A report for the Climate Change Committee

Risks to Health and Health Services from Extreme Heat

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Greencroft Economics

Edge Health

Report Outline

Contents

Glossary of Key Terms

Hazard	The extent to which the extreme heat hazard occurs. This includes consideration of the frequency (# of days), longevity (consecutive days) and intensity (how high the temperature is, and how persistent across day and night time) of the occurrence.
Elderly	Anyone aged 65 or over. This is used as one of the population archetypes and is used for clarity of definition, as opposed to other possible terms such as "older people" or "ageing", which are relative terms.
Exposure	How often people or health care services are exposed to the hazard (e.g. in this study, the number of extreme-heat-person-days).
Extreme-heat-person-days	The cumulative measure of population exposure to heat; calculated by multiplying the number of days of extreme temperature by the number of people exposed to that temperature.
Vulnerability	How much people are affected by exposure; in this case the impact on different population groups of exposure to each day of extreme temperature.
Risk	Risk is the result of combining hazard, exposure, and vulnerability, and will vary across time, across regions, and across population groups as their exposure and vulnerability varies.
Relative risk (RR)	Relative risk describes the additional risk of hospital attendance, hospital admission, or mortality, caused by extreme heat. That is, it is net of the underlying, non-heat related, risk of each of these three outcomes (attendance, admission, mortality).
Heat event	Any day above the defined LSOA-level heat thresholds of 25-29°C.
Extreme heat	Temperatures above defined heat threshold of 25°C or more at LSOA or data zone level, following the UK Met Office approach to derive meteorological thresholds for heat waves (which vary by region between 25-28°C, and when using LSOA thresholds by 25°C-29°C).
Present-day baseline	The period from 1991 to 2020. Average values across this period are applied consistently to climate data and other outcome metrics to represent recent and current experience.
Healthcare supply	The capacity and capability of the healthcare system to deliver health care, including the resources needed to deliver care?
Healthcare demand	The level of healthcare services utilised by the population based on their needs.
Health event	An occurrence affecting an individual's health, which may be acute or chronic in nature. Examples include a stroke, asthma attack, or heat-related illness such as dehydration or heat stroke.
Health outcome	A measurable result of a health event. In this context, health outcomes of interest are A&E attendance in ED department, emergency hospital admission in secondary care, and mortality.
Heat-related health outcome	Health outcomes (e.g. illnesses, deaths) that are directly caused by the exposure to heat.

Heat-attributed health outcome	Health outcomes (e.g. illnesses, deaths) in where the underlying cause is heat.

1 Executive Summary

Climate change is reshaping the UK's temperature profile, driving heat events that are more frequent, intense, and longer lasting than ever before.[1] Extreme heat is no longer a rare disruption; it is becoming a frequent occurrence, escalating pressure on public health and the health and social care system.[2] This report quantifies the present and future burden of extreme heat on health outcomes and healthcare services across the UK and assesses how targeted adaptation could reduce these impacts.

Projecting the UK's vulnerability to extreme heat for health outcomes

For this study, extreme heat is defined in line with the Met Office definitions for heat waves, which results in LSOA[3] specific thresholds between 25°C and 29°C.

The occurrence of extreme heat across the UK is projected forward to 2050 using UKCP18[4] Local data, to estimate how often region-specific (at LSOA level[5]) extreme heat thresholds are breached (25°C to 29°C depending on the LSOA). These hazard occurrences are then mapped to current and future UK population projections to determine exposure to the risk in terms of extreme-heat-person-days. Vulnerability across the UK is assessed by looking at projected demographic changes and regional health data. Microsimulation modelling is then used to estimate future health outcomes (mortality, hospital admissions, A&E attendances), accounting for the specific vulnerability of the elderly to heatwaves while incorporating regional differences in underlying chronic conditions like cardiovascular disease and diabetes.

Current extreme heat days and associated health burden (1991 to 2020)

Extreme heat already takes a significant toll. In the baseline period for this study, 1991 to 2020, there were on average 4.9 days of extreme heat annually. Extreme temperatures were associated with an annual average of approximately 850 excess deaths, 17,000 excess A&E attendances, and 2,900 excess emergency admissions. These figures represent a subset of impacts occurring only on days exceeding Met Office temperature thresholds. While these averages provide a baseline, mortality in recent years (notably 2022) has exceeded these historical levels.

Projected escalation under future warming

In a central climate scenario, equivalent to 2°C global warming by 2050, the UK would see more than twice as many days of extreme heat per year by 2050. This would result in a near three-fold increase in extreme-person-heat days, accounting for population growth of 10% projected by the ONS by 2050. In a reasonable worst-case climate scenario, equivalent to 2.5°C global

[1] Met Office. (2025). UK and Global extreme events – Heatwaves. Exeter: Met Office. Link
[2] UK Health Security Agency. (2023). Health Effects of Climate Change in the UK: 2023. UKHSA. Link
[3] Lower Layer Super Output Area, a geographic area typically around 1,000 households – there are around 34,000 LSOAs in England.
[4] UK Climate Projections 2018
[5] Lower Layer Super Output Area, a geographic area typically around 1,000 households – there are around 34,000 LSOAs in England.

warming by 2050, there would be almost six times as many days of extreme heat by 2050 compared to the baseline period.

As a consequence, extreme heat-related adverse health impacts are projected to rise sharply. Under the central climate scenario, these impacts are expected to more than double by the 2030s and to triple by the 2050s.

- **Mortality**: In the central warming scenario, annual heat-related deaths increase to 2,200 by the 2030s and to 3,200 by the 2050s. In the worst-case scenario, this figure could reach 7,400 deaths annually by the 2050s, more than eight times the 1991-2020 baseline.
- **A&E Attendances**: The largest volume impacts are projected for emergency care. Attendances are expected to climb to 39,000 by the 2030s (central scenario) and 53,000 by the 2050s. In a worst-case 2050s heat year, attendances could surge to 123,000, with London alone exceeding 27,000 attendances, nearly seven times its baseline level of 4,000 attendances.
- **Emergency Admissions**: Admissions increase to 7,250 by the 2030s from 2,900 in baseline, and 11,000 by the 2050s in the central scenario, reaching 26,000 annually in the worst-case scenario.

Together, these projections underscore that even the central climate scenario will place significant strain on the health system. In economic terms, the total monetised impacts of these health-related outcomes could exceed £4 billion by the 2050s in the worst-case scenario, compared to around £0.5 billion in the 1991-2020 baseline scenario. The 1991-2020 baseline heat-related economic impact is roughly 80% of the economic impact from seasonal influenza. The economic costs included are estimated using published NHS unit costs applied to projected emergency admissions and A&E attendances, combined with the economic value of life years loss.

Uneven impacts across the UK

The burden of extreme heat falls unevenly across both geographies and populations. The largest absolute impacts are concentrated in London and Southern England; using the 2050s worst-case scenario as an example, the South East alone approaches nearly 2,000 heat-related deaths, accounting for around 27% of the total UK heat-related mortality burden. Yet the steepest proportional increases occur in regions historically unaccustomed to high temperatures. In Northern Ireland, for example, annual heat-related deaths rise from about 3 to nearly 79 in the 2050s worst-case scenario, equivalent to a rate of 4.0 deaths per 100,000 people – significantly higher than the baseline extreme-heat-related mortality rate of London (1.3 per 100,000 people).

Vulnerability also varies sharply across populations:

- People aged 75+ experience extreme heat-related mortality at around eight times the rate of other age groups.

- Emergency admissions similarly cluster in this age group, reflecting the higher prevalence of co-morbidities and age-related frailty that are exacerbated by heat stress.
- By contrast, A&E attendances are disproportionately concentrated among younger adults, creating distinct pressures across different parts of the system.
- People with multiple long-term conditions experience consistently higher risk.

Age-related differences are partially driven by varying health seeking behaviours. For instance, parents of young children are more likely seek medical care, or heat-sensitive lifestyle factors in younger adults, can increase healthcare utilisation independently of physiological strain.

System-wide pressures on health and social care

Extreme heat places substantial and immediate pressure on the health and social care system. Surges in A&E attendances and emergency admissions lead to longer waits and higher bed occupancy, both of which are linked to increased short-term mortality and greater operational risk, such as higher infection rates, increased delays in emergency departments and the inability to handle sudden surges in demand. A two-week heatwave could push some regions close to full capacity, and excess admissions alone are estimated to add £80.7 million per year in bed-day costs in the 2050s worst case.

Heat also affects system functioning beyond hospitals. Overheated clinical spaces, increased staff absenteeism, and reductions in workforce productivity disrupt day-to-day operations, including theatre activity and planned care. These pressures spill into social care as well, with heat-related strokes and long-term conditions driving additional demand and associated costs.

These strains illustrate how vulnerable the health and care system becomes during extreme heat, highlighting the need to strengthen resilience and to put in place a coherent set of adaptation measures that can reduce these risks.

Optimal adaptation package

The adaptation measures included in this report span: (1) measures to reduce demand on health care during extreme events, for example providing care in the community, public cooling stations, health advice etc., and (2) supply side measures which improve the ability of health care facilities and professionals to provide care during extreme heat, such as passive and active cooling in hospitals, changing working patterns etc.

Both types of measures will be important. To reduce the strain on acute healthcare during periods of extreme heat, preventative care and community-based health care could deliver a significant risk reduction and health benefit by ensuring those most vulnerable in communities are supported. Similarly, the provision of care homes for the elderly and social care for those most at risk can simultaneously reduce risks of heat-related illness and mortality while easing the pressure on acute healthcare services. The healthcare system will need to adapt working patterns and ensure staff are equipped and trained to respond to heat events. Last but not least,

the ageing healthcare estate will need to be upgraded to ensure indoor temperatures can be kept within safe ranges for both patients and staff.

In total, adaptation measures required to mitigate the heightened risk of mortality, A&E attendance, and emergency admissions, are estimated to cost (an additional) around £17.6 billion in Net Present Value (NPV) between now and 2080. These measures are projected to deliver health system benefits of £25.7 billion – a net benefit of £8.1 billion.

Reflecting the nature of the extreme heat hazard, exposure and vulnerability of the population, the urgency of adaptation measures is uneven across the UK. For example, the South East has a growing and elderly population, which is particularly at-risk of extreme heat; investing in cooling measures for care home residents in that region is likely to be more cost-effective than the same measure in, for example, the North of England, Scotland, and Northern Ireland.

Retrofitting hospitals is the most expensive adaptation measure identified, but also generates both the highest benefit, and the highest benefit-cost ratio. While retrofits should be targeted first to regions where extreme heat poses the highest risks, they are likely to represent good value for money across much of the UK, particularly as heat pumps support other key outcomes, such as the decarbonisation of heating and cooling under the Seventh Carbon Budget.

2 Introduction

Rising temperatures pose an escalating and uneven threat to public health in the UK, with extreme heat events disrupting healthcare delivery and straining system capacity. As the frequency, intensity, and duration of these events increase, so too does the pressure on individuals, communities, and public services, particularly within health and social care. This pressure is not distributed equally across the UK. Different regions experience varying levels of heat exposure, and within these regions, impacts vary significantly across different population groups. These disparities reflect inequalities in health status, housing quality, and socioeconomic conditions.

The summer of 2022 underscored the urgency of this issue, with nearly 3,000 excess deaths associated with five extreme heat events.[6] One in five UK doctors also reported cancellations of elective surgeries during the heatwaves, primarily due to staff shortages and overheating in surgical theatres.[7]

This work forms part of a wider programme of work commissioned by the Climate Change Committee (CCC) to support the UK's Fourth Climate Change Risk Assessment (CCRA4). Specifically, it contributes to the CCC's Well-Adapted UK report, a policy-facing synthesis designed to guide senior decision-makers across all four nations of the UK government.

This report focuses on one of the CCC's key risk areas: the impacts of extreme heat on health outcomes and the functioning of the health and care system, and how best to reduce these risks. For this study, extreme heat is defined based on regional thresholds, above a minimum of 25°C. There is evidence of increased health risks, including mortality, at lower temperatures; these are not captured here given the focus on the increasing risk of extreme heat only.

The analysis is shaped by two overarching objectives:

- To assess the scale and distribution of extreme heat-related health risks, including mortality, morbidity, demand for health and care services, and resilience across health systems
- To identify and appraise cost-effective adaptation strategies, from public health measures to infrastructure and service-level interventions, that can reduce risks and build long-term system capacity

The approach to this technical study draws on insights from climate science, public health, and health economics. It was structured into two key phases guided by consultation with the CCC and a multidisciplinary Steering Group to ensure methodological rigour, policy relevance, and real-world impact. The first phase involved a rapid evidenced review, and the second phase comprised bespoke scenario-based modelling of future health impacts, the vulnerability of population and the health system to extreme heat, and appraisal of adaptation options.

[6] UK Health Security Agency. (2022). Heat Mortality Monitoring Report: 2022. London: UKHSA. Link
[7] GreenSurg Collaborative. (2023). Elective surgical services need to start planning for summer pressures. BJS, 110(4), 508–510. Link

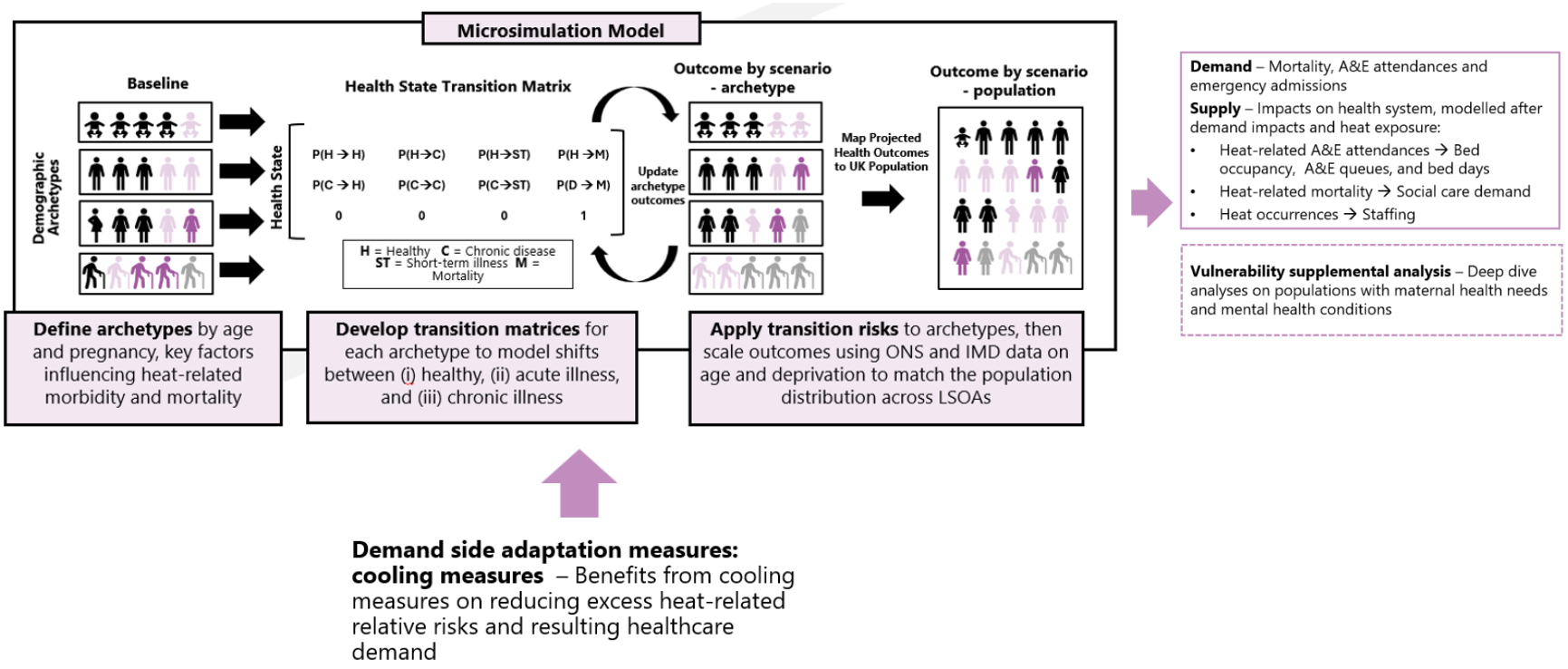
By establishing a robust evidence base and identifying practical responses, this report aims to support climate adaptation planning across the health sector, helping to ensure the UK is better prepared for the growing health challenges posed by extreme heat.

The report focuses on UK-wide analysis to support high-level planning of how the UK health sector may need to adapt in response to increasing occurrences of extreme heat. While it is built up from modelling of extreme temperatures at granular regional level (e.g. LSOAs), the assessment of extreme heat risk is aggregated up to each of the 12 main UK regions, as is the assessment of adaptation options and prioritisation. There may be significant variation in how each of the 12 UK regions may experience risk of extreme heat, and how each region should adapt, which is beyond the level of detail captured in this report.

The remainder of this report is structured as follows:

- Section 3 – Methodology
- Section 4 – Literature Review
- Section 5 – Impact of Extreme Heat on Health Outcomes
- Section 6 – Optimal Adaptation Response
- Section 7 – Conclusion
- Section 8 – Appendix

Figure 1. Our overall modelling approach



Source: Edge Health & Greencroft Economics

3 Methodology

3.1 Defining the Extreme Heat Hazard and Exposure Levels

Three factors need to be considered in defining extreme heat. First, the type of metric used to measure heat. Next, the threshold above which heat should be considered extreme heat. Finally, at what point(s) in time to measure heat.

The hazard metric used to represent and extreme heat day in this study is maximum air temperature equal to or higher than a regionally varying threshold of 25°C to 28°C. However, it is important to note that a range of relevant heat-related metrics exist, each of which may have different implications for human health impacts.

3.1.1 Selecting a heat hazard metric

Air temperature is used as the metric to measure heat in this study. However, air temperature is not the only metric that could be used, with no single metric perfectly capturing the complexity of the relationship between heat and human health. The ability of the human body to cool itself depends not only on ambient temperature, but on its ability to cool itself down. Body temperature is affected by a range of factors including air temperature, air flow, humidity, solar irradiation levels etc. This matters both in terms of choosing the right metric to measure extreme heat, and when considering adaptation measure to respond to extreme heat.

