36. Page, L., Hajat, S., & Kovats, R. S. (2007). Relationship between daily suicide counts and temperature in England and Wales. *The British Journal of Psychiatry*, 191(2), 106–112. <https://doi.org/10.1192/bjp.bp.106.031948>
37. Deisenhammer, E. A., Kemmler, G., & Parson, P. (2003). Association of meteorological factors with suicide. *Acta Psychiatrica Scandinavica*, 108(6), 455–459.
38. Grjibovski, A. M., Kozhakhmetova, G., Kosbayeva, A., & Menne, B. (2013). Associations between air temperature and daily suicide counts in Astana, Kazakhstan. *Medicina (Kaunas)*, 49(5), 379–385.
39. Kim, Y., Kim, H., Honda, Y., Guo, Y. L., Chen, B. Y., Woo, J. M., & Ebi, K. L. (2016). Suicide and ambient temperature in East Asian countries: A time-stratified case-crossover analysis. *Environmental Health Perspectives*, 124(1), 75–80. <https://doi.org/10.1289/ehp.1409392>
40. Kim, Y., Kim, H., & Kim, D. S. (2011). Association between daily environmental temperature and suicide mortality in Korea (2001–2005). *Psychiatry Research*, 186(2–3), 390–396.
41. Marion, S. A., Oluwafemi Agbayewa, M., & Wiggins, S. (1999). The effect of season and weather on suicide rates in the elderly in British Columbia. *Canadian Journal of Public Health*, 90(6), 418–422.
42. Qi, X., Hu, W., Mengersen, K., & Tong, S. (2014). Socio-environmental drivers and suicide in Australia: Bayesian spatial analysis. *BMC Public Health*, 14, 681. <https://doi.org/10.1186/1471-2458-14-681>
43. Dixon, P. G., McDonald, A. N., Scheitlin, K. N., Stapleton, J. E., Allen, J. S., Carter, W. M., et al. (2007). Effects of temperature variation on suicide in five U.S. counties, 1991–2001. *International Journal of Biometeorology*, 51(5), 395–403.
44. Hiltunen, L., Haukka, J., Ruuhela, R., Suominen, K., & Partonen, T. (2014). Local daily temperatures, thermal seasons, and suicide rates in Finland from 1974 to 2010. *Environmental Health and Preventive Medicine*, 19(4), 286–294.



45. Sung, T. I., Chen, M. J., & Su, H. J. (2013). A positive relationship between ambient temperature and bipolar disorder identified using a national cohort of psychiatric inpatients. *Social Psychiatry and Psychiatric Epidemiology*, *48*(2), 295–302.
46. Lee, H.-C., Tsai, S.-Y., & Lin, H.-C. (2007). Seasonal variations in bipolar disorder admissions and the association with climate: A population-based study. *Journal of Affective Disorders*, *97*(1–3), 61–69.
47. Shapira, A., Shiloh, R., Potchter, O., Hermesh, H., Popper, M., & Weizman, A. (2004). Admission rates of bipolar depressed patients increase during spring/summer and correlate with maximal environmental temperature. *Bipolar Disorders*, *6*(2), 90–93.
48. Carney, P. A., Fitzgerald, C. T., & Monaghan, C. E. (1988). Influence of climate on the prevalence of mania. *British Journal of Psychiatry*, *152*, 820–823.
49. McWilliams, S., Kinsella, A., & O'Callaghan, E. (2014). Daily weather variables and affective disorder admissions to psychiatric hospitals. *International Journal of Biometeorology*, *58*(10), 2045–2057.
50. Shiloh, R., Munitz, H., Stryjer, R., & Weizman, A. (2007). A significant correlation between ward temperature and the severity of symptoms in schizophrenia inpatients – a longitudinal study. *European Neuropsychopharmacology*, *17*(6), 478–482.
51. Shiloh, R., Shapira, A., Potchter, O., Hermesh, H., Popper, M., & Weizman, A. (2005). Effects of climate on admission rates of schizophrenia patients to psychiatric hospitals. *European Psychiatry*, *20*(1), 61–64.
52. Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D., & Tucker, G. (2008). The effect of heat waves on mental health in a temperate Australian city. *Environmental Health Perspectives*, *116*(9), 1369–1375.
53. Trang, P. M., Rocklöv, J., Giang, K. B., Kullgren, G., & Nilsson, M. (2016). Heatwaves and hospital admissions for mental disorders in Northern Vietnam. *PLoS One*, *11*(3), e0155609.
54. Page, L. A., Hajat, S., Kovats, R., & Howard, L. M. (2012). Temperature-related deaths in people with psychosis, dementia and substance misuse. *British Journal of Psychiatry*, *200*(6), 485–490.
55. Ding, N., Berry, H. L., & Bennett, C. M. (2016). The importance of humidity in the relationship between heat and population mental health: Evidence from Australia. *PLoS One*, *11*(8), e0160606.
56. Garcia, F., Boada, S., Collsamata, A., Joaquim, I., Perez, Y., & Tricio, O., et al. (2009). Meteorological factors and psychiatric emergencies. *Actas Españolas de Psiquiatría*, *37*(1), 34–41.
57. He, Y., Cheng, L., Bao, J., Deng, S., Liao, W., Wang, Q., et al. (2020). Geographical disparities in the impacts of heat on diabetes mortality and the protective role of