The following metrics were evaluated:

- *Air temperature.* This metric is widely used in literature that seeks to estimate the relationship between heat and mortality and is relatively simple to construct both a historic baseline and source projections for future scenarios. However, air temperature is only one of several factors that influence human heat stress and does not capture other important components such as humidity, radiant heat, and airflow.
- *Wet bulb globe temperature (WBGT)*, or the simplified WBGT. This metric captures all the factors that are relevant for human health impacts (air temperature, humidity, radiant heat, air flow). However, the evidence linking WBGT to the impacts of interest in this study – mortality, hospital admissions, and hospital attendance – is much more limited than the evidence using air temperature. It is also more complex to measure consistently and to project into future scenarios.

Defining extreme heat

For this study, extreme heat is defined as maximum external air temperatures meeting or exceeding LSOA/data-zone level thresholds that have been derived following the UK Met Office's approach to meteorological heatwave definition (**Error! Reference source not found.**).[8]

[8] UK Met Office, Link

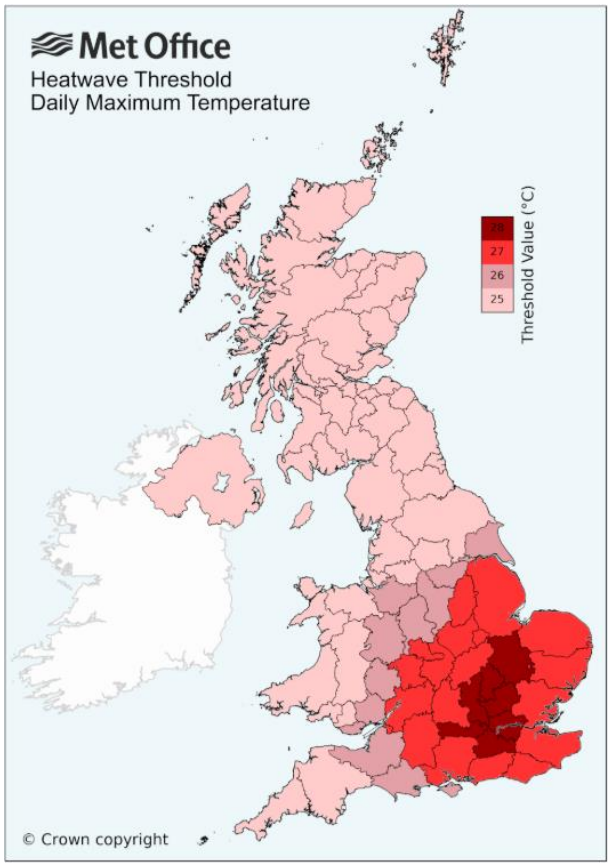
The Met Office uses a regionally-varying threshold across the UK, of 28°C for London and surrounding counties and then two rings of 24 counties for which the threshold is 27°C and 12 counties for which the threshold is 26°C. The remainder of the UK, including all of Northern Ireland, Scotland, much of Wales and the South West, have a 25°C threshold. In this report, the same definition of extreme heat has been applied but computed at LSOA/data zone level rather than regionally to ensure exposure metrics are targeted to the most granular spatial units possible.

The Met Office thresholds are used as a reasonable and established threshold for heat days that could be considered extreme – outside of the normal experience of each of the UK regions. There may be health impacts, including a moderate increase in mortality at lower temperatures, which are not considered within the scope of this assignment as they are within norms that the health sector already responds to as part of its routine operations.

Heat-health alerts issued by UKHSA use slightly different maximum temperature thresholds as one of the factors.[9] The heat thresholds are at least 28°C in London and 27°C in all other regions (i.e. higher than the Met Office's meteorological definition for heat waves), and temperature is one input alongside other metrics when deciding whether to issue an alert and at what level. In this report, we define extreme heat using the Met Office's threshold-based meteorological criteria. This uses a slightly lower temperature threshold for some regions that the UKHSA heat-health alert guidance would use, although the difference is relatively minor.

[9] UKHSA and Met Office (2025). "User Guide - Weather-Health Alerting System", Link

Figure 2. Threshold based approach to define extreme heat days



Source: UK Met Office, Link

While extreme heat days are highly concentrated in the summer months of June to August, all days throughout the year are included in this study and the discussion below. In the baseline period, 89% of all days over 25°C were between June and August, and 10% in either May or September.

Different regions experience different health impacts for the same maximum daily temperature for a range of reasons. For example: (1) average temperatures or night-time temperatures may vary by region, for a given maximum temperature, (2) different regions may have different humidity, radiation, or air flow at the same air temperatures, (3) the impact on human health is determined to a certain extent not by a fixed biological response common to all people, but by relative temperature changes compared to what people are used to experiencing. So, a 28°C day for someone living in Inverness may experience a different impact than a 24°C day for someone living in London. The variation in relative risk by regions is discussed further in Section 5.4.1.

While maximum air temperature is used to define extreme heat days, in most cases the corresponding average (mean) temperature is used to model the heat-health relationship. This is because most of the epidemiological literature reviewed establishes heat-health relationships

using daily mean temperatures.[10] In practice this means, for example, that for an extreme heat day with a *maximum* air temperature of 25°C, the health impacts are based on the relationship between the *average* air temperature on that day (which could be for example 14°C).

3.1.2 What point in time to measure extreme heat

For simplicity, this piece of work defines an extreme heat occurrence as each individual day above the threshold. In practice, there are several other considerations that have important implications on human health in the context of extreme heat.

The first is the persistence of the heat within a single day. There is evidence that the body can recover (at least to some extent) if night-time temperatures are low. So, a day with both a high maximum temperature and a high minimum temperature is a more important hazard than a day with a high maximum temperature but a relatively cooler minimum temperature.

Another consideration is the duration of a heatwave, spanning several days. A single hot day poses less risk to human health than several days or weeks of sustained high temperatures. The UK Met Office defines a heatwave as three consecutive days of high temperatures (above the regional thresholds set out in **Error! Reference source not found.**).[11]

While both within-day and consecutive days are important, they are not used in the modelling here. While (as noted above) both duration of heat events, and day-night temperature variation are important, there is insufficient evidence to quantify and model these parameters separately, within the limitations of this scope of work. Nonetheless, as discussed in Section 5.1, it is worth noting that not only the number of hot days is expected to increase, but that these are likely to be contiguous, resulting in prolonged hot periods. Given this, the impacts presented here are likely to be conservative – as consecutive hot days will accentuate health risks.

3.1.3 Extreme heat scenarios

Exposure to extreme heat is estimated for a present-day baseline and for two future climate scenarios. A detailed description of the data used and approach to generating these baseline and future exposures is provided in Section E, which is summarised briefly here.

The present-day baseline is constructed using average temperature profiles over the period 1991-2020. The two future scenarios are estimated at two single points in time – in 2030 and 2050:

- *The central scenario* corresponds to an average global warming level of 1.5°C by 2030 and of 2°C by 2050, compared to pre-industrial levels.

[10] Son et al. (2019) Temperature-related mortality: a systematic review and investigation of effect modifiers, Link, has estimated ~45% of epidemiological literature uses daily mean air temperatures

[11] McCarthy et al (2019) "A new heatwave definition for the UK", Link

- *The reasonable worst-case scenario* corresponds to average global warming levels of 2°C by 2030 and 2.5°C by 2050.

These two scenarios are selected in-line with guidance from the UK Climate Change Committee and are intended to make sure planning takes into account a reasonable central-case scenario for future climate and a reasonable worst-case. It does not represent an absolute worst-case tail-end scenario – there could be plausible (but low likelihood) future scenarios with much higher occurrence of extreme heat which could be extremely impactful. This is because the modelling approach selects the worst-case ensemble member (out of 16 ensemble member models), but all of those 16 models are defining a worst-case scenario as 2°C global warming levels by 2030 and 2.5°C global warming levels by 2050.

3.2 Exposure of the UK Population to Extreme Heat

The exposure of the UK population to extreme heat is assessed on the basis of the number of person-days which people are exposed to the heat hazard defined in Section 3.1. For present day, this is simply the extreme heat day occurrences described above, weighted by the population in each region that would be exposed to those occurrences. To estimate future exposure, the UK population is forecasted using local authority specific population projects (for details of the datasets used, see Section C.3).[12]

3.3 Vulnerability of the UK Population to Extreme Heat

Vulnerability of the UK population to extreme heat is a function of the extreme heat hazard (Section 3.1), exposure of the UK population to the hazard (Section 3.2), and how sensitive the population is once exposed to the hazard.

Two key factors affect the sensitivity of people exposed to extreme temperatures:

1. **Demographic change** – The changing age structure of the UK population, particularly population ageing, is likely to lead to a population that is more sensitive (vulnerable) to extreme heat.[13]

   Demographic change is projected using the same dataset as for population projections, at Local Authority level (for details of the datasets used, see Appendix C.3).

2. **Multimorbidity prevalence** – Multimorbidity prevalence and the multimorbidity-adjusted mortality rates were estimated for the underlying population at present-day baseline.[14] The prevalence of multimorbidity and underlying health service utilisation

[12] Within each Local Authority, each LSOA's population is assumed to grow at the same rate as the larger Local Authority.
[13] Falchetta, G., De Cian, E., Sue Wing, I. *et al.* Global projections of heat exposure of older adults (2024). Link
[14] Adjusted hazard ratios from a UK Biobank cohort study are used to modify baseline all-cause mortality rates by the number of long-term conditions, in which multimorbidity is defined by >=2 long-term conditions (Link). The prevalence of chronic illness is estimated using the age-weighted prevalence of multiple long-term conditions from an England-wide population study based on GP data (Link).

rates (A&E attendance and emergency admissions) by age groups are assumed to remain constant in our projections. However, demographic change (i.e. the ageing population) means that multimorbidity prevalence will grow overtime.[15]

Demographic change will substantially alter the UK population's vulnerability to extreme heat. As discussed in Section 4, elderly people over the age of 60 are much more vulnerable to extreme heat.[16] Future demographic shifts reflect an ageing population that will be inherently more susceptible to adverse heat-related health impacts. Consequently, the projected rise in heat-related deaths is driven by both temperature change and changes in population size and age structure.

This study also assumes vulnerability is invariant over time. That is to say that the current estimates of vulnerability (i.e. the relative risks discussed in Section 3.4 below) are based on evidence today, and assume populations are equally vulnerable in the future. This may be an overly cautious assumption – it is also possible that as temperatures increase, there will be physiological adaptation such that vulnerability decreases as temperatures increase.

A final factor important for vulnerability, is where people experience heat events. While the hazard metric used in this study is external air temperature, many people will experience higher temperatures indoors. For example, as outlined in the adaptation sections below, many elderly individuals – especially those over 75 – will not be exposed to higher outdoor temperatures. Instead, their risk is shaped by how rising outdoor temperatures affect the indoor environment of their homes or care homes.

3.3.1 Population archetypes

The model simulates the impact of extreme heat on the population by grouping individuals within that population into mutually exclusive archetypes. These archetypes reflect population cohorts with differing levels of vulnerability. These archetypes are primarily defined based on age ranges. The age ranges used are: (1) 0-4, (2) 5-17, (3) 16-64, (4) 65-74, (5) 75+. Within each age range, multimorbidity is also assessed to include the impact of having two or more long-term conditions on the risk of mortality during extreme heat events.[17] This captures key vulnerability factors identified from the literature, specifically age-related physiological differences and the compounding effects of multiple chronic conditions on the response to extreme heat.

[15] Dambha-Miller et al. Temperature extremes, climate change and multimorbidity: A rapid scoping review, Link
[16] Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O (2009) Heat stress in older individuals and patients with common chronic diseases, Link
[17] For A&E attendance and emergency admissions, age remains the primary archetype, as the literature does not provide robust evidence for multimorbidity-specific relative risks for these outcomes. Deprivation is assessed separately through distributional analysis at the MSOA level.

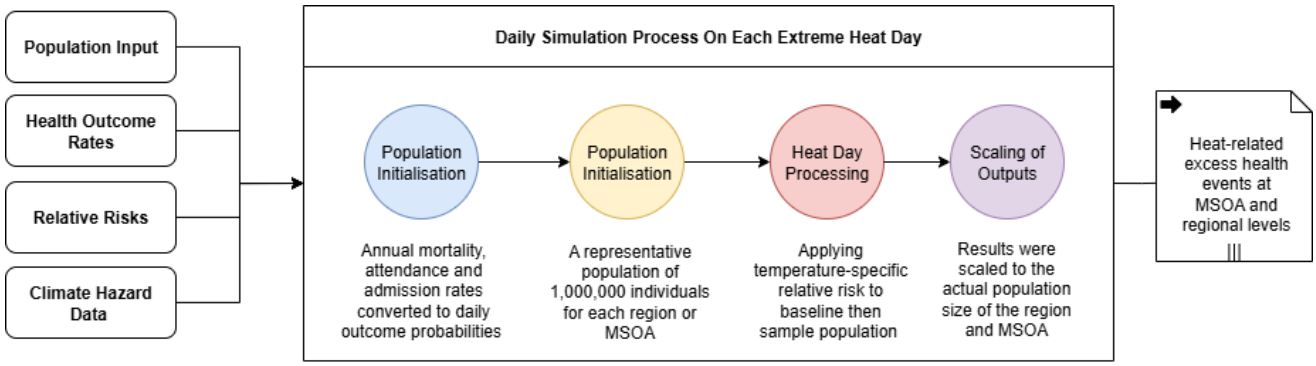
3.4 Modelling Impact of Extreme Heat on Health Outcomes

3.4.1 Microsimulation modelling framework

The microsimulation modelling framework estimates the health impacts of extreme heat across the UK's four nations by simulating the impact of temperature exposure on population-level health. This framework integrates climate projections with demographic data and health-outcome relationships to assess current and future heat-related health burdens.

For each extreme heat day, the model estimates the likelihood of excess heat-related health outcomes for each population archetype by applying literature-derived relative risks to baseline health outcome rates. These relative risks are based on daily mean temperature and vary by age group and health outcome type. The simulation model estimates heat-related mortality and morbidity for the UK's four nations following the process outlined below (Figure 3.). More details of the modelling steps and assumptions are outlined in Appendix C.

Figure 3. Overview of the simulation model framework



Source: Edge Health & Greencroft Economics

The following outlines the model inputs and simulation steps used to estimate heat-related health impacts:

- **Simulation input:** The simulation model estimates heat-related mortality and morbidity for the UK's four nations using the following inputs:
    - *Population demographics* during the three time periods: 1991-2020, 2030s and 2050s
    - *Health outcome rates*
    - *Temperature-related relative risks*
    - *Projected extreme heat occurrences under varying climate scenarios*
- **Simulation steps**:
    1. Input populations are constructed for the three time periods (1991-2020, 2030s and 2050s) by age band and multimorbidity at the regional and MSOA level.

2. These populations have underlying baseline mortality, A&E attendance and emergency admission rates, which are converted from annual to daily probabilities.
3. For each extreme heat day, excess risk is calculated by applying age-adjusted relative risks from the literature to baseline all-cause rates for health outcomes (mortality, attendance and admissions). The likelihood of an excess heat-related health event for each individual on each extreme heat day is calculated as:

$$\text{Excess Heat Related Health Outcome} = \text{Baseline Health Outcome Rate} \times (\text{Relative Risk} - 1)$$[18]

4. A representative population per region is then sampled based on the excess risk using a binomial distribution to estimate the number of individuals experiencing each heat-related health outcome.
5. These results were scaled to the actual population size, producing estimates of excess heat-related health outcomes at regional and MSOA levels.

Alongside this, the impacts on the health system were modelled from two angles: 1) healthcare capacity and 2) demand and staffing. Outputs from the simulation model were used to predict levels of A&E attendances, A&E admissions, and strokes to understand increases in demand. Specifically, our modelling includes only direct effects on health, excluding indirect effects such as impact of heat on food chains. NHS public figures were used to calculate increased bed occupancy and its costs, as well as staff absences and the cost of replacing staff. Figures from literature were used to calculate the projected impact on the wider healthcare system.[19]

3.5 Adapting to Extreme Heat

The overall approach to determining an optimal adaptation package is summarised in this section, while a detailed explanation of the costs and benefits of adaptation measures is provided in Section H.

The aim of the adaptation modelling is to provide a UK-wide estimate of the optimal approach for the health sector to adapt to the increased risk posed by extreme temperatures. The optimal adaptation package is such that the net benefits of adaptation are maximised – adaptation measures are incurred up to the point that they deliver higher benefits than their costs.

The ability of the UK healthcare system to respond to extreme heat events could operate through one of two channels. Either (1) by reducing the demands on health care services during extreme heat events, or by (2) augmenting the ability of health services to respond to the increase in health needs during extreme heat events.

[18] Hundessa et al. (2025) Global excess deaths associated with heatwaves in 2023 and the contribution of human-induced climate change, Link
[19] Appendix C – Data Sources

A Multi-Criteria Analysis (MCA) framework was used to prioritise and sequence measures. An optimal adaptation package was developed based of this MCA analysis, and the optimal package tested against alternative packages.

3.5.1 Developing a longlist of measures

A focussed literature review was supplemented by input from engagement with 23 key experts. Expert input was sought through Steering Group meetings and through bilateral interviews, to cover NHS representatives from each of the devolved nations, UKHSA leads and academic specialists, and academic experts. Respondents provided inputs on the emerging longlist, and advised on practical constraints, and co-benefits not well-captured in the literature. Their insights helped identify new adaptation measures and refine the definitions, costs and benefits of others. For example, (1) identifying heat pumps as a cost-effective and low-carbon active cooling technology, (2) highlighting workforce implications and (3) informed preliminary feasibility scores later formalised within the MCA framework.

Each measure went through a two-stage screening process. First, relevance was confirmed by mapping the intervention to at least one priority extreme heat health risk type (mortality, admissions, attendance). Second, an evidence-grading matrix appraised data depth and quality, ranking measures from "quantifiable" (robust cost and effect parameters) to "qualitative only" (directional evidence, insufficient for monetisation). Where quantitative estimates existed, parameters were extracted for model inputs; where data were partial, expert elicitation bounded uncertainty. The filtered list constituted the basis for the MCA scoring that follows.

3.5.2 Prioritising adaptation packages – MCA

The MCA assessed each adaptation measure against eight criteria:

1. Capital costs
2. Operating costs
3. Direct benefits (risk reduction of heat-health impacts, avoided costs)
4. Implementation feasibility
5. Co-benefits (such as carbon emissions reductions)
6. Scalability
7. Flexibility and option value
8. Distributional targeting and distributional benefits

Each measure was scored between 1 (worst, e.g. high cost or low benefits) and 5 (best) for each criterion. The scores were based on a review of evidence from literature and stakeholder consultations, but are inherently judgement calls, based on limited underlying information.

The scores were weighted and summed for each adaptation measure. Four different weightings were applied, to test the relative importance of each criterion.

1. *Costs and benefits (risk reduction) – criteria 1-3:* assessment of the costs and direct benefits, with overall costs and benefits having equal weighting.
2. *+ Feasibility – criteria 1-4:* as above, including an assessment of the feasibility of delivering the measure.
3. *+ Co-benefits – criteria 1-5:* as above, with an assessment of the potential to delivery co-benefits.
4. *All accounted for – criteria 1-8:* as above, now also including an assessment of scalability, flexibility/option value, and the distributional impact of implementation.

Scores for all four weightings are reported in Table 45 of Section G. The fourth "all accounted for" weighting was selected as the basis for prioritising the longlist, as it assesses the full array of factors for each adaptation measure. Based on the resulting MCA scoring, measures were allocated into the categories below:

- *Immediate actions:* measures which, at least in high-risk areas, should begin immediately, and be implemented within a 5-year horizon. These are "low" and "no" regret actions.
- *Near-term actions:* measures where the benefit cost ratio is highly likely to be positive at a medium level of risk from extreme heat and should be implemented in the very near-term in at-risk regions. They may be associated with high initial expenses and entailing some lead time and costs for preparation. Roll out is expected to commence within 5-10 years for high-risk areas, and within 10-20 years for regions at medium or high risk (see regional risk scores below).
- *Medium-term actions:* measures with the potential to deliver substantial risk reductions but which also come with relatively higher costs and should therefore only be implemented once regions progress to a higher extreme heat risk level.
- *Watching brief:* measures where there is not sufficient evidence on the magnitude of costs and benefits to prioritise rollout. These are classified as "watching brief" and should be monitored, with further information gathered, and implemented if circumstances evolve (or as a result of new information). These measures are not included in the cost-benefit appraisal results presented in Section 5.8, but should be regularly reviewed and updated as more evidence is gathered on their effectiveness.

The resulting prioritisation of measures is presented in Table 1 below.

Some of the immediate actions are policies that would be pre-requisites to being able to implement infrastructure and other solutions. For example, there is insufficient information on the current status of the NHS building stock's resilience to and ability to respond to extreme

heat, so before any programme of investment in retrofitting would be carried out, an investigation would need to be carried out to understand appropriate site-specific solutions.

Immediate actions include low-hanging fruit, while near-term actions also capture high-priority actions, but where rollout would have to be more carefully managed to balance implementation costs with health benefits. For example, an immediate action is to ensure new hospital builds are designed considering the potential exposure and vulnerability in that region to extreme heat, as not doing so would risk expensive lock-in, requiring more costly retrofits in future. For existing NHS building stock, the immediate priority is to decide the appropriate site-specific adaptation approach. Each estate will need to carry out a more detailed site-specific study of the state of buildings, their overheating risk, and the prevalence of adaptation measures such as passive and active cooling already available. This will help inform which are the appropriate solutions to rolled out taking into account the specific characteristics of each site – hence retrofitting existing facilities is phased across immediate, near term, and medium-term measures.

As described in Section 3.6 below, how quickly the immediate and near-term actions should be implemented varies depending on the extreme heat risk profile of each region. In higher-risk regions, near-term priorities should be implemented almost immediately, while in regions that are low risk throughout the 2030s, the same near-term measures should be deferred.

Table 1. Categories of adaptation measures

	Immediate Action	Near-term	Medium term	Watching brief
Demand side	Heat-Health Action Plans (Local Authorities)	Improve heat-preparedness of care homes	Public cooling spaces	
	Preventative contact with care-at-home	Heat advice and information services		
	Building public awareness			
Supply side	Targeted staff training for extreme heat events	Increase maintenance and facilities management during heat alerts	Adapt working patterns and staffing across the health care system	Increase availability of rapid response and ambulances during heat events
	Health facility heat management policies	Medium intensity cooling (e.g., dedicated cooling stations)	Improve cooling / storage / backup of critical (incl. digital) infrastructure	Protocol for regional patient transfer
	Health facility heat and humidity monitoring		Staff refreshment policies and guidance nationwide	Improve resilience of medical supply chains
	Retrofit policy for at-risk health centres (hospitals)		High intensity cooling (e.g. full climate control with A2A heat pumps)	Train community health care workers

	Low intensity cooling (e.g. low-cost passive cooling)	Stock management of cold chains and heat-vulnerable supplies
	Building code/design for new-built facilities (hospitals)	

Source: Edge Health & Greencroft Economics

3.5.3 Description of the watching brief measures

Four measures are allocated to the watching brief category on the basis that there is insufficient evidence to quantify their costs and benefits and to classify as an immediate or a near-term action:

- *Protocol for regional patient transfer:* To respond to spikes in demand for hospital services, one response could be to transfer patients to nearby health centres with spare capacity. This is not modelled, as the arrangements are already in place through the Mutual Aid system – used in response to the Covid-19 pandemic for example. One of the risks of this approach that may warrant further study during future extreme heat events is that all hospitals in a region are likely to experience the same heat-related spike in demand at the same time, which may limit the flexibility to transfer patients across hospitals.
- *Increase availability of rapid response and ambulances in heat waves:* Heat increases demand for ambulance services and patients which must be then transferred to emergency departments. This requires: (1) increased availability of ambulance services during extreme heat, (2) vehicles that can keep vulnerable patients cool, and (3) availability at hospitals to receive patients from ambulances. This has not been modelled as there is insufficient evidence to quantify the costs or the benefits.
- *Improve resilience of medical supply chains:* There is limited evidence of both (1) the extent of the risk to medical supply chains as UK temperatures increase, and (2) the effectiveness of potential measures. Supply chain issues are likely to be broader than the UK, including ability of global supply chains to stand up to higher temperatures, which are likely to occur across whole regions at the same time, with the potential to both increase demand for certain medications, and to disrupt the supply of those medications.
- *Train community care workers.* Training community care workers could become an increasingly important part of how healthcare is delivered through decentralised models in the future.

3.5.4 Additional measures not assessed in this study

Five measures are not included in the shortlist, as their primary benefit is not to supporting the health care sector to adapt to extreme heat. These measures could deliver substantial co-benefits to the health care sector during periods of extreme heat but would not be justified primarily on the basis of the extreme heat. These measures are:

- *Investing in improving health on key co-morbidity factors:* Investing in preventative care and in promoting lifestyle change that could improve the health of the UK population could deliver significant benefits in general. It is also highly likely to contribute to reducing the health risks of extreme heat, since co-morbidity factors such as obesity, cardiovascular and respiratory diseases all increase the risks of heat-related mortality. This adaptation measure is not assessed as part of this study as its cost and feasibility is challenging to assess, and the benefits of improving the health of the UK population are far wider than the response to extreme heat.
- *Improve housing stock in key deprived / heat exposed regions:* Many people will primarily experience the effects of extreme heat at home – especially those most vulnerable (e.g. the elderly, those with long-term illnesses) who are least mobile. Improving housing stock, could generate a substantial reduction in extreme heat related health risks. However, the benefits of improving the housing stock expands far beyond reducing the risks associated with extreme heat. The potential benefits – including health benefits – of improving housing stock are explored in more detail in a separate technical assessment of the impact of higher temperatures in urban settings (see Arup (2026) *Heat Risk and Adaptation in the Urban Built Environment*).
- *Monitor and review heat stress protocol for at-risk professions:* Extreme heat may place pressure on workers, especially those in physically intense activities, and working outdoors or in indoor environments without appropriate cooling technologies. However, the risks appear to be mostly related to productivity and comfort, not on the health outcomes considered in this study (mortality, A&E attendance, or hospital admission).
- *Adaptation for key institutions, such as prisons and schools:* Extreme temperatures could have important consequences for children in schools, or for prison populations. However, there is insufficient evidence to link extreme heat to demand for health care services arising from prisons or schools. There may be a need to adapt health care provision within prison settings, which has also not been assessed in this study.
- *Green / blue spaces:* Green and blue spaces support health during heat events by lowering local temperatures (shade, cooler microclimates, etc.), and by improving mental health and overall resilience. They also deliver co-benefits, such as more physical activity, better air quality, and reduced morbidity, that strengthen population health. However, these effects are less directly related to extreme heat related mortality and A&E attendance and hospital admissions and are therefore not quantified in this study.

3.6 Cost-Benefit Appraisal

3.6.1 Valuing benefits

Throughout the report values are stated in 2025 prices. In the case of some of the evidence on costs and benefits where these are from recent years, we have used the nominal prices, as it is not clear whether these would have risen in line with general inflation, and so we have not adjusted these to a different 2025 value.

Two key metrics were used to value changes in population health outcomes, in line with the UK Treasury Green Book recommendations:[20]

- **Mortality** is valued using *Statistical Life Years (SLYs)*, comprising:
    - An estimate of the expected years of life lost (YLL), based on the individual's age
    - A monetary value of £60,000 per YLL
- **Morbidity** is valued using *Quality Adjusted Life Years (QALYs),* comprising:
    - An estimate of the reduction in quality of life (on a 0-1 scale) using EuroQol measures
    - A monetary value of £70,000 per QALY

For this study, the years of life lost is estimated on the basis of the average life expectancy at each age. This may result in an overestimate in the value of life lost, to the extent that those who most likely to die during extreme heat events are relatively more vulnerable than the population average for their age, and so would have a shorter life expectancy. For example, in care home settings, different assumptions on life expectancy of residents can have a significant impact on how the benefits of reducing heat risk are valued.[21]

A final benefit type considered is avoided cost. This is expenditure saved due to implementing adaptation measures; for example, avoided cost of hiring agency or bank staff due to staff productivity losses or absences.

While this approach is consistent with the Green Book guidance, it should be noted that there is considerable uncertainty surrounding the appropriate monetary value of health outcomes, where estimates could differ across geographies and years.[22]

These additional methodology choices were also adopted:

[20] UK HMT (2024) "The Green Book – Central Government Guidance on Appraisal and Evaluation", Link. Note that this is 2021-22 base price, we took nominal costs and benefits from estimates as it is not clear they would follow general inflation trends, therefore we have retained the nominal values from the time of the estimate.
[21] Ibbetson et al (2021) "Mortality benefit of building adaptations to protect care home residents against heat risks in the context of uncertainty over loss of life expectancy from heat", Link
[22] For example, a 2019 European study estimated QALY values ranging from €20,000 to €80,000 in Germany, with a UK-specific estimate of £30,786. Similarly, a 2020 UK Government review found evidence supporting a QALY value range of £30,000 to £40,000.

- QALYs are applied to partial years on a pro-rata basis for short-term acute illnesses caused by heat.
- Discounting follows Green Book guidance, using the lower 1.5% discount rate for health benefits (declining after 30 years).
- No additional value is included for dread or anxiety effects related to future heatwaves.

3.6.2 Valuing costs

Three types of costs are analysed for each adaptation measure:

- *Capex:* one-off upfront expenses to implement adaptation measures;
- *Repex:* costs to maintain capital, for example, expenses incurred to repair or replace equipment;
- *Opex:* recurring expenses associated with adaptation options, such as wages, electricity bills, etc.

Discounting of non-health related impacts (avoided costs, and costs) is done using the 3.5% discount rate specified in the Green Book guidance, declining to 3% after 30 years.

For the appraisal, all (health and non-health) costs and benefits are captured with a time horizon until 2080. Since the model only analyses three distinct points in time (baseline, 2030 and 2050), any annually recurring costs and benefits derived from model outputs are interpolated linearly between those years to capture changes over time (for example, due to a gradual increase in temperatures between 2030 and 2050).

3.7 Optimal Adaptation Packaging and Sequencing

3.7.1 Sequence adaptation measures

Adaptation measures should be rolled out according to the heat-health risk profile of across the UK and over time. While Section 3.5 has set out how each measure is prioritised for a given risk profile, this section describes how adaptation measures would be prioritised to deliver a sensible rollout across time and across UK regions.

Adaptation measures would be rolled out in higher intensity for the most at-risk regions (i.e. with both more measures introduced as risk increases, and more of each measure deployed). Regional risk is assessed on the basis of both exposure – i.e. frequence of extreme heat days and the size of the population exposed to those days in each region, and vulnerability – i.e. the underlying population's vulnerability when extreme heat events occur.[23] This risk assessment is applied for each of the 12 major regions of the UK, on the basis of the highest risk score across three criteria (Table 2): heat-related mortality, hospital admissions, and hospital attendance. The thresholds are determined based on an assessment of the current rates of mortality, admissions,

[23] As per the archetypes presented previously, vulnerability considers factors such as (1) age, (2) comorbidities, (3) deprivation

and attendance under the baseline climate scenario, and how these are projected to evolve under the future climate scenarios. This is a modelling assumption to provide a reasonable profile of how at-risk the different UK regions are to extreme heat between today and 2050, to enable sequencing of adaptation measures based on the risk profile of each region.

Table 2. Categorising regions by risk profile

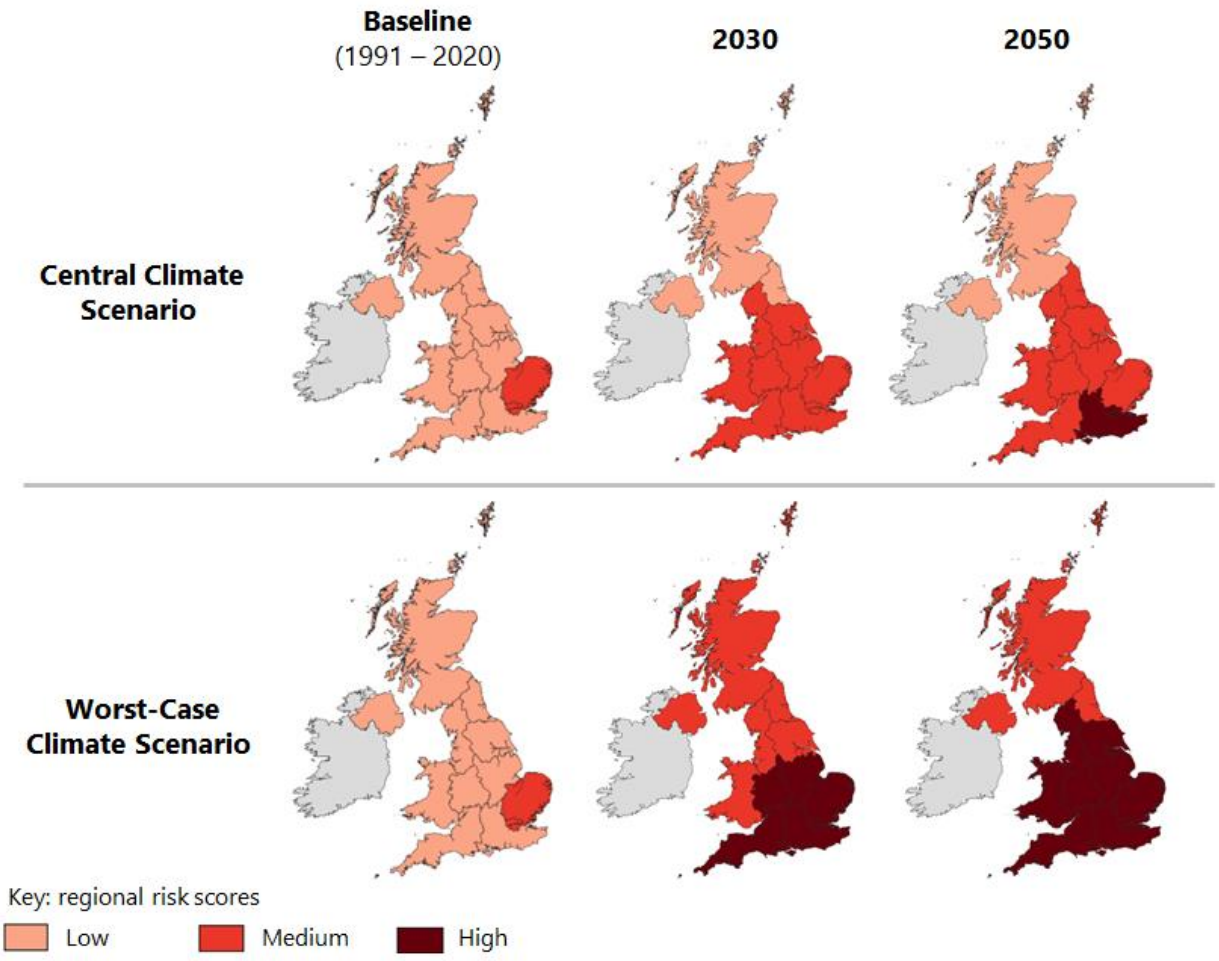
Risk factor (per 100,000 people)	Low risk	Medium risk	High risk
Heat-related excess mortality	< 4	4 – 8	> 8
Heat-related excess admissions	<10	10 – 40	> 40
Heat-related excess attendance	<30	30 – 120	> 120

Source: Edge Health & Greencroft Economics

This results in a gradation of risk profiles across regions and over time. Under present-day baseline (1991-2020) climate conditions, only two regions are classified as medium risk: London and the East England, with no regions at high risk (Figure 4). In the central climate scenario, there are still no high-risk regions by 2030, while all regions except the Northeast, Scotland, and Northern Ireland become medium risk. By 2050, London and the Southeast are high risk, while the Northeast also becomes medium risk.

This analysis may mask sub-regional priorities and is not intended to represent detailed spatial planning. It provides a high-level prioritisation for UK-wide planning, not a detailed needs assessment within each region. It may be that there are sub-regions which have characteristics that mean their heat-health risk profile is different from the rest of the region; for example, the right approach to and amount of preventative health care visits at home may vary by region both in function of risk, and how health care is currently delivered in that region.

Figure 4. Variation in risk profile across regions and time



Source: Edge Health & Greencroft Economics

3.7.2 Optimisation the package of adaptation measures

The ability to determine the optimal combination, and amount, of adaptation measures within a cost benefit framework is limited by the available evidence. For some of the adaptation measures, it is difficult to derive reliable estimates for both the benefits in terms of risk reduction, and for the costs which can then be scaled within and across regions of the UK. Furthermore, there is very limited evidence on how the effectiveness (marginal cost and marginal benefit) of adaptation measures would evolve as they are scaled up, or how measures may interact with one another.