greenness in Thailand: A nationwide case-crossover analysis. *Science of the Total Environment*, 711, 135098.

58. Li, J., Xu, X., Yang, J., Liu, Z., Xu, L., Gao, J., et al. (2017). Ambient high temperature and mortality in Jinan, China: A study of heat thresholds and vulnerable populations. *Environmental Research*, 156, 657–664.
59. Isaksen, T. B., Fenske, R. A., Hom, E. K., Ren, Y., Lyons, H., & Yost, M. G. (2016). Increased mortality associated with extreme-heat exposure in King County, Washington, 1980–2010. *International Journal of Biometeorology*, 60(1), 85–98.
60. Oudin Åström, D., Schifano, P., Asta, F., Lallo, A., Michelozzi, P., Rocklöv, J., et al. (2015). The effect of heat waves on mortality in susceptible groups: A cohort study of a Mediterranean and a northern European city. *Environmental Health*, 14, 30.
61. Kim, C. T., Lim, Y. H., Woodward, A., & Kim, H. (2015). Heat-attributable deaths between 1992 and 2009 in Seoul, South Korea. *PLOS ONE*, 10(3), e0118577. <https://doi.org/10.1371/journal.pone.0118577>
62. Gasparrini, A., Armstrong, B., Kovats, S., & Wilkinson, P. (2012). The effect of high temperatures on cause-specific mortality in England and Wales. *Occupational and Environmental Medicine*, 69(1), 56–61. <https://doi.org/10.1136/oem.2010.059782>
63. Jiang, S., Warren, J. L., Scovronick, N., Moss, S. E., Darrow, L. A., Strickland, M. J., et al. (2021). Using logic regression to characterize extreme heat exposures and their health associations: A time-series study of emergency department visits in Atlanta. *BMC Medical Research Methodology*, 21(1), 87. <https://doi.org/10.1186/s12874-021-01301-3>
64. Xu, Z., Tong, S., Cheng, J., Crooks, J. L., Xiang, H., Li, X., et al. (2019). Heatwaves and diabetes in Brisbane, Australia: A population-based retrospective cohort study. *International Journal of Epidemiology*, 48(4), 1091–1100. <https://doi.org/10.1093/ije/dyz080>
65. Buchanan, R. D., McDonnell, C. M., & Nassar, N. (2010). The impact of heat on glucose control in type 1 diabetes. *Diabetes Care*, 33(8), 1735–1740. <https://doi.org/10.2337/dc09-2284>
66. Capon, A., Howard, S., & Dharmage, S. C. (2017). Obesity and type 2 diabetes and their impact on thermoregulation: A review of recent research on heat stress. *Environmental Health Perspectives*, 125(6), 1234–1239. <https://doi.org/10.1289/EHP832>
67. Gao, D., Friedman, S., Hosler, A., Sheridan, S., Zhang, W., & Lin, S. (2022). Association between extreme ambient heat exposure and diabetes-related hospital admissions and emergency department visits: A systematic review. *Hygiene and Environmental Health Advances*, 4, 100031. <https://doi.org/10.1016/j.heha.2022.100031>
68. Basu, R., Pearson, D., & Malig, B. (2012). Association between high apparent temperature and diabetes-related hospital admissions in California. *Environmental Health Perspectives*, 120(1), 61–66. <https://doi.org/10.1289/ehp.1003956>