The optimal adaptation package would be such that the benefit cost ratio of each measure is equal to 1. This has two implications:

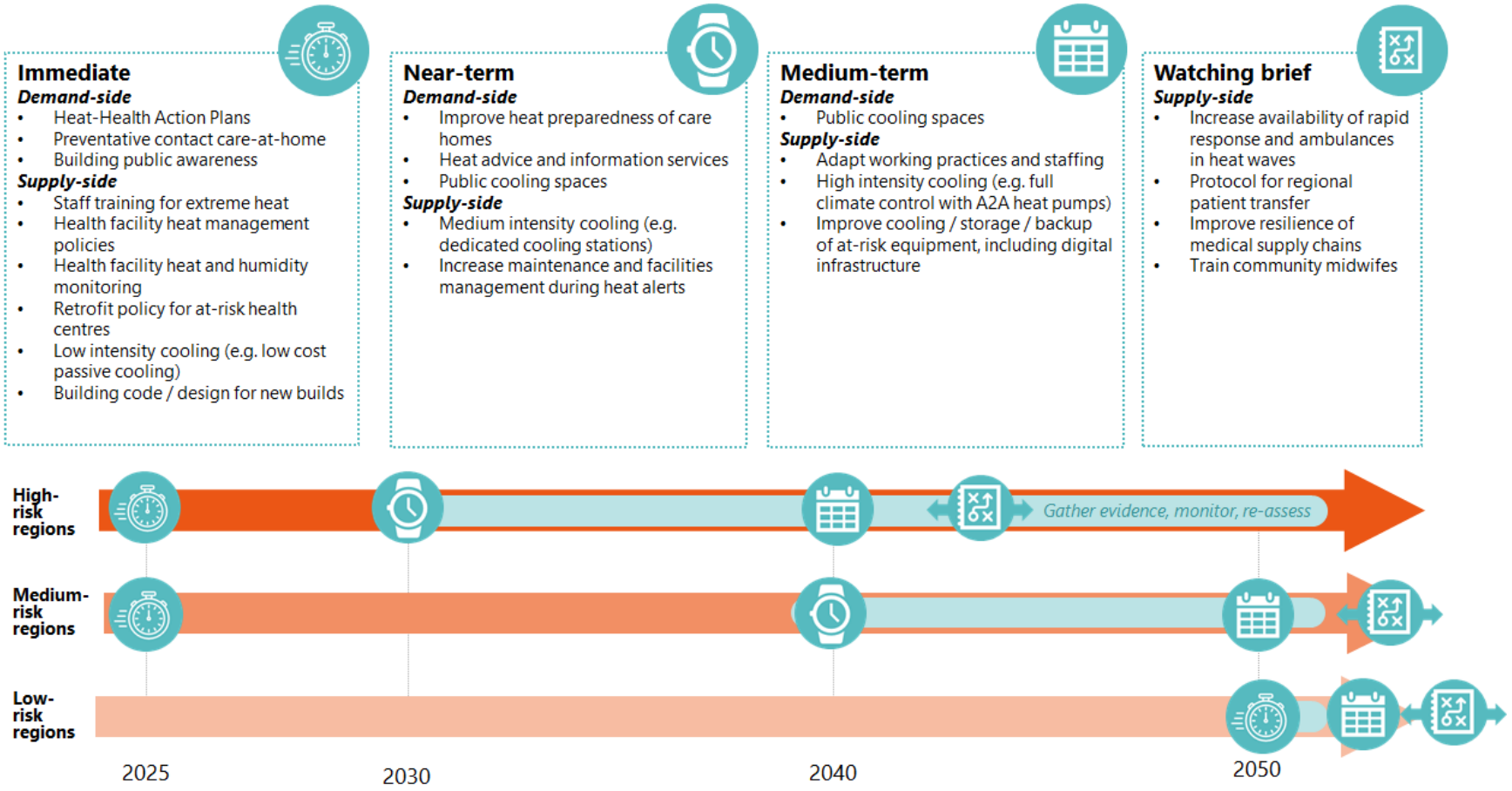
- Each measure should be implemented up to the point where the benefits no longer outweigh the costs. That is, incurring an extra pound of costs would not deliver (at least) an extra pound of benefit.
- Each measure should be implemented only if there is not another more cost-effective measure that could achieve the same benefit.

In principle, this would mean that each measure would be deployed such that spending a little more on "measure X" would deliver you the same amount of benefit per pound spent as if you spent the same increment on another measure. However, there is insufficient data and evidence available to come up with: (1) a detailed estimate of how marginal costs and marginal benefits change as each measure is scaled up, and (2) the interactions between measures.

An optimal package of adaptation measures is arrived at through a combination of quantitative analysis and a structured approach to determine phasing and sequencing. Given the limitations noted above, it is not feasible to fully optimise accounting for interactions between adaptation measures and how marginal costs and benefits change as a measure is scaled up. Instead, the optimal adaptation package is arrived at by combining (1) the prioritisation approach to provide a hierarchised timing of measures, and (2) an application of this hierarchy to each of the 12 UK regions depending on the evolution of the region's extreme heat related risk rating. The sequencing principles are illustrated in Figure 5, but it is important to note that the risk-rating per region is not static, as shown above in Figure 4.

The optimal adaptation package represents an indicative allocation of priorities at the UK-wide level, as a guiding principle.

Figure 5. Proposed optimal phasing of adaptation measures



Source: Edge Health & Greencroft Economics

3.7.3 Testing the optimal adaptation package

Notwithstanding the limitations on modelling different adaptation intensities, this section sets out various alternative adaptation packages and compares them to test the optimal adaptation package arrived at above.

The first key driver of the optimal package is timing. While there are already benefits to adapting to higher temperatures, particularly in the south of the UK, the nature of the risks increases substantially between today and 2050. This means that there are trade-offs between incurring adaptation costs today (and unlocking some existing benefits) and deferring the cost of some adaptation until the benefits increase.

The second key driver of the optimal package is varying regional deployment intensity. Given regions have different heat-health risk profiles, they are allocated a different intensity of adaptation measures.

To test these two key differentiating factors (timing and regional deployment), a set of alternative packages are considered, as set out in Table 3 and Table 4, with the results presented in Section 5.8.

- *Package B – Front-load investment:* bring forward investments that involve capital investment to as early as possible, to explore the benefits (or disbenefits) of bringing forward the major one-off investment costs.
- *Package C – No regionality:* implements adaptation measures equally across all of the UK regions, to test the regional phasing matches the regional risk profiles.
- *Package D – Accelerated:* tests the effect of moving forward all adaptation measures but maintains the regional phasing approach.
- *Package E – Deferred:* tests the effect of deferring all adaptation measures but maintains the regional phasing approach.

Table 3. Adaptation packages – varying capex profiling

Adaptation measures / bundle	Package A Optimal	Package B Front-load investment
Local heat-health action plans	Immediate	Immediate
Heat advice and information	Near-term	Near-term
Preventative care at home	Immediate	Immediate
Public cooling	Medium-term	Medium-term
Cooling in care settings	Near-term	Immediate
Retrofit policies	Immediate	Immediate
Low intensity cooling (e.g. low-cost passive cooling)	Immediate	Immediate
High intensity cooling (e.g. full climate control with A2A heat pumps)	Medium-term	Immediate

Medium intensity cooling (e.g. dedicated cooling stations)	Near-term	Immediate
Increased maintenance	Near-term	Near-term
Adapt working patterns and staffing	Medium-term	Medium-term

Source: Edge Health & Greencroft Economics

Table 4. Adaptation packages – varying phasing

Action type	Package A Optimal	Package C No-regionality	Package D Accelerated	Package E Defer
High-risk regions				
Immediate measures	2025	2025	2025	**2030**
Near-term measures	2030	2030	2030	**2040**
Medium-term measures	2040	2040	2040	**2050**
Long-term measures	Monitor	Monitor	Monitor	Monitor
Medium-risk regions				
Immediate measures	2025	**2025**	2030	**2030**
Near-term measures	2040	**2030**	**2035**	**2050**
Medium-term measures	2050	**2040**	**2045**	**2060**
Long-term measures	Monitor	Monitor	Monitor	Monitor
Low-risk regions				
Immediate measures	2040	**2025**	**2035**	**2050**
Near-term measures	2081	**2030**	**2045**	2081
Medium-term measures	2081	**2040**	**2055**	2081
Long-term measures	Monitor	Monitor	Monitor	Monitor

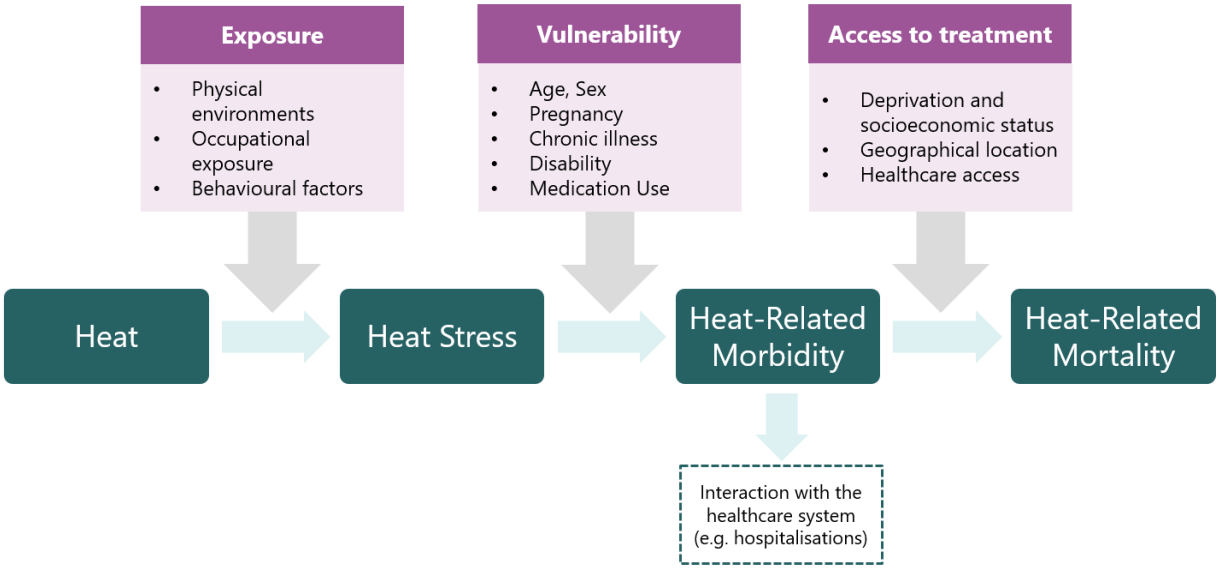
Source: Edge Health & Greencroft Economics

4 Literature Review

4.1 Overview of the Heat and Health Literature

The relationship between exposure to extreme heat and adverse health outcomes involves a complex causal pathway, progressing from initial exposure to hazard to final health impacts, such as illness or death (Figure 6).

Figure 6. Heat-health causal impact pathways



Source: Edge Health & Greencroft Economics, based on Kovats and Hajat (2008) Link

Most epidemiological literature quantifies impacts through relative risks (RR), measuring the increase in likelihood of adverse health outcomes associated with extreme heat exposure compared to baseline conditions, typically defining thresholds based on local temperature percentiles where health events begin to increase. Through a bottom-up approach of the literature review, UK-relevant studies published recently were reviewed. More details of the findings and the appraisal of the literature can be found in Appendix B.3 - Literature Review on Heat-Health Impacts.

Heat-related mortality impacts are robustly evidenced across the UK, with significant geographical variation, where the annual excess deaths related to heat are the highest in London and the South East of England, and lower relative risks in Scotland and Northern Ireland.[24]

[24] Gasparrini, Masselot et al. (2022), Small-area assessment of temperature-related mortality risks in England and Wales: a case time series analysis, Link

Evidence for morbidity outcomes is comparatively limited, with most UK studies focusing on hospital-related outcomes, including emergency admissions and A&E attendance. Overall, heat has a greater impact on mortality than on hospital admissions. For example, one time-series analysis found a non-significant 2.5% increase in admissions, but a significant 10.8% increase in mortality, though evidence is more limited on the heat-related impact on admissions.[25] Emergency admissions for respiratory disease, infectious disease, metabolic disease and injuries show significant positive associations with extreme heat exposure, while cardiovascular admissions demonstrate less pronounced impacts, despite cardiovascular conditions being strongly linked to heat-related mortality.[26] Risk of hospitalisations due to renal diseases are also heightened during heatwaves.[27] This highlights the differences in how heat affects various pathways between health outcomes as well as the differences in the healthcare seeking behaviour associated with heat.

For A&E attendances, one UK study on the London population indicates that heat does not significantly increase overall attendance rates (1.0%, 95% CI 0.8-1.4), although it does significantly impact age-specific attendance patterns. Specifically, younger age groups have the highest relative risks, in contrast to age-related mortality risk patterns, where older populations experience the greatest relative risks.[28]

4.2 Summary of Heat-Health Vulnerability Factors

A summary of the vulnerability factors related to heat-related adverse outcomes is shown below. For more details of the findings see Appendix B.3 – Literature Review on Heat-Health Impacts.

Table 5. Summary of vulnerability factors highlighted in the literature

Vulnerability Factors	Findings
Age	This emerges as the most critical vulnerability factor with the population aged 65+ being most vulnerable, where vulnerability increases by age in this age group. Heat-related relative risks also increase in those under five. For hospital admissions, younger children have the highest A&E attendance relative risks, contrasting mortality patterns.
Multimorbidity and disease-specific vulnerabilities	Individuals with chronic conditions face disproportionately high heat-related risks, specifically the relative risks for mortality due to respiratory and cardiovascular diseases are the highest. This is also due to the impact of medications on the thermoregulatory functions of elderly population.[29] Populations with mental health conditions show

[25] Kovats et al. (2004), Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK, Link
[26] Rizmie et al. (2021), Impact of extreme temperatures on emergency hospital admissions by age and socio-economic deprivation in England, Link
[27] Hansen AL, Bi P, Ryan P, Nitschke M, Pisaniello D, Tucker G. (2008) The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. Int J Epidemiol, Link
[28] Hotz and Hajat et al. (2020), The Effects of Temperature on Accident and Emergency Department Attendances in London: A Time-Series Regression Analysis, Link
[29] Wee J et la. (2023), Effects of Medications on Heat Loss Capacity in Chronic Disease Patients: Health Implications Amidst Global Warming, Link

	elevated heat-related mortality relative risks (4.9% mortality increase per 1°C).
Sex and demographics	Research shows that females, particularly older females, have slightly higher relative mortality risk during extreme heat events, though findings are inconsistent across UK literature and may be confounded by age effects.[30]
Deprivation	Studies examining deprivation effects on heat-related mortality have generally found minimal impact, with only one study showing significant effects on emergency admissions for injuries.[31]
Pregnancy and maternal health	International evidence shows significant heat-related risks of adverse neonatal and maternal health outcomes such as preterm births, hypertensive disorders of pregnancy and obstetric complications, but there is a lack of UK-based quantitative evidence.[32]
Outdoor working population	There is clear evidence on occupational heat stress on outdoor workers, such as impacting wellbeing and productivity.[33] However, there was limited evidence on the impact of their exposure on hospital attendance and admissions.

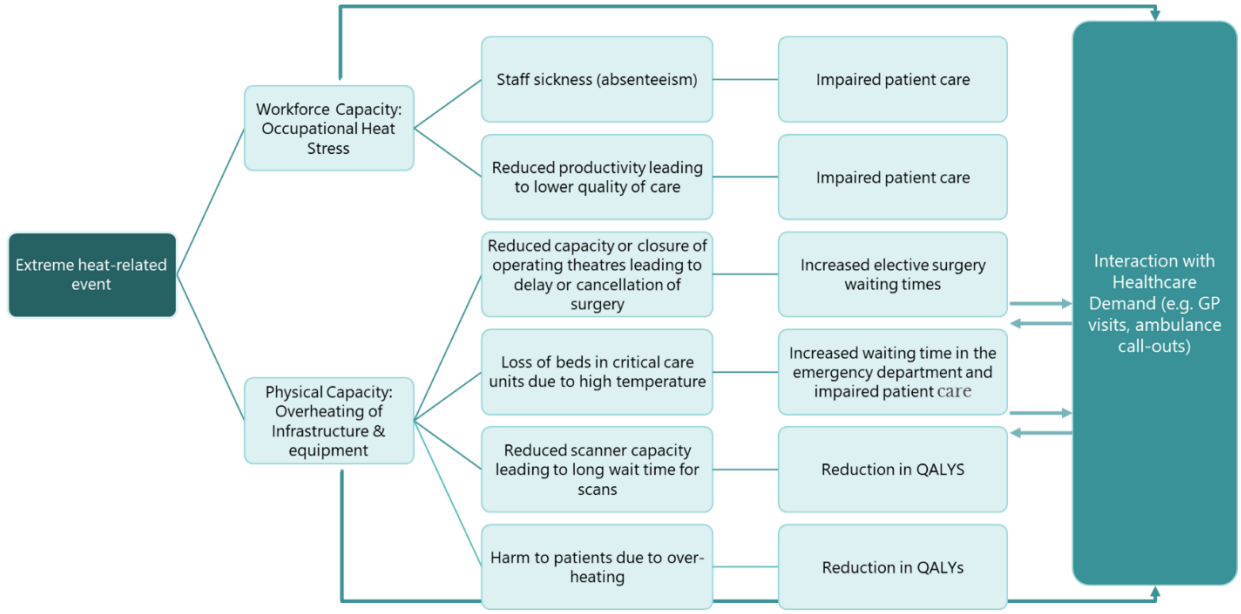
Source: Edge Health & Greencroft Economics

4.3 Overview of the Heat and Health System Literature

Extreme heat impacts the overall healthcare system through two primary pathways (Figure 7): by reducing the capacity of the system to deliver care (through impacts on infrastructure and the workforce) and by increasing the demand for healthcare services. These two pathways can and do interact; for example, during periods of extreme heat, the increased demand can create further pressure on the health system, thus adding pressure on the healthcare supply.

[30] Pinho-Gomes et al. (2024), Sex differences in mortality associated with heatwaves, Link
[31] Rizmie et al. (2021), Impact of extreme temperatures on emergency hospital admissions by age and socio-economic deprivation in England, Link
[32] Lakhoo et al. (2025), A systematic review and meta-analysis of heat exposure impacts on maternal, fetal and neonatal health, Link
[33] Ioannou LG et al. (2022), Occupational heat strain in outdoor workers: A comprehensive review and meta-analysis. Link

Figure 7. Healthcare system impacts of extreme heat events



Source: Edge Health & Greencroft Economics

Healthcare facility overheating is widespread across the UK, where overheating often occurs within clinical spaces despite low ambient outdoor temperatures.[34] The NHS England ERIC data shows overheating occurrences increased by 23% in 2022/23 compared to the previous year, although this may be affected by reporting bias.[35] Temperature monitoring studies highlight the extent of this problem; for example, Royal Berkshire Hospital breached overheating guidelines in all examined clinical areas during a 35-day assessment during the heatwave period from July to August 2018.[36] This is also prevalent in care homes, where some London-based care homes have been shown to consistently overheat across several overheating criteria.[37] Qualitative evidence from a survey of healthcare professionals suggests that hospitals lack summer pressure plans, and extreme heat has caused operating theatre and MRI room closures, loss of critical beds and equipment malfunctions.[38] However, there is a lack of evidence quantifying the system-wide impacts due to overheating likely driven by lack of systematic reporting.

Similarly, evidence on the impact of extreme heat on workforce capacity is scarce in the UK and largely qualitative. A UK survey of more than 1,000 healthcare professionals found that 90%

[34] Short et al. (2012), Building resilience to overheating into 1960's UK hospital buildings within the constraint of the national carbon reduction target: Adaptive strategies, Link
[35] An overheating occurrence is defined as an occupied ward or clinical area having a daily maximum of over 26˚C: This definition excludes incidents in areas defined as non-clinical space (e.g. medicine cabinets in central storage areas away from wards). The 26˚C threshold is set by the Heatwave Plan for England.
[36] Gough et al. (2019), Assessment of Overheating Risk in Gynaecology Scanning Rooms during Near-Heatwave Conditions: A Case Study of the Royal Berkshire Hospital in the UK, Link
[37] Gupta, et al (2021), Examining the magnitude and perception of summertime overheating in London care homes, Link
[38] Brooks et al (2022), Heatwaves, hospitals and health system resilience in England: a qualitative assessment of frontline perspectives from the hot summer of 2019, Link

reported occupational heat stress, which affected both their physical and cognitive performances. Additionally, 20% reported heat-related absenteeism averaging 2.2 days. Staff shortages emerged as the primary cause of cancellations during heatwaves, with one in five healthcare professionals reporting surgeries being cancelled in their hospitals, though the exact number of cancellations was not quantified.[39] A UKHSA-commissioned qualitative research showed that social care practitioners often have limited understanding of the health risks posed by extreme heat, both for the individuals they care for as well as for their own occupational exposure. This research also highlights the need for better communication of heat-health alerts to frontline workers.[40]

Given the significant gaps in the literature, with most UK evidence being qualitative rather than quantitative, the review was supplemented with grey literature sources. Two UK-based case studies, presented in Appendix B – Literature Review, illustrate the real-world consequences of extreme heat on health and healthcare systems.

4.4 Research Gaps and Limitations

Current UK heat–health evidence is limited in scope, consistency, and relevance, with notable gaps in morbidity impacts, methodological alignment, and healthcare system resilience. The following outlines key research gaps and limitations:

- **Evidence base availability**: Heat-health research focuses predominantly on mortality rather than morbidity outcomes. Most epidemiological studies characterising heat-health relationships were conducted before the COVID pandemic, meaning that potential changes to population vulnerability might not be adequately captured in current heat-health relationships. Additionally, much of the existing literature on heat and health originates from regions with historically higher temperatures, which limits its relevance to the UK.
- **Methodology and definitions of heat hazard**: Studies use a range of heat hazard metrics (for example, air temperature vs. heat index vs. WBGT) and varying threshold approaches (percentile-based vs. absolute temperatures) limit comparability and generalisation of findings. There are also challenges associated with the case definition of heat-attributed mortality using time-series analysis (e.g., whether mortality should be attributed to ambient heat or only during heatwave periods).[41] Lastly, most studies rely on short-term or event-specific data rather than longitudinal analyses needed to understand cumulative and long-term impacts.
- **Healthcare system knowledge gaps**: There is a lack of quantitative evidence on how extreme heat affects healthcare supply capacity, workforce productivity, and infrastructure resilience. There is insufficient understanding of demand-supply

[39] GreenSurg Collaborative (2023), Elective surgical services need to start planning for summer pressures, Link
[40] UKHSA (2024), Research exploring the experience of social care practitioners in relation to extreme temperatures, Link
[41] Bouchama et al. (2024), Beyond heatwaves: A nuanced view of temperature-related mortality, Link

interactions during heat events, costs of system disruptions, recovery times, and effectiveness of adaptation measures across NHS estates and social care systems.

5 Impact of Extreme Heat on Health Outcomes

5.1 Projected Occurrence of Extreme Heat

5.1.1 Baseline heat hazard occurrence

In the present-day baseline period, the UK experiences an average of 9.4 days per year exceeding 25°C. On these days, the daily mean temperature is 20°C. Most of these days above 25°C are concentrated in the south of the UK, particularly in Greater London, with 20.4 days over 25°C annually, and the East of England, with 16 days per year. In contrast, Scotland and Northern Ireland experience far fewer days over 25°C, at just 1.3 and 1.5 days per year, respectively.

Most hot days remain at relatively lower temperatures. Only 10% exceed 30°C, and just 0.34% reach above 35°C. More information on the occurrence of relatively higher hazard levels (hotter days) is described alongside future scenarios in Section 5.1.2 below.

5.1.2 Future heat hazard occurrence

Central scenario – extreme heat days

In the central climate scenario, the number of days above 25°C double in most regions by 2050 (Figure 8). Across all regions, there will be on a rise from 9.4 days per year above 25°C at present, to 17.4 days by 2030, and 21.3 days by 2050.[42] Most of this increase is expected to happen in the near term; by the 2030s, the UK will experience twice as many days over 25°C, with only a slight further increase between 2030 and 2050.

The highest relative increase in days over 25°C is in the South West, which where there will be three-times as many days over 25°C by 2050, rising from 8.3 days at present, to 24.7 days.

The absolute increase in days over 25°C compared to the present-day baseline increases most in the South and South East. London sees both the highest increase, and the highest overall number of days over 25°C by 2050, rising from 23.8 days at present to 53.1 days.

Scotland is the least affected region, with an average of just 1.3 days of temperatures over 25°C at present, rising to 2.1 days by 2050.

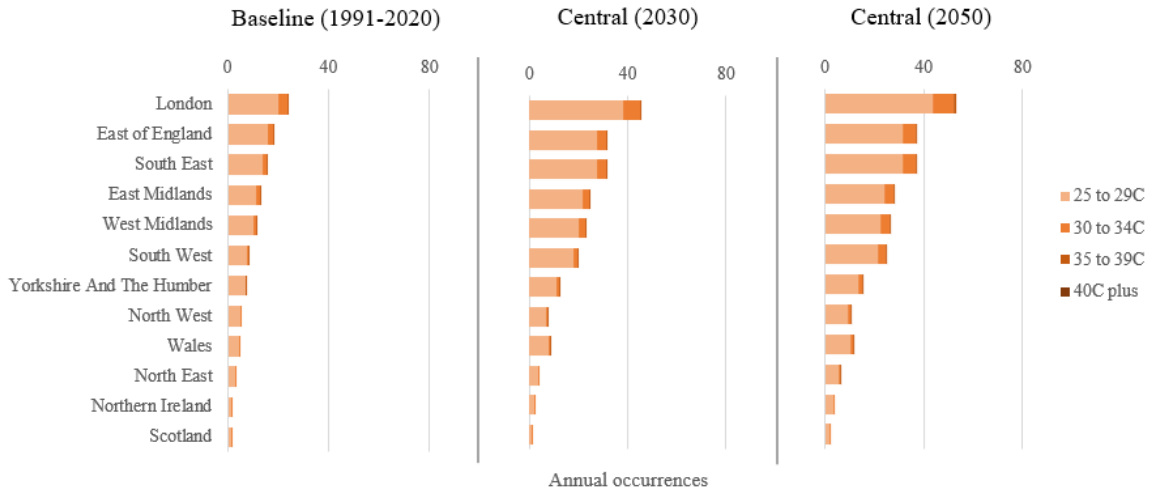
Across the UK, most heat days are expected to be at the relatively mild end of the spectrum. In the present-day baseline, 91% of extreme heat days are below 30°C, and while this falls to 86% by 2050, there are still relatively few expected days per year breaching 30°C.

There are very few days expected above 35°C (in the worst-affected region, London, an average of one day per year by 2050), and no days above 40°C in the average year. However, it is worth noting that these charts present averages aggregated to regional level, which may mask higher

[42] Unweighted average across all 12 UK regions

temperatures in individual LSOAs; indeed, the UK experienced its first day over 40°C in 2022, and a 50-50 chance of seeing another occurrence over 40°C in the coming 12 years.[43]

Figure 8. Annual occurrence (# of days) of days above 25°C by region – central scenario



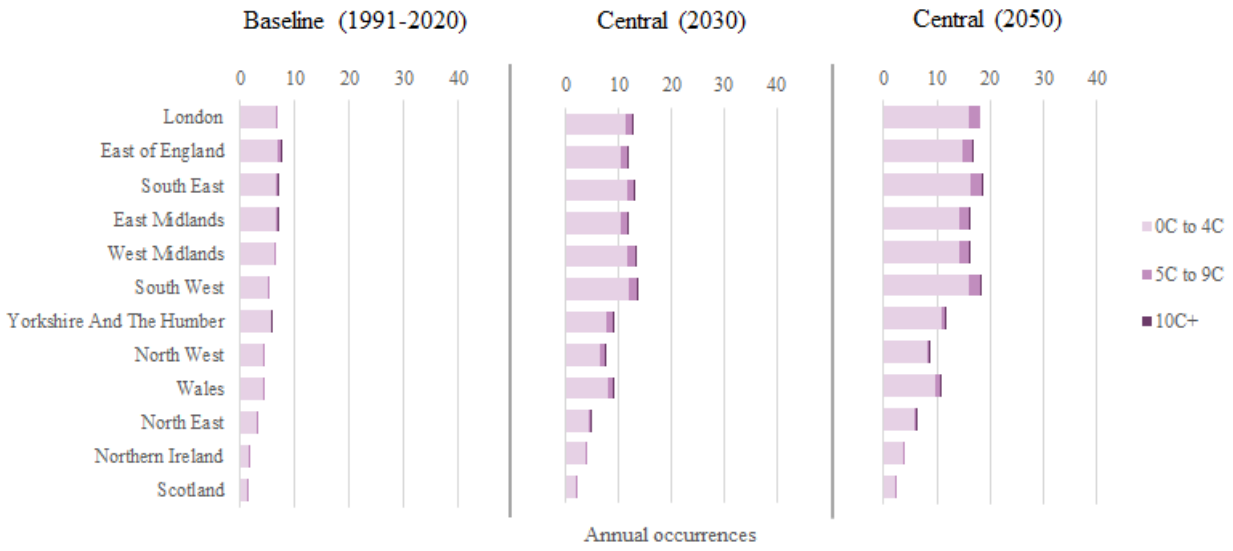
Source: Edge Health & Greencroft Economics

Using the regional heat thresholds as described in Section 3.1 means the occurrence of extreme heat is relatively flat across many of the UK regions. Across the UK, there is an average of 4.9 days of extreme heat per year in the baseline, rising to 9.2 days per year by 2030 and 12.1 days per year by 2050.

As shown in Figure 9, the extreme heat days are relatively evenly distributed across much of the UK. In the baseline period, the East of England experiences the most extreme heat days – 6.9 per year on average, followed by the East Midlands at 6.6 days, then London and the South East at 6.4 days. It is worth noting that this is a significant reduction in the prevalence of the heat hazard in London compared to using a single 25°C threshold, which as noted above has 20.4 days per year above 25°C, but only 6.4 days above the regional specific threshold of 28°C. By 2050, the risk profile of southern regions increases fastest, with the South East projected to experience an average of 16.4 extreme heat days per year, London 16.1 days, and the South West 16.0 days.

[43] Kay et al (2025), "Rapidly increasing chance of record UK summer temperatures", Link

Figure 9. Annual occurrence (# of days) of extreme heat by region – central scenario



Source: Edge Health & Greencroft Economics

Reasonable worst-case scenario – extreme heat days

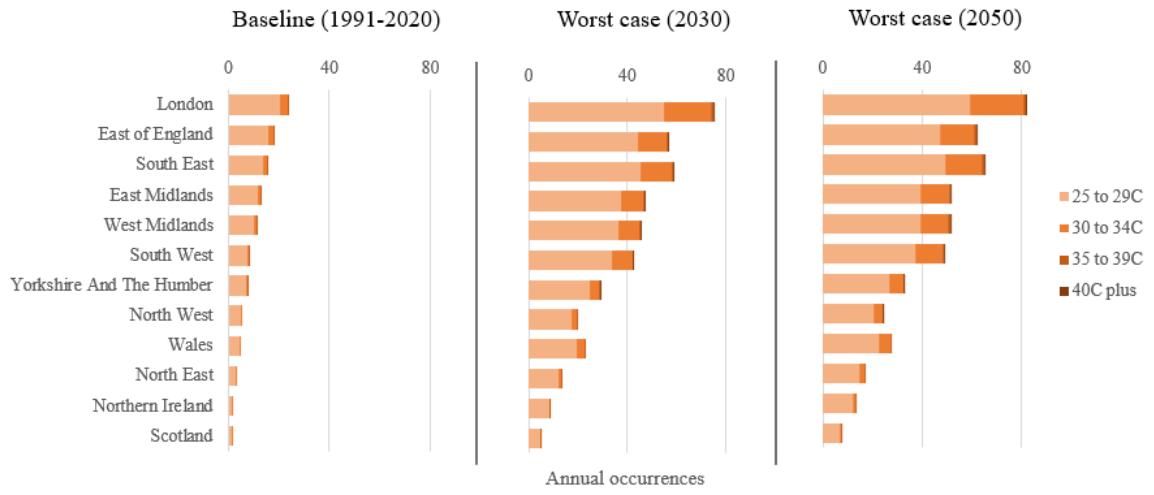
In the reasonable worst-case climate scenario, days over 25°C increase far more drastically – four-fold by 2050 across the UK (Figure 10), from 9.4 days in the present-day baseline to 35.2 days by 2030, and 40.1 days by 2050.[44]

The spatial distribution is slightly different in the reasonable worst-case scenario compared to the central scenario. Northern Ireland, Scotland and Wales see the largest relative increases in the number of days over 25°C, rising seven-fold in Northern Irland, and four-fold in Scotland and Wales. This represents both low baselines (in Northern Ireland and Scotland which see around 1.5 days of extreme heat in the present-day baseline) but nonetheless underlines the need to plan ahead and adapt for all regions of the UK.

In seven of the 12 UK regions, there would be more than 30 days over 25°C per year by 2050. London sees by far the largest absolute increase in extreme heat days, rising from an average of 21 days per year in the baseline, to 82 days by 2050, of which 22 would breach 30°C. This would mean very hot summer periods in London and could be expected to imply many consecutive days (weeks) of high temperatures. For example, recent analysis found that in the South East over two thirds of summer days could exceed 28°C, including the potential for a month-long heat wave.[45]

[44] Unweighted average across all 12 UK regions
[45] Kay et al (2025), "Rapidly increasing chance of record UK summer temperatures", Link

Figure 10. Annual occurrence (# of days) above 25°C by region – worst-case scenario

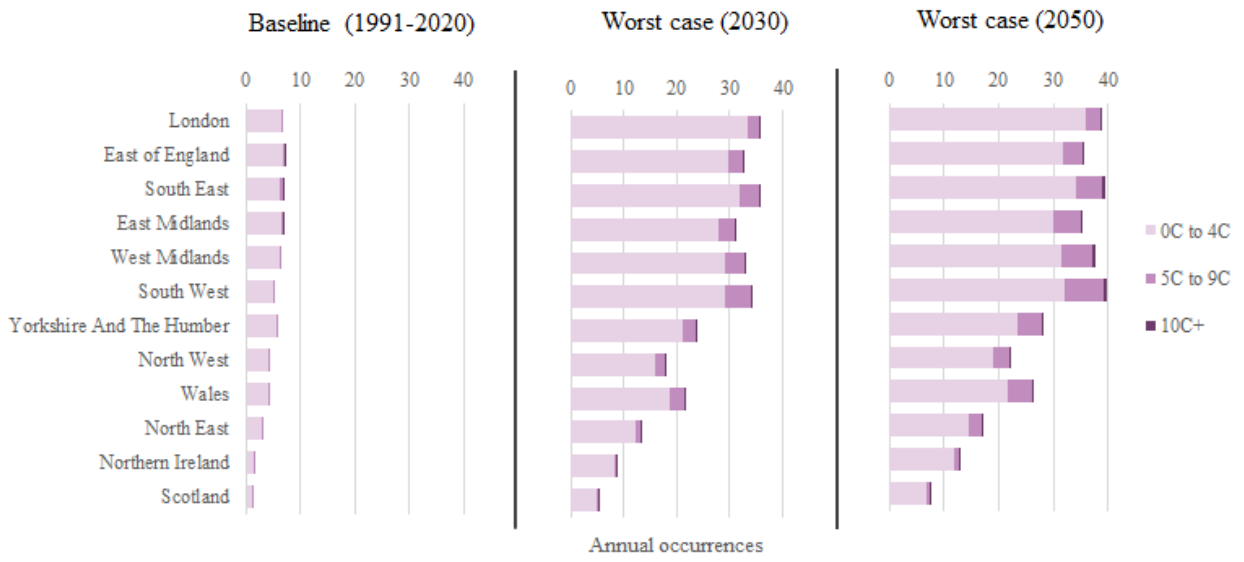


Source: Edge Health & Greencroft Economics

As shown in Figure 11, the extent of extreme heat days in the reasonable worst-case climate scenario double by 2050 relative to the central climate scenario. The risk remains highest in southern regions, with London experiencing the highest incidence of extreme heat at 35.8 days, followed by the South East (34.2 days) and the South West (32.2 days).

It is notable that in this scenario, other regions of the UK experience significantly higher extreme heat hazard occurrences. Scotland would see 6.7 days of extreme heat per year, which is higher than London in the baseline, while Northern Ireland would see an average of 11.9 days of extreme heat each year. The East of England and the Midlands each experience more than 30 days of extreme heat per year.

Figure 11. Annual occurrence (# of days) of extreme heat by region – worst-case scenario



Source: Edge Health & Greencroft Economics

5.2 Projected Exposure to Extreme Heat

The exposure of the UK population is illustrated by the number of extreme-heat-person-days in each region. This is estimated (as described in Section 3) as the number of extreme heat days at LSOA level, multiplied by the population per LSOA. These LSOA estimates are aggregated to each of the 12 UK regions and presented in Table 6.