69. Wilson, L. A., Black, D. A., Veitch, C., & Waller, M. (2013). Heatwaves and the risk of hospitalization for diabetes in Sydney, Australia: A case-crossover study. *Environmental Health*, 12(1), 1–8. <https://doi.org/10.1186/1476-069X-12-96>
70. Winquist, A., Schauer, J. J., & Turner, M. C. (2016). Association between temperature and emergency department visits for diabetes in Atlanta, Georgia, USA: A time-series analysis. *Environmental Health*, 15(1), 1–10. <https://doi.org/10.1186/s12940-016-0183-3>
71. Xu, R., Zhao, Q., Coelho, M. S. Z. S., Saldiva, P. H. N., Huxley, R. R., Abramson, M. J., & Guo, Y. (2019). Association between heat exposure and hospitalization for diabetes in Brazil: A nationwide time-series study. *Science of the Total Environment*, 694, 133741. <https://doi.org/10.1016/j.scitotenv.2019.133741>
72. Green, R. S., Basu, R., Malig, B., Broadwin, R., Kim, J. J., & Ostro, B. (2010). The effect of temperature on hospital admissions in nine California counties. *International Journal of Public Health*, 55(2), 113–121. <https://doi.org/10.1007/s00038-009-0060-7>
73. Ogbomo, A. C., Zaitchik, B. F., & Gohlke, J. M. (2017). Vulnerability to extreme-heat-associated hospitalization in three counties in Michigan, USA, 2000–2009. *International Journal of Biometeorology*, 61(7), 1205–1214. <https://doi.org/10.1007/s00484-016-1290-9>
74. Liu, W., Wu, X., Wang, Y., & Li, T. (2020). Impact of short-term exposure to extreme temperatures on diabetes mellitus morbidity and mortality: A systematic review and meta-analysis. *Environmental Research*, 191, 110013. <https://doi.org/10.1016/j.envres.2020.110013>
75. Chersich, M. F., Pham, M. D., Areal, A., Haghghi, M. M., Manyuchi, A., Swift, C. P., Wernecke, B., Robinson, M., Hetem, R., Boeckmann, M., Hajat, S., & Climate Change and Heat-Health Study Group. (2020). Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: Systematic review and meta-analysis. *BMJ*, 371, m3811. <https://doi.org/10.1136/bmj.m3811>
76. Hajat, S., Casula, A., Murage, P., Omoyeni, D., Gray, T., Plummer, Z., Steenkamp, R., & Nitsch, D. (2024). Ambient heat and acute kidney injury: Case-crossover analysis of 1,354,675 automated e-alert episodes linked to high-resolution climate data. *The Lancet Planetary Health*, 8(3), e156–e162. [https://doi.org/10.1016/S2542-5196\(24\)00008-1](https://doi.org/10.1016/S2542-5196(24)00008-1)
77. Davis, B. C., Tillman, H., Chung, R. T., Stravitz, R. T., Reddy, R., Fontana, R. J., McGuire, B., Davern, T., Lee, W. M., & Acute Liver Failure Study Group. (2017). Heat stroke leading to acute liver injury & failure: A case series from the Acute Liver Failure Study Group. *Liver International*, 37(4), 509–513. <https://doi.org/10.1111/liv.13373>
78. Leon, L. R., & Bouchama, A. (2015). Heat stroke. *Comprehensive Physiology*, 5(2), 611–647. <https://doi.org/10.1002/cphy.c140017>
79. Misset, B., De Jonghe, B., Bastuji-Garin, S., Gattolliat, O., Boughrara, E., Annane, D., Hausfater, P., Garrouste-Orgeas, M., & Carlet, J. (2006). Mortality of patients with



heatstroke admitted to intensive care units during the 2003 heat wave in France: A national multiple-center risk-factor study. *Critical Care Medicine*, 34(4), 1087–1092. <https://doi.org/10.1097/01.CCM.0000206469.33615.02>

80. Arbuthnott, K. G., & Hajat, S. (2017). The health effects of hotter summers and heat waves in the population of the United Kingdom: A review of the evidence. *Environmental Health*, 16(Suppl 1), 119. <https://doi.org/10.1186/s12940-017-0322-5>
81. Hajat, S., Kovats, R. S., & Lachowycz, K. (2007). Heat-related and cold-related deaths in England and Wales: Who is at risk? *Occupational and Environmental Medicine*, 64(2), 93–100. <https://doi.org/10.1136/oem.2006.029017>
82. Bennett, J. E., Blangiardo, M., Fecht, D., Elliott, P., & Ezzati, M. (2014). Vulnerability to the mortality effects of warm temperature in the districts of England and Wales. *Nature Climate Change*, 4(4), 269–273. <https://doi.org/10.1038/nclimate2123>
83. Gasparrini, A., Masselot, P., Scortichini, M., Schneider, R., Mistry, M. N., Sera, F., Macintyre, H. L., Phalkey, R., & Vicedo-Cabrera, A. M. (2022). Small-area assessment of temperature-related mortality risks in England and Wales: A case time series analysis. *The Lancet Planetary Health*, 6(7), e557–e568. [https://doi.org/10.1016/S2542-5196\(22\)00114-0](https://doi.org/10.1016/S2542-5196(22)00114-0)
84. Yardley, J., Sigal, R., & Kenny, G. (2011). Heat health planning: The importance of social and community factors. *Global Environmental Change*, 21, 670–679. <https://doi.org/10.1016/j.gloenvcha.2011.02.002>
85. Friends of the Earth. (2022). *Who suffers most from heatwaves in the UK?* <https://policy.friendsoftheearth.uk/insight/who-suffers-most-heatwaves-uk>
86. Applegate, W. B., Runyan, J. W., Jr., Brasfield, L., Williams, M. L., Konigsberg, C., & Fouche, C. (1981). Analysis of the 1980 heat wave in Memphis. *Journal of the American Geriatrics Society*, 29(8), 337–342. <https://doi.org/10.1111/j.1532-5415.1981.tb01238.x>
87. Guo, Y., Wang, Z., Li, S., Tong, S., & Barnett, A. G. (2013). Temperature sensitivity in Indigenous Australians. *Epidemiology*, 24(3), 471–472. <https://doi.org/10.1097/EDE.0b013e31828b76b3>
88. Green, D., King, U., & Morrison, J. (2009). Disproportionate burdens: The multidimensional impacts of climate change on the health of Indigenous Australians. *Medical Journal of Australia*, 190(1), 4–5. <https://doi.org/10.5694/j.1326-5377.2009.tb02238.x>
89. Hansen, A., Bi, L., Saniotis, A., & Nitschke, M. (2013). Vulnerability to extreme heat and climate change: Is ethnicity a factor? *Global Health Action*, 6, 21364. <https://doi.org/10.3402/gha.v6i0.21364>
90. Brimicombe, C., et al. (2024). Effects of ambient heat exposure on risk of all-cause mortality in children younger than 5 years in Africa: A pooled time-series analysis.



The Lancet Planetary Health, 8(9), e640–e646. [https://doi.org/10.1016/S2542-5196\(24\)00123-5](https://doi.org/10.1016/S2542-5196(24)00123-5)

91. Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R. F., Achebak, H., Ebi, K. L., García-León, D., Martínez-Solanas, È., Pascal, M., Díaz, J., & Linares, C. (2023). Heat-related mortality in Europe during the summer of 2022. *Nature Medicine*, 29, 1857–1866. <https://doi.org/10.1038/s41591-023-02419-z>
92. Gifford, R. M., Todisco, T., Stacey, M., Fujisawa, T., Allerhand, M., Woods, D. R., & 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>
93. Parry, M., Green, D., Zhang, Y., & Hayen, A. (2019). Does particulate matter modify the short-term association between heat waves and hospital admissions for cardiovascular diseases in Greater Sydney, Australia? *International Journal of Environmental Research and Public Health*, 16(18), 3270. <https://doi.org/10.3390/ijerph16183270>
94. Hajat, S., Vardoulakis, S., Heaviside, C., & Eggen, B. (2014). Climate change effects on human health: Projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *Journal of Epidemiology and Community Health*, 68(7), 641–648. <https://doi.org/10.1136/jech-2013-202449>
95. Armstrong, B. G., Chalabi, Z., Fenn, B., Hajat, S., & Kovats, R. S. (2011). Association of mortality with high temperatures in a temperate climate: England and Wales. *Journal of Epidemiology & Community Health*, 65(4), 340–345. <https://doi.org/10.1136/jech.2009.093161>
96. Kim, H., Kim, J., & Ha, J. (2018). Evaluating the applicability of the wet-bulb globe temperature as a heatwave index for predicting health-related heat risk. *Environmental Research*, 167, 700–706. <https://doi.org/10.1016/j.envres.2018.09.034>
97. Cheng, J., Xu, Z., Bambrick, H., Su, H., Tong, S., & Hu, W. (2013). The mortality risk attributable to high and low ambient temperature: A multi-city study in China. *Environmental Health Perspectives*, 121(5), 506–512. <https://doi.org/10.1289/ehp.1205091>
98. Kawano, S., Uehara, R., Onozuka, D., & Fushimi, K. (2024). Association between wet bulb globe temperature and in-hospital mortality due to heat-related illness in Japan: A nationwide inpatient database study. *The Science of the Total Environment*, 906, 167651. <https://doi.org/10.1016/j.scitotenv.2023.167651>
99. Guo, Q., Mistry, M. N., Zhou, X., Zhao, G., Kino, K., Wen, B., Yoshimura, K., Satoh, Y., Cvijanovic, I., Kim, Y., Ng, C. F. S., Vicedo-Cabrera, A. M., Armstrong, B., Urban, A., Katsouyanni, K., Masselot, P., Tong, S., Sera, F., Huber, V., Bell, M. L., ... Oki, T. (2024). Regional variation in the role of humidity on city-level heat-related mortality. *PNAS Nexus*, 3(8), pgae290. <https://doi.org/10.1093/pnasnexus/pgae290>