The UK population is currently concentrated in regions that have higher levels of heat exposure. Scotland's population of 5.4 million in the baseline period and Northern Ireland's population of 1.9 million, are much lower than in regions where higher temperatures are more common, such as London (8.9 million) as the South East (9.4 million).

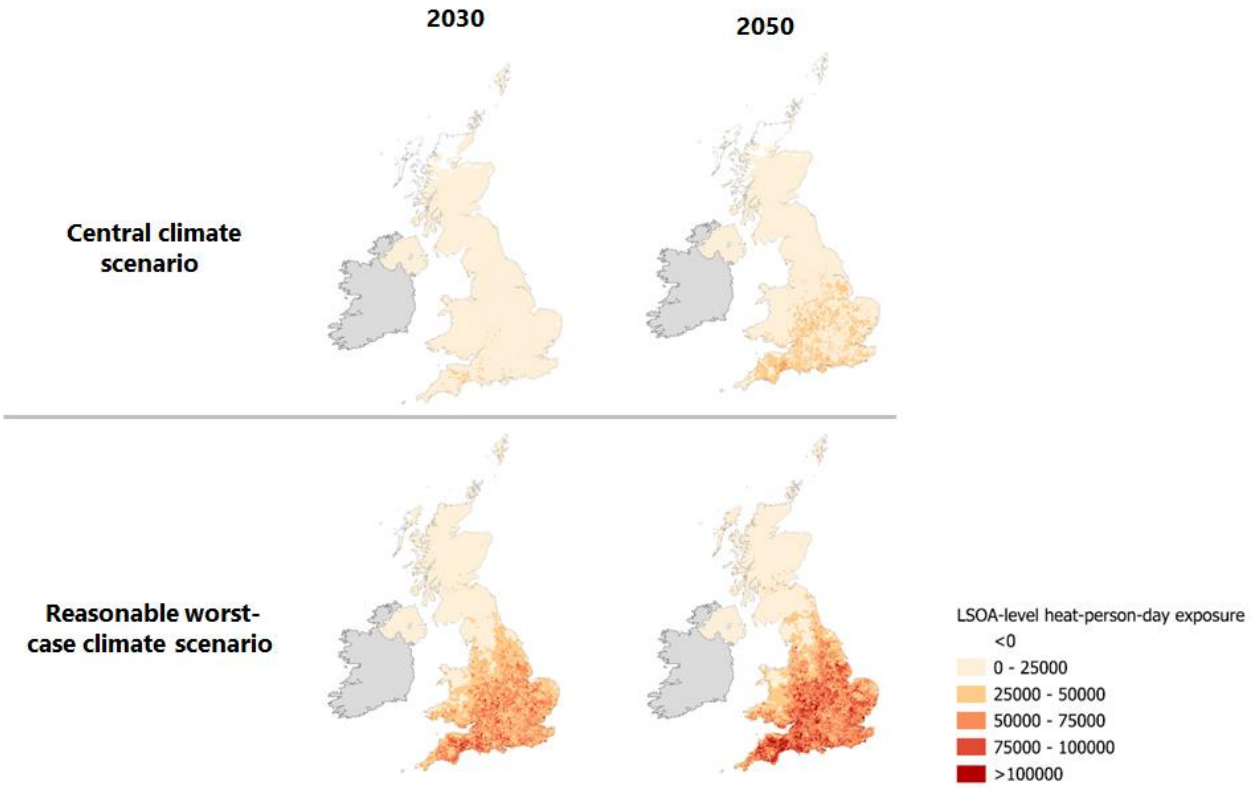
The UK population is projected to increase by 9.8% between 2022 and 2050 – to over 74 million. Population growth is higher in the Midlands (15% for both West Midlands and East Midlands) and the South of the UK (15% in the South West, 10% in London). Meanwhile, Scotland's population is not projected to increase by 2050, while Northern Ireland and the North East are projected to grow by just 5%. This means that the future distribution of the population across the UK is likely to make it more exposed to extreme heat.

In the baseline period, there are 403 million extreme-heat-person-days across the UK. The South East experiences the most extreme-heat-person-days at 64 million, followed by London at 61 million, which reflects both relatively high hazard levels, and large populations exposed to the hazard.

In the central climate scenario, by 2050, the number of extreme-heat-person-days is projected to rise by 185%, to 1.1 billion. The South West sees the largest rise in relative terms of 297%, which reflects both a significant increase in the hazard (as shown in Section 5.1, noting that the South West regional threshold is 25°C – lower than London and the South East at 28°C and 27°C respectively), and a significant increase in population (at 15% the highest regional growth rate in the UK, as noted above).

In the reasonable worst-case scenario, by 2050, extreme-heat-person-days would be projected to increase six-fold to 2.5 billion. Northern Ireland sees the largest relative rise in extreme-heat-person-days of 922%, rising to 31 million – comparable to the South West of England in the baseline period.

Figure 12. Change in the number of heat-exposure-person-days in each climate scenario



Source: Edge Health & Greencroft Economics

Table 6. UK population exposure to extreme heat by region – Central Scenarios

	Population (millions)			Extreme-heat-person-days (millions)				
					Central Scenario		Worst-Case Scenario	
	Baseline (2022)	2030	2050	Baseline	2030	2050	2030	2050
East Midlands	4.9	5.2	5.7	34	64	95	171	211
East of England	6.4	6.6	7.1	47	79	123	224	264
London	8.9	9.1	9.8	61	114	177	325	378
North East	2.7	2.7	2.8	11	19	27	54	66
North West	7.5	7.7	8.2	46	85	111	195	249
Northern Ireland	1.9	1.9	2.0	3	8	9	20	31
Scotland	5.4	5.5	5.5	12	23	29	63	85
South East	9.4	9.7	10.3	64	125	195	347	407
South West	5.8	6.0	6.6	32	86	129	221	279
Wales	3.1	3.2	3.3	17	36	47	88	109
West Midlands	6.0	6.3	6.9	40	89	122	220	274
Yorkshire and the Humber	5.5	5.7	6.0	36	61	86	161	196
Total – all regions	**67.6**	**69.7**	**74.2**	**403**	**791**	**1,148**	**2,090**	**2,549**

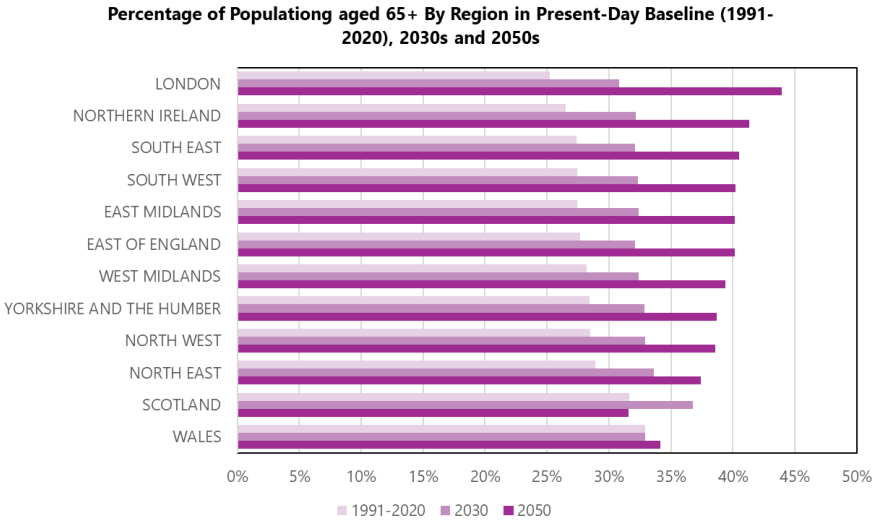
Source: Edge Health & Greencroft Economics

5.3 Projected Vulnerability to Extreme Heat

Changes to the UK's age profile and the underlying health of population (including levels of comorbidity), are likely to increase overall vulnerability to extreme heat. The UK population is expected to both grow and become relatively older over time (Figure 13). In the current study, the percentage of population with multimorbidities is assumed to be constant in future scenarios; however, as the population is projected to be older, there is slight shift of percentage of individuals with multimorbidities. But this is likely to be an underestimate.

In the current population of the UK in the present-day baseline (1991-2020), most of the deaths are estimated to occur in people aged 75+, even without heat events. Across regions within the UK, there is variation in the percentage of people that are aged 75+. For example, the South West of England has almost twice the percentage of people aged 75+ as London. This will have a substantial impact on projections for the impact of extreme heat, as people aged 75+ have both higher mortality rates and a greater relative risk of mortality due to heat.

Figure 13. Growth in population aged 65+, by region, baseline to 2050

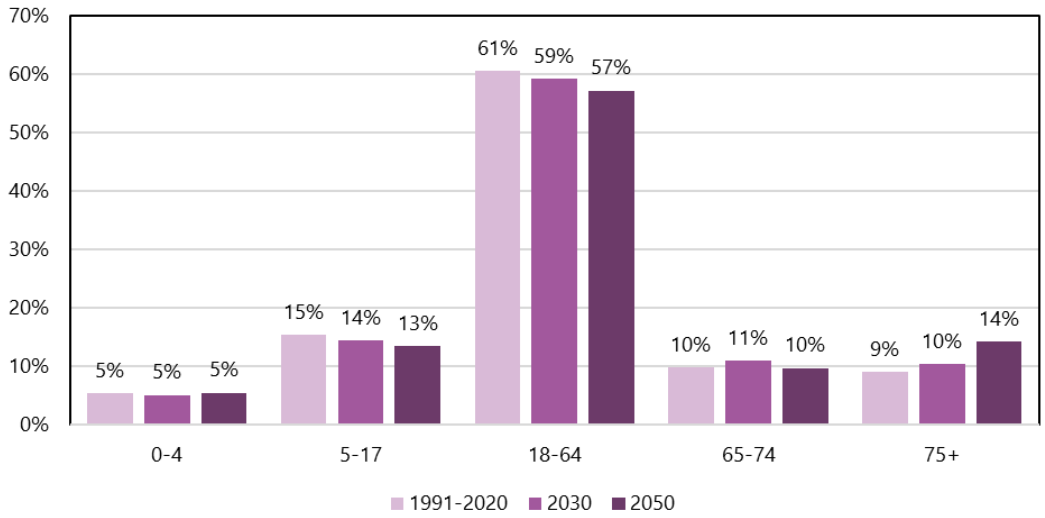


Source: Edge & Greencroft

As populations are projected to the 2050s, the percentage of population stays mostly constant within the age range of 0-4. The percentage of population aged 5-17 and 18-64 reduces by 2% and 4% respectively, and the percentage of population aged 75+ increases by 5%. In absolute terms, this reflects an increase of around 4 million people in this age band. Overall, this reflects a

shift towards an older population that are inherently more vulnerable towards extreme heat-related health impacts.

Figure 14. Proportion of UK population by age band, baseline to 2050



Source: Edge & Greencroft

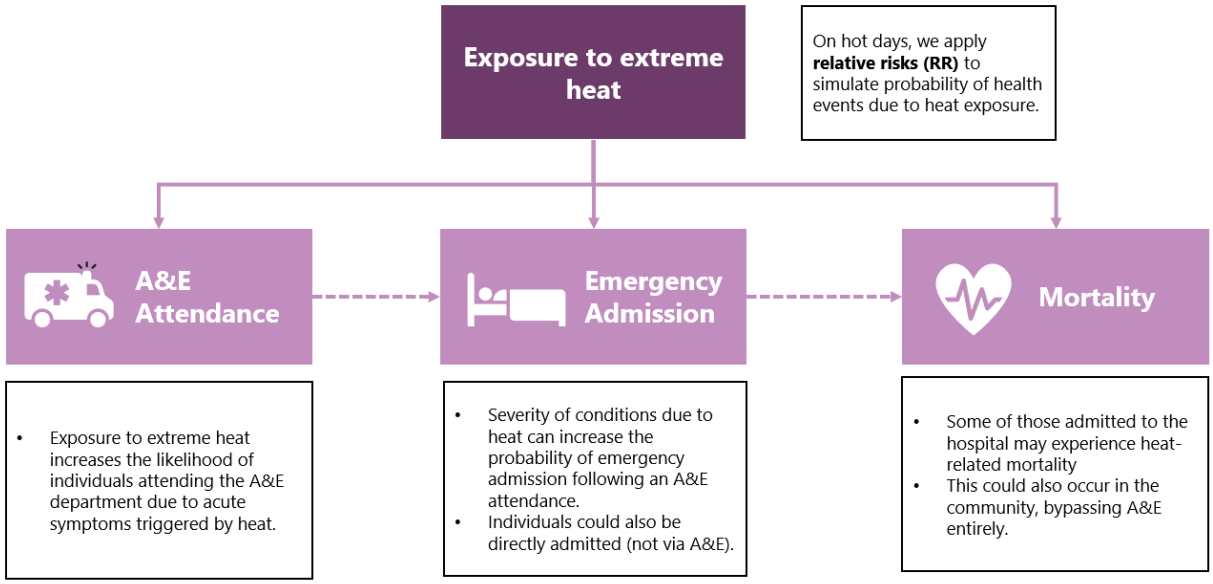
5.4 Projected Impacts of Extreme Heat on Health Outcomes

5.4.1 Health impacts

This section presents the estimated health impacts of extreme heat under different climate scenarios. For each scenario and time period (1991–2020, 2030s, and 2050s), the expected number of extreme heat days was modelled. Populations at those time periods were then simulated, allowing health outcomes to be estimated.

Informed by our literature review, the analysis focuses on three key indicators: *A&E attendances*, *emergency admissions,* and *mortality*. These metrics reflect three distinctive stages of the heat and health impact causal pathways, where heat-related morbidity may cause individuals to attend A&E or to be admitted to the emergency department, with the most severe cases resulting in mortality. The results summarised below show how these impacts may change over time and vary by region and population group, using relative risks computed from three literature sources (Appendix C.1.4 - Relative risks).

Figure 15. Health outcome indicators linked to extreme heat exposure



Source: Edge Health & Greencroft Economics

The modelling results in this section are based on the mean age-specific relative risks computed from the literature. The model results using the upper and lower confidence intervals of these relative risks are presented in Section 5.7.1.

Methodological Assumptions

1. Relative risks are quantified from distributed lag non-linear models, based on the historical relationship between mortality and temperature. The relationship between mortality and temperature is assumed to be linear overtime, though this assumption is not yet well-established in the literature.

2. Regional relative risks are used for extreme heat related mortality risk, derived from Murage et al. (2022). However, it should be noted that confidence intervals across regional mortality relative risks have a high degree of overlap, suggesting that the relative risks may be similar between most regions. See Section B.3 for further discussion.

3. For A&E attendances and emergency admissions, there is no evidence available to inform region-specific relative risks, which are instead derived from London (Hotz et al. and Rizmie et al.) and applied uniformly across all UK regions.

4. The model assumes that the baseline health outcome rates (i.e. underlying baseline mortality, admission, and A&E attendance rates under non-extreme heat temperature) by age groups remain constant in future scenarios. These rates represent the starting point to which heat-related excess risks are applied.

Implications

1. For A&E attendance and emergency admissions, the magnitude of regional differences may be over- or under-estimated in the absence of region-specific relative risks. Therefore, comparison between mortality, admission, and attendance impacts at the regional level should be intrepreted carefully.

2. There is some evidence suggesting that the rates of attendance and emergency admission have increased for older populations.[46] Consequently, future increases in baseline mortality, A&E attendance, and emergency admission rates would mean that the extreme heat-related impacts projected here are likely underestimates.

[46] The Health Foundation (2014), "Focus on: A&E attendances—Why are patients waiting longer?": July 2014, Link

Mortality Impacts

Present-day baseline impacts

In the baseline, the UK-wide extreme heat-related mortality rate is 1.3 per 100,000 per year (Figure 16). The South East experiences the highest impacts, with a mortality rate more than twice the national average, followed by the South West and East of England. The South East experiences the highest absolute impact, followed by the East of England and London.

For context, there were a total of 662,062 deaths registered in the UK in 2023, meaning that our present-day baseline estimate is roughly 0.13% of the annual number of deaths.[47]

Figure 16. Impact of extreme heat on mortality averaged across the present-day baseline (1991-2020) by small-area (MSOAs, SDZs and IZs) (left) and by regions (right)

Region	Average Mortality Rate per 100,000	Average Number of Heat–Related Deaths
SOUTH EAST	2.5	231
SOUTH WEST	1.8	102
EAST OF ENGLAND	1.7	107
WALES	1.5	46
LONDON	1.3	112
WEST MIDLANDS	1.0	60
EAST MIDLANDS	0.9	45
NORTH WEST	0.9	68
YORKSHIRE AND THE HUMBER	0.7	42
NORTH EAST	0.7	18
SCOTLAND	0.3	14
NORTHERN IRELAND	0.2	3
UK Grand Total	**1.3**	**846**

Source: Edge Health & Greencroft Economics

Despite having the highest number of heat days, London has a lower absolute number of extreme heat-related deaths compared to the South East. This is primarily driven by the South

[47] Summed figures from (1) ONS, Deaths registered in England and Wales: 2023, Link [581,363 deaths] (2) National Records of Scotland, Deaths Time Series Data, 2023, Link [63,445 deaths] (3) Northern Ireland Statistics and Research Agency, Registrar General Annual Report 2023, Link [17,254 deaths]

East's higher region-specific relative risks (2-10% higher than London), particularly for the 75+ age group, which accounts for 80-90% of mortality impact within that region.

Projected impacts – central scenario

Table 7. Projected extreme heat-related mortality impacts in central and worst-case scenarios averaged across 2030s and 2050s

	2030				2050			
	Central		Worst		Central		Worst	
Region	Average rate per 100,000	Average number of Deaths	Average rate per 100,000	Average number of Deaths	Average rate per 100,000	Average number of Deaths	Average rate per 100,000	Average number of Deaths
SOUTH EAST	6.2	597	16.8	1,624	8.9	915	19.5	1,998
SOUTH WEST	6.1	371	15.6	941	7.8	520	18.8	1,251
EAST OF ENGLAND	3.3	221	9.6	632	4.9	350	10.8	770
LONDON	3.0	274	8.4	766	4.9	480	10.5	1,025
WALES	3.0	95	7.9	250	3.1	104	8.2	269
EAST MIDLANDS	2.5	127	6.4	334	3.2	182	7.6	432
WEST MIDLANDS	2.7	168	6.5	407	3.0	211	7.4	510
NORTH WEST	2.0	157	4.9	375	2.4	198	6.0	493
YORKSHIRE AND THE HUMBER	1.6	92	4.3	244	2.1	126	5.3	317
NORTH EAST	1.5	40	4.2	115	2.1	58	5.2	146
SCOTLAND	0.6	35	1.8	102	0.8	43	2.4	133
NORTHERN IRELAND	0.7	14	2.1	40	1.0	19	4.0	79
UK Grand Total	**3.1**	**2,192**	**8.4**	**5,830**	**4.3**	**3,206**	**10.0**	**7,423**

Source: Edge Health & Greencroft Economics

In the central scenario, the extreme heat-related mortality rate per 100,000 people more than doubles by the 2030s (+152%) and more than triples by the 2050s (+245%) (Table 7). Comparing the 2030s and 2050s central scenarios, the UK-wide rate has increased by 37% from 3.1 per 100,000 (2,192 deaths) in 2030s to 4.3 per 100,000 (3,206 deaths) in 2050s. Mortality rates per 100,000 are projected to rise substantially across all regions by 2050s under the central scenario, with the South East (8.9 per 100,000, 915 deaths) and the South West (7.8 per 100,000, 520 deaths) recording the highest rates nationally. London is projected to have the third highest impact in both central scenarios (2030s: 274 deaths and 2050s: 480 deaths).