100. Welsh Government. (2019). *Prosperity for All: A Climate Conscious Wales – A Climate Change Adaptation Plan for Wales 2020–2025*. Cardiff: Welsh Government.
101. Climate Change Committee. (2021). *Independent Assessment of UK Climate Risk: Advice to Government for the UK's Third Climate Change Risk Assessment (CCRA3)*. London: Climate Change Committee.
102. UK Health Security Agency. (2025). *Heat Mortality Monitoring Report, England: 2024*. London: UKHSA.
103. Scottish Government. (2019). *Climate Ready Scotland: Second Scottish Climate Change Adaptation Programme 2019–2024*. Edinburgh: Scottish Government.
104. Northern Ireland Executive. (2019). *Northern Ireland Climate Change Adaptation Programme 2019–2024 (NICCAP2)*. Belfast: Northern Ireland Executive.
105. Santé publique France. (2022). *Bulletin de santé publique – Heatwaves, France – Summer 2022*. Retrieved from <https://www.santepubliquefrance.fr/en/bulletin-de-sante-publique-heatwaves-france-summer-2022Accueil>
106. Santé publique France. (2023). *Impact des vagues de chaleur sur les passages aux urgences pour insuffisance rénale aiguë, décompensation cardiaque et ischémie myocardique en Auvergne-Rhône-Alpes, 2015–2022*. Retrieved from <https://www.santepubliquefrance.fr/content/download/716226/4646645?version=1>
107. Centers for Disease Control and Prevention. (2022). QuickStats: Percentage distribution of heat-related deaths, by age group — National Vital Statistics System, United States, 2018–2020. *Morbidity and Mortality Weekly Report*, 71(24), 808. <https://doi.org/10.15585/mmwr.mm7124a6>
108. Centers for Disease Control and Prevention. (n.d.). *Heat & heat-related illness / Tracking program*. Retrieved April 15, 2025, from <https://www.cdc.gov/environmental-health-tracking/php/data-research/heat-heat-related-illness.html>
109. Department of Human Services. (2009). *January 2009 Heatwave in Victoria: An Assessment of Health Impacts*. Melbourne: State Government of Victoria.
110. Heaviside, C., Vardoulakis, S., & Cai, X. M. (2016). Attribution of mortality to the urban heat island during heatwaves in the West Midlands, UK. *Environmental Health*, 15(Suppl 1), S27. <https://doi.org/10.1186/s12940-016-0100-9>
111. Murage, P., Macintyre, H. L., Heaviside, C., Vardoulakis, S., Fučkar, N., Rimi, R. H., & Hajat, S. (2024). Future temperature-related mortality in the UK under climate change scenarios: Impact of population ageing and bias-corrected climate projections. *Environmental Research*, 259, 119565. <https://doi.org/10.1016/j.envres.2024.119565>
112. McMichael, A. J., Woodruff, R. E., & Hales, S. (2014). Comparative assessment of the effects of climate change on heat- and cold-related mortality in the United Kingdom



and Australia. *Environmental Health Perspectives*, 122(12), 1285–1292. <https://doi.org/10.1289/ehp.1307524>

113. Gasparrini, A., Armstrong, B., & Kenward, M. G. (2010). Distributed lag non-linear models. *Statistics in Medicine*, 29(21), 2224–2234. <https://doi.org/10.1002/sim.3940>



Further information and contact details

About Public Health Wales

Public Health Wales exists to protect and improve health and wellbeing and reduce health inequalities for people in Wales. We work locally, nationally, and internationally, with our partners and communities.

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