The projected mortality rates per 100,000 people are up to 15 times higher in southern England compared to Northern Ireland (0.7 per 100,000), Scotland (0.6 per 100,000), and the North East of England (1.5 per 100,000) in 2030s. In terms of absolute numbers of deaths, the South East remains the most affected region, followed by the South West. London is projected to have the

third highest absolute burden in both central and worst-case scenarios, exceeding the East of England. Again, this was driven by the higher mortality relative risks in South East.

While regions in the North, such as Northern Ireland, Scotland and the North East of England, have the lowest absolute mortality rates, these regions experience relatively large increases in relative risk compared to the present-day baseline period. For example, Northern Ireland experiences the steepest relative rise, with its mortality rate increasing by 36% from 0.7 per 100,000 (14 deaths) in 2030s to 1.0 per 100,000 (19 deaths) in 2050s.

Projected impacts – worst-case scenario

In the worst-case scenario, UK-wide mortality rate increases by 20% from 8.4 per 100,000 people in 2030s to 10.0 per 100,000 people in 2050s, with extreme heat-related deaths rising from 5,830 to 7,423 (Table 7).

Comparing how much extreme heat-related deaths has grown in the worst-case scenario relative to the central scenario, the UK-wide mortality rate has increased by 185% within 2030s (2.7 to 7.7) and 133% within 2050s (4.3 to 10.0). This indicates exposure to higher global warming levels could more than double the impact on extreme heat-related mortality rate.

Methodological Assumptions

Murage regional mortality relative risks computed from 2007-2018 can be applied to baseline 1991-2020, 2030s and 2050s, which assumes the risk-exposure relationships stay constant.

Implications

Potential changes to the risk-exposure relationships in the future is not captured within this model.

A&E Attendance Impacts

Present-day baseline impacts

In the present-day baseline, an annual average of 16,938 extreme heat-related A&E attendances (25.1 per 100,000 population) were estimated. The impact is disproportionately concentrated in London, with 45.1 per 100,000 people (3,996 attendances), which is nearly more than 1.5 times the impact seen across all other regions of the UK. Following London, the highest burdens fall on the East of England, South East, East Midlands, and West Midlands. This pattern reflects London's higher frequency of extreme heat days and may also be influenced by the Urban Heat Island effect.

For context, an average of 46,200 people visited major hospital Accident and Emergency (A&E) departments in England each day in April 2025.[48] This means our *annual* estimated heat-related A&E attendance in the present-day baseline is around ~40% of the *daily* caseload.[49]

Figure 17. Impact of extreme heat on A&E attendance averaged across the present-day baseline (1991-2020) by small-area (MSOAs, SDZs and IZs) (*left*) and by regions (*right*)

Region	A&E Attendance Rate per 100,000	Number of Heat–related A&E Attendance
LONDON	45.1	3,996
EAST OF ENGLAND	31.3	2,002
SOUTH EAST	28.3	2,658
WEST MIDLANDS	27.5	1,657
EAST MIDLANDS	26.4	1,305
NORTH WEST	24.1	1,808
YORKSHIRE AND THE HUMBER	22.9	1,271
SOUTH WEST	18.6	1,073
NORTH EAST	15.1	405
WALES	14.6	458
NORTHERN IRELAND	4.9	94
SCOTLAND	3.9	212
UK Grand Total	**25.1**	**16,938**

Source: Edge Health & Greencroft Economics

[48] Commons Library Research Briefing, 29 May 2025, NHS key statistics: England, Link

[49] It is important to note that there are other heat-related presentations, primary care presentations, NHS111 calls that are not included in this estimate.

Projected impacts – central scenario

Table 8. Projected A&E attendances in central and worst-case scenarios averaged across 2030s and 2050s

	2030				2050			
	Central		Worst		Central		Worst	
Region	Average Rate per 100,000	Average Number of Attendances	Average Rate per 100,000	Average Number of Attendances	Average Rate per 100,000	Average Number of Attendances	Average Rate per 100,000	Average Number of Attendances
LONDON	95.4	8,697	260.5	23,749	129.5	12,647	278.5	27,196
EAST OF ENGLAND	60.5	3,998	163.9	10,835	81.0	5,760	177.2	12,599
SOUTH EAST	63.6	6,138	169.3	16,342	85.8	8,809	183.5	18,841
WEST MIDLANDS	70.2	4,414	171.9	10,800	82.1	5,687	192.3	13,324
EAST MIDLANDS	59.4	3,076	153.6	7,950	73.2	4,159	169.9	9,659
YORKSHIRE AND THE HUMBER	44.9	2,551	119.5	6,782	56.2	3,384	138.1	8,314
NORTH WEST	49.8	3,845	120.9	9,343	56.8	4,685	142.4	11,742
SOUTH WEST	55.5	3,357	142.1	8,590	68.2	4,523	160.7	10,665
NORTH EAST	32.4	883	94.9	2,586	42.5	1,196	113.4	3,191
WALES	38.8	1,232	100.2	3,183	45.8	1,510	118.1	3,897
NORTHERN IRELAND	16.2	314	47.0	913	16.9	338	64.9	1,303
SCOTLAND	9.1	504	27.8	1,535	11.2	614	38.1	2,084
UK Grand Total	**56.0**	**39,009**	**147.3**	**102,609**	**71.8**	**53,313**	**165.4**	**122,813**

Source: Edge Health & Greencroft Economics

Under the central scenario, the UK-wide extreme heat-related attendance impact could more than double in the 2030s (+123%) and 2050s (+187%). Across both time periods, London experiences particularly severe impacts (95.4 per 100,000 in 2030s and 129.5 per 100,000 in 2050s). While the geographical variation in 2030s and 2050s is largely similar to the present-day baseline estimates, the impact in the South West is projected to overtake that of Yorkshire and the Humber and North West by the 2030s.

The East of England and South East follow London as the next most impacted, and the South East is projected to overtake the East of England in the heat-related attendance rate. Compared to the East of England, the South East has a higher number of extreme heat-related attendances. Comparing 2030s to the present-day baseline, the relative increases are the highest in Northern Ireland (+227%) followed by the South West (+198%) and Wales (+165%). This differs from the trend observed when comparing the 2050s to the present-day baseline, where the South West sees the highest relative increase (+266%), followed by Northern Ireland (+241%) and Wales (+213%). This indicates that historically cooler regions still exhibit the highest relative increases from 2030s to 2050s.

Projected impacts – worst-case scenario

This burden nearly doubles in worst-case scenario. Similar to the central scenarios, London experiences the most severe increases compared to the present-day baseline, with the attendance rate increasing 478% in the 2030s and 518% in the 2050s. This indicates that exposure to higher global warming levels could double the impact on extreme heat-related attendance.

Methodological Assumptions:

1. A uniform A&E attendance relative risk is applied for those aged 5-64, meaning that our model might not capture the heightened risk for A&E attendance in the working population.

2. Time period is not perfectly aligned with our present-day baseline period, where the study period is 2007-2012, covering only six years of the present-day baseline definition.

Implications:

1. The model does not capture the heightened risk for A&E attendance in the working population due to a uniform relative risk for those aged 5-64.

2. Relative risk relationships might not be representative of the baseline and future populations.

Emergency Admission Impacts

Present-day baseline impacts

Extreme heat-related emergency admissions represent a smaller absolute burden than A&E attendances, with an estimated 2,901 admissions in the baseline period. The admission rate attributable to extreme heat varies across UK regions, ranging from 0.9 to 5.1 per 100,000 people. Here the heat-related admission rates are more closely related to the number of extreme heat days; however, emergency admissions show less geographical concentration than mortality, due to the adoption of a single relative risk curve across the UK.

For context, on average there were 17,600 emergency admissions to hospital each day in England in April 2025.[50] This means our estimated *annual* extreme heat-related emergency admissions in the present-day baselineline is around 16% of the *daily* caseload.

Figure 18. Impact of extreme heat on emergency admissions averaged across the present-day baseline (1991-2020) by small-area (MSOAs, SDZs and IZs) (*left*) and by regions (*right*)

Region	Average Emergency Admission Rate per 100,000	Average Number of Heat–Related Emergency Admissions
EAST OF ENGLAND	5.28	338
YORKSHIRE AND THE HUMBER	5.13	284
WEST MIDLANDS	5.10	307
LONDON	4.72	419
NORTH WEST	4.70	353
SOUTH EAST	4.54	426
EAST MIDLANDS	4.49	222
SOUTH WEST	4.11	237
WALES	3.77	118
NORTH EAST	3.77	101
SCOTLAND	1.43	78
NORTHERN IRELAND	0.92	17
UK Grand Total	**4.3**	**2,901**

Source: Edge Health & Greencroft Economics

[50] NHS key statistics: England, 30th May 2025, Link

Projected impacts – central scenario

Table 9. Projected heat-related emergency admissions in central and worst-case scenarios averaged across 2030s and 2050s

	2030				2050			
	Central		Worst		Central		Worst	
Region	Average Rate per 100,000	Average Number of Admissions	Average Rate per 100,000	Average Number of Admissions	Average Rate per 100,000	Average Number of Admissions	Average Rate per 100,000	Average Number of Admissions
EAST OF ENGLAND	11.3	748	31.2	2,062	17.2	1,222	38.4	2,731
YORKSHIRE AND THE HUMBER	10.8	611	28.1	1,595	14.0	840	35.0	2,106
WEST MIDLANDS	13.6	852	34.6	2,173	17.7	1,228	42.6	2,949
LONDON	11.3	1,030	31.4	2,867	18.1	1,763	40.5	3,958
NORTH WEST	10.4	806	25.2	1,944	13.1	1,082	31.7	2,612
SOUTH EAST	11.3	1,095	30.2	2,913	17.0	1,742	37.3	3,831
EAST MIDLANDS	10.5	545	28.3	1,463	14.8	839	35.5	2,021
SOUTH WEST	13.6	820	35.7	2,157	19.0	1,258	44.7	2,965
WALES	8.9	283	22.5	714	10.2	335	26.0	858
NORTH EAST	8.3	227	23.2	632	11.4	320	29.7	835
SCOTLAND	3.1	171	8.7	480	3.4	188	11.1	606
NORTHERN IRELAND	3.0	59	8.3	161	3.6	71	12.8	258
UK Grand Total	**10.4**	**7,247**	**27.5**	**19,162**	**14.7**	**10,887**	**34.7**	**25,729**

Source: Edge Health & Greencroft Economics

Comparing central scenarios with the present-day baseline, the UK-wide extreme heat-related admission rate is projected to nearly double in the 2030s (+142%) and triple in the 2050s (+242%). It is projected to increase by 41% from 10.4 per 100,000 (7,247 admissions) in the 2030s to 14.7 per 100,000 (10,887 admissions) in the 2050s.

The geographical pattern of impact in the 2030s differs slightly from the present-day baseline, suggesting a shift in regional vulnerability due to changes in extreme heat conditions and demographics. The South West and West Midlands are the most affected regions in 2030s in terms of impact rates per population. This is because these regions experience the highest total number of extreme heat days above their respective regional temperature thresholds. The South East has the highest absolute number of admissions, followed by London and West Midlands. In the 2030s and 2050s, the highest absolute burden is concentrated in parts of southern and central England (South East, London, and West Midlands).

Projected impacts – worst-case scenario

In the worst-case scenario, the UK-wide rate has increased by 541% to 27.5 per 100,000 in 2030s and by 708% to 34.7 per 100,000 in the 2050s compared to the present-day baseline. In the 2030s, the South West remains the most severely impacted, followed by West Midlands and London. In both time periods, Northern Ireland has the highest relative increase in extreme heat-related admission rate compared to all UK regions, increasing by 801% in the 2030s and 1301% in the 2050s.

Comparing how much the worst-case scenario has grown relative to the central scenarios, the UK-wide admission rate in the worst-case scenario is around two times the rate in the central scenario (2030s: 27.5 compared to 10.4, 2050s: 34.7 compared to 14.7). This indicates that exposure to higher global warming levels could double the impact on emergency admissions.

Although the national number of admissions is lower than A&E attendances (discussed in the next section), this does not necessarily reflect a lower impact. Emergency admissions typically involve more serious and costly clinical conditions, longer hospital stays, and higher resource use, making them a substantial burden on healthcare services. The lower number of admissions may also reflect clinical thresholds, with only the most severe cases progressing to admission, rather than a lower overall health impact of heat. It is also possible that there could be knock-on effects in surrounding regions if one region is facing significant demand pressure, though impacts are likely to be localised within the regions.

Methodological Assumptions:

1. London-specific relative risks are applied to all regions, due to limited evidence availability.

2. Injury-related emergency admissions do not include heat-related illnesses such as heatstroke. The relative risks for cardiovasulcar admissions are not statistically significant and was not accounted for in this study, which could be underestimating the total emergency admission burden.

3. Relative risks are calculated for two temperature bands based on daily maximum temperatures: 25-30°C and above 30°C. These groupings were determined by available evidence in the literature.

Implications:

1. Potential changes to the risk-exposure relationships in the future are not captured within this model.

2. Emergency admissions due to heatstroke are not captured in our modelling results, limited by the data source used (Rizmie et al. 2022), furthermore broader pressures on primary care and telehealth are also not incorporated. As a result, we could be underestimating the number of emergency admissions due to heat.

3. Our modelling will assume that the effect of extreme heat on hospital emergency admissions at a 25°C daily max is the same as at a 30°C daily max.

5.4.2 Impact of extreme temperatures

To isolate the contribution of projected extreme temperatures from demographic change, a counterfactual scenario was constructed in which heat exposure was held constant at the present-day baseline, while future populations for the 2030s and 2050s were applied. This scenario represents the heat-related health impact expected under constant climatic conditions but changing population size and structure.

The resulting impacts were compared with the main modelling results, which incorporate both projected future temperature extremes and demographic change. In the central scenarios for the 2030s and 2050s, projected extreme temperatures were found to account for approximately 52–67% of total heat-related health impacts across the UK. This increases up to 82%-86% in the worst-case scenarios, indicating that most projected heat-related impacts were driven by increases in extreme temperatures rather than by demographic change alone.

Table 10. Impact of extreme heat scenarios to projected UK-wide heat-related health outcomes (% of total impacts)

	Impact of central scenario on 2030s population	Impact of worst-case scenario on 2030s population	Impact of central scenario on 2050s population	Impact of worst-case scenario on 2050s population
Mortality	1,140 (52%)	4,839 (83%)	2,151 (67%)	6,373 (86%)
A&E Attendance	19,504 (50%)	84,139 (82%)	34,762 (65%)	104,213 (85%)
Emergency Admissions	3,551 (49%)	15,712 (82%)	6,861 (63%)	21,719 (84%)

Source: Edge Health & Greencroft Economics

5.4.3 Impact of demographic change

To isolate the effects of demographic change, population figures for the 2030s and 2050s are held constant at the present-day baseline levels and only heat scenarios are varied. Subsequently, this was compared to the main modelling results to understand the magnitude of health impacts driven by demographic changes. Note that in the current study, the mortality rates are projected to change in the future based on available data; however, attendance and emergency admission rates are assumed to stay constant. This means that the impact of demographic changes for A&E attendance and emergency admissions include only the changes in the population size and age structure.

The rise in heat-related mortality is partly driven by demographic change. By the 2030s, demographic change contributes an estimated 175 additional heat-related deaths in the central scenario, while in the worst case, this rises to 466. By the 2050s, the impact of a growing and aging population becomes more pronounced; in the central scenario, demographic change accounts for an additional 675 heat-related deaths (21% of heat-related mortality), while in the worst-case scenario, this increases to 1,601 additional deaths (22% of heat-related mortality). Relative to the modelling results, the percentage of heat-related attendance impact that are contributed by demographic changes are around 2%-9%, and heat-related emergency admissions at around 10%-30%.

Table 11. Impact of demographic changes on UK-wide health outcomes (% of modelling results)

	2030s central scenario	2030s worst-case scenario	2050s central scenario	2050s worst-case scenario
Mortality	175 (8%)	466 (8%)	675 (21%)	1,601 (22%)
A&E Attendance	780 (2%)	2,360 (2%)	4,728 (9%)	11,072 (9%)
Emergency Admissions	725 (10%)	1,916 (10%)	3,159 (29%)	7,595 (30%)

Source: Edge Health & Greencroft Economics

5.4.4 Economic valuation of health impacts

Extreme heat poses significant health risks, particularly for vulnerable populations, and this has broader financial implications for the UK's health system. The economic impact of heat-related health outcomes is explored in this section, focusing on mortality, A&E attendance, and emergency admissions. These are the assumptions that could impact valuation results. More detailed assumptions underlying the cost estimates are set out in Appendix C.5.

Methodological Assumptions:

1. Mortality – Individuals will live out their full life expectancy for the calculation of YLL for mortality, this might overestimate the economic impact of mortality as those affected by heat-related mortality may be disproportionately impacted by other vulnerabilities, such as underlying health conditions, that reduce life expectancy.

2. A&E Attendance – Assume a set proportion of A&E attendances in each HRG category[51] of emergency medicine (75% in Category 2, 15% in Category 3 and 10% in Category 1), and that all heat-related A&E attendance falls within Types 1 & 2 Emergency.

2. Emergency admission – Length of stay and cost per bed day stays constant in the future.

As outlined in the figure below (Figure 19), the economic costs of heat-related health outcomes are projected to increase significantly in the coming decades. In the worst-case scenario for 2050, the total impact on the UK health system is expected to exceed £4 billion, with heat-related mortality contributing to majority of the economic impacts.[52]

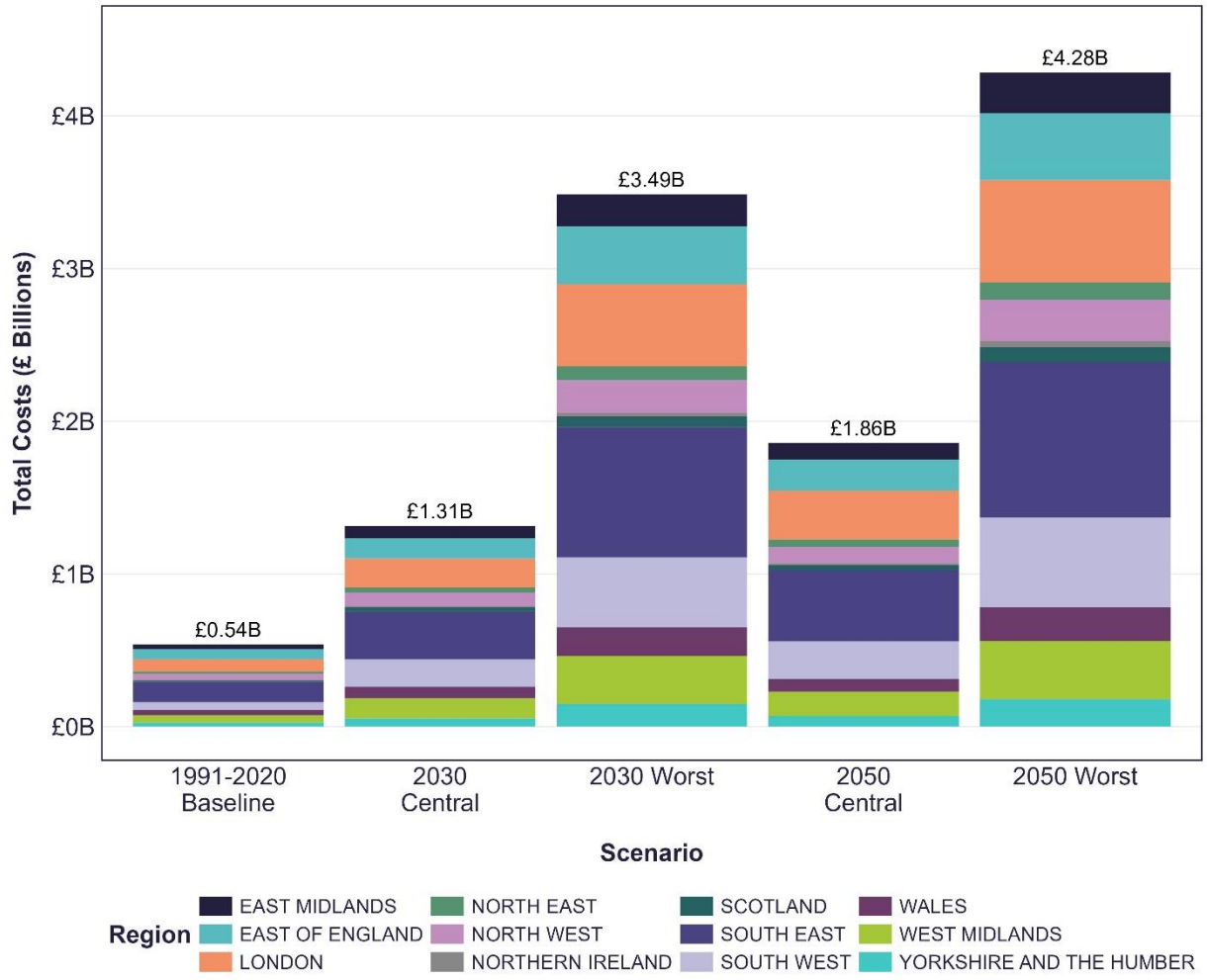
In 2023, seasonal influenza was estimated to be associated with £644m loss to the UK's economy.[53] Using flu season as a benchmark, the baseline heat-related economic impact of £538 million is estimated to be around ~80% of the impact from seasonal influenza.

[51] An HRG category refers to a Healthcare Resource Group which is a standard way the NHS groups similar patient treatments and activities that use comparable amounts of healthcare resources, helping standardize funding, compare services, and understand costs for things like hospital stays and procedures. Each HRG (like M04 or M28) represents a bundle of clinically similar care based on diagnoses and procedures, making costs comparable across different providers.

[52] Note that this differs from the £14.7 billion previously estimated by UKHSA (2023), Link, likely due to different definition for heat-related mortality heat risk, which was quantified by comparing mortality risk at the 93rd and 99th temperature percentiles for daily mean temperatures. This means that there is a higher mortality burden attributable to heat in the UKHSA's study, leading to higher economic valuation of health impacts.

[53] Romanelli RJ, Cabling M, Marciniak-Nuqui Z, Marjanovic S, Morris S, Dufresne E, Yerushalmi E. The Societal and Indirect Economic Burden of Seasonal Influenza in the United Kingdom. Rand Health Q. 2023 Sep 15;10(4):2. PMID: 37720072; PMCID: PMC10501821. Link.

Figure 19. Total annual costs from heat-related health impacts by scenario



Source: Edge Health & Greencroft Economics

Table 12. Total annual costs from heat-related mortality impacts by scenario

Nations	1991-2020 Baseline	2030s Central	2030s Worst	2050s Central	2050s Worst
England	£473,562,827	£1,165,931,666	£3,102,242,649	£1,675,424,842	£3,794,869,279
Wales	£34,149,246	£72,754,518	£183,893,976	£81,950,995	£216,718,125
Scotland	£10,682,372	£25,863,214	£68,117,938	£30,231,140	£92,446,129
Northern Ireland	£1,790,925	£7,276,389	£21,480,829	£9,926,629	£39,520,331

Source: Edge Health & Greencroft Economics

Table 13. Total annual costs from heat-related attendance impacts by scenario

Nations	1991-2020 Baseline	2030s Central	2030s Worst	2050s Central	2050s Worst
England	£3,520,993	£8,046,217	£21,111,974	£11,070,183	£25,150,902
Wales	£99,779	£268,133	£693,001	£328,698	£848,386
Scotland	£46,214	£109,775	£334,138	£133,763	£453,585
Northern Ireland	£20,472	£68,342	£198,805	£73,582	£283,597

Source: Edge Health & Greencroft Economics

Table 14. Total annual costs from heat-related admission impacts by scenario

Nations	1991-2020 Baseline	2030s Central	2030s Worst	2050s Central	2050s Worst
England	£13,425,116	£31,733,261	£81,162,612	£46,614,059	£105,052,423
Wales	£608,901	£1,443,445	£3,470,701	£1,709,794	£4,075,014
Scotland	£427,023	£899,288	£2,489,085	£998,515	£3,111,301
Northern Ireland	£99,482	£316,231	£840,249	£369,073	£1,278,183

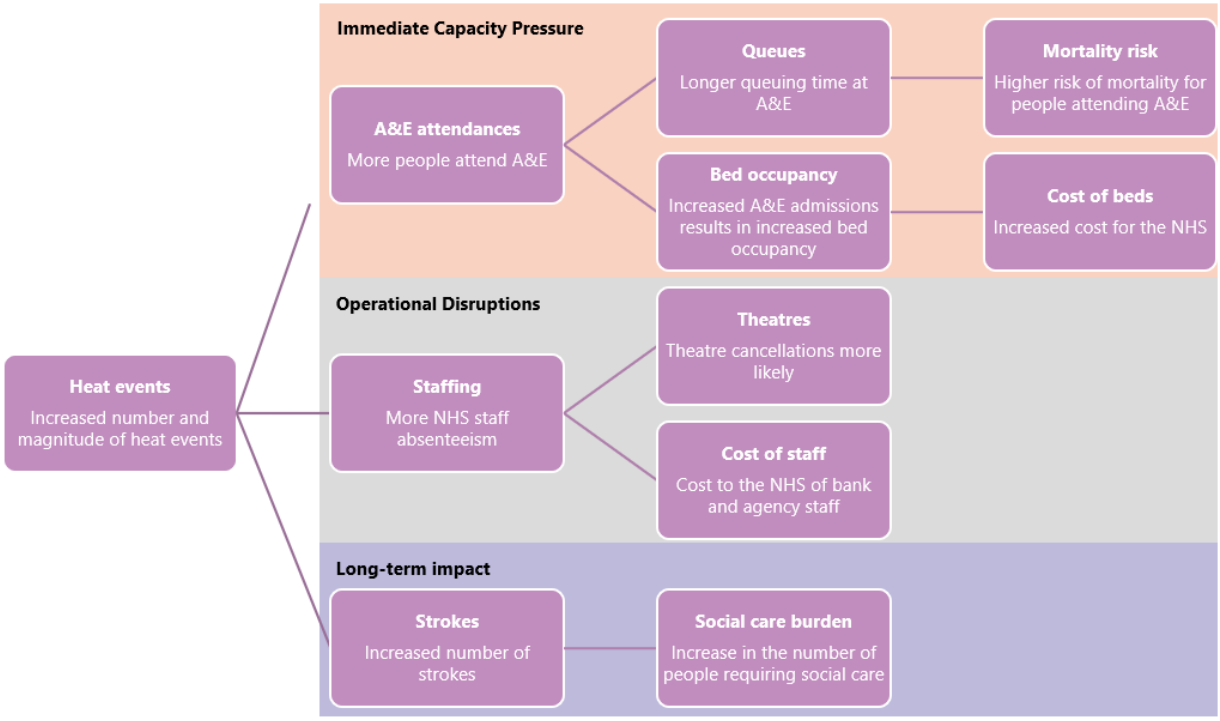
Source: Edge Health & Greencroft Economics

5.4.5 Health system impacts

The projected increases in extreme heat-related mortality, A&E attendances, and emergency admissions translate into considerable pressure on the health system. Higher temperatures can lead to more people becoming unwell, resulting in increased visits to A&E, more hospital admissions, and a greater need for social care. These impacts can in turn cause longer waiting times, higher bed occupancy, staff shortages, and increased costs. The diagram below (Figure 20) illustrates how interconnected impacts generate system-wide impact, ultimately affecting the population that relies on the health service.

Due to the lack of quantitative evidence across the field of heat-related health system impacts within the UK, the current study focused on the following specific impacts that could be reasonably quantified with the evidence availability and study scope. For example, impact on strokes is served as a case study to examine the long-term impact of heat on social care burden, though it is recognised that there are other long-term consequences in social care not covered by the current study.

Figure 20. How do extreme heat events affect the health system?



Source: Edge Health & Greencroft Economics

As demand spikes, the health system's ability to respond effectively declines, prolonging patient recovery and increasing mortality risk. Prolonged or repeated heatwaves allow less recovery time for both the population and the health workforce; these effects can compound over time. While each factor carries its own cost and pressure, together they can amplify one another, creating greater strain and reducing overall performance and resilience of the health system.

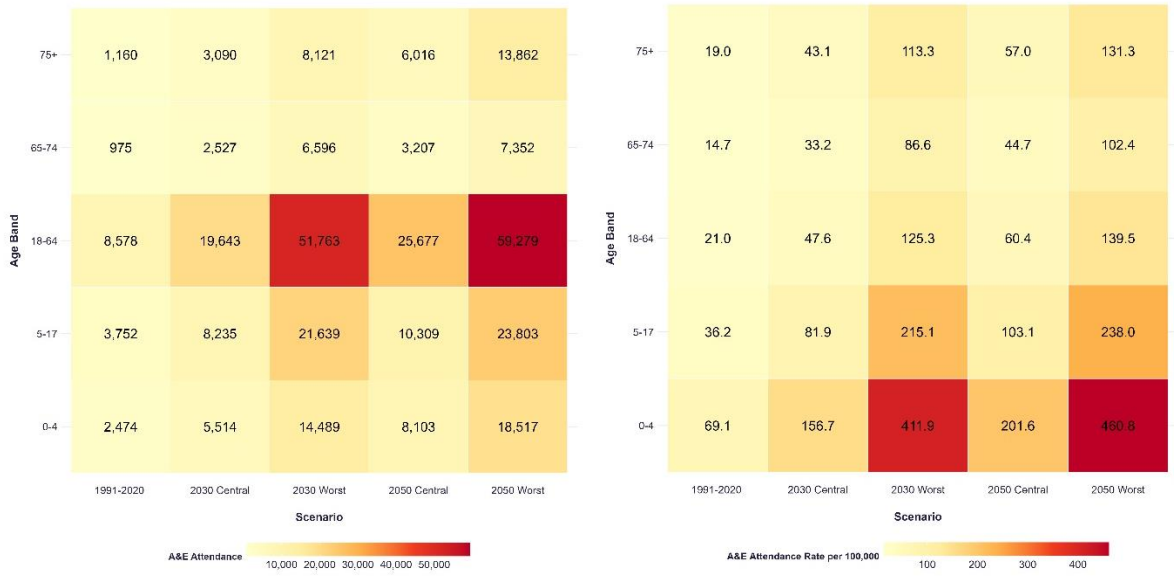
This section outlines how extreme heat could lead to immediate capacity pressures on the health system (A&E queues and bed occupancy), operational disruptions (infrastructure and staff absentees) and longer-term consequences on social care, such as stroke-related impact.

Immediate Capacity Pressures

Increased A&E attendance and queueing

Extreme heat events place additional strain on emergency services, with notable impacts on both patient volumes and outcomes. Higher temperatures are associated with a rise in A&E attendances, which in turn leads to longer waiting times. Prolonged waits in A&E have been linked to worse health outcomes, including higher mortality rates.[54,55]

Figure 21. Extreme heat-related A&E attendance rate (*left*) and absolute A&E attendance (*right*) across warming scenario and age band



Source: Edge Health & Greencroft Economics. Note that this is directly taken from the main modelling results and is the same as the impacts presented in Section 5.5.

With the UK-wide extreme heat-related A&E attendances projected to more than triple from 16,939 in baseline to 53,312 by the 2050s central scenario (Figure 21) emergency departments will face increased pressure from higher A&E attendance demand, particularly among children and young people.

As more people attend A&E, the waiting time for a patient to be seen tends to increase. Increased waiting times in turn could result in worsening health outcomes for people attending A&E. For example, an article in the *Emergency Medicine Journal* reported a 10% increase in the standardised mortality rate within 30 days for admitted patients remaining in the emergency

[54] Royal College of Emergency Medicine (2025) "Excess deaths linked to long A&E waits increased to over 16,600 last year", Link
[55] BMJ (2025) "Patients waiting over 12 hours in A&E have double the risk of death", Link

department between 8 and 12 hours, compared with those discharged within 6 hours. The same study found that one additional death occurs for every 82 patients whose stay is delayed by more than 6 to 8 hours.[56]

> Heat events increase A&E attendances, contributing to delays in care. In England, patients who spend more than 12 hours in A&E have over twice the odds of dying within 30 days compared with those seen within two hours.[57]

In 2023/24 financial year, only 72% of patients were seen within four hours in A&E, falling far below the national target of 95%.[58] The number of heat related attendances is projected to increase by over three times the baseline number in the central 2050 scenario and over seven times the baseline number in the worst 2050 scenario, which is likely to lead to a substantial additional pressure of queues. This could further increase the mortality risk for patients facing longer waits in A&E.

The largest increase in A&E attendances during heat events is among children and young people, often presenting with sunburn, heatstroke, dehydration, or injuries from accidents. While most of these cases are not life-threatening, extended queues and delays may still increase mortality risk for both extreme heat-related and non-heat-related attendances. This assumes that children and young people continue to attend A&E at baseline rates, and that A&E triage systems and queue times will remain the same, conditions which would be altered by the introduction of alternative services or flexible staffing.

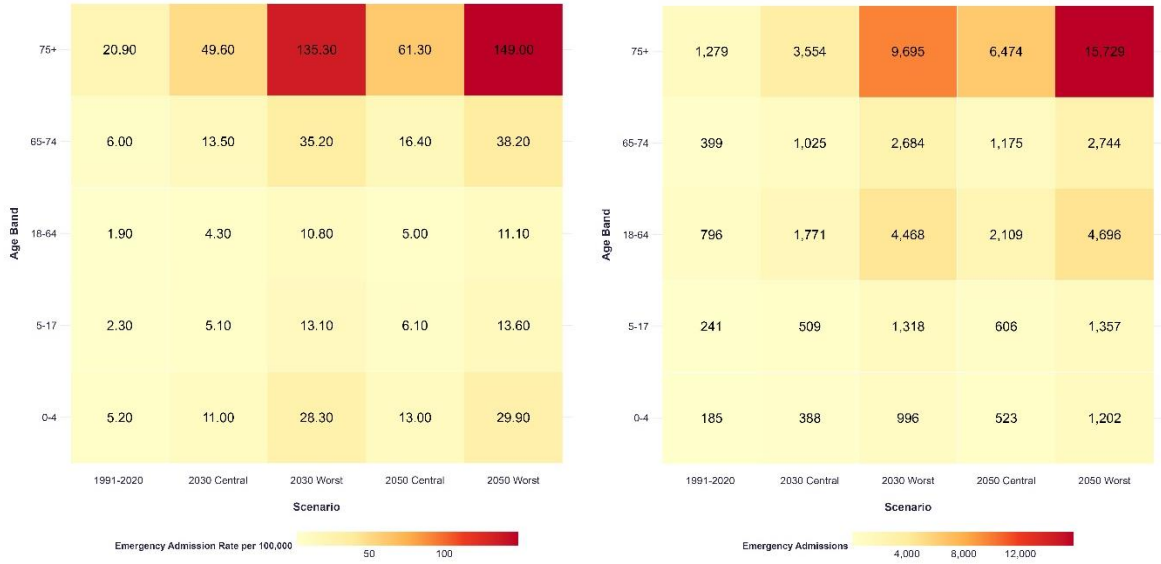
Increased admissions and bed capacity strain

High bed occupancy is linked to higher mortality and delays in urgent care. The point at which mortality risk begins to rise varies between hospitals, but once this threshold is exceeded, each additional day at that level increases the risk of death by around 2%.[59] High occupancy is also associated with poorer patient-reported health outcomes, such as lower overall satisfaction with care, delayed or rushed care and an increased risk of errors. During heat events, discharging patients can be more challenging due to difficulties in acclimatisation and in securing appropriate post-discharge care.

[56] Jones, S. (2022) "Association between delays to patient admission from the Emergency Department and all-cause 30-day mortality: a retrospective study using Hospital Episode Statistics", Link
[57] ONS (2025) "Association between time spent in emergency care and 30-day post-discharge mortality, England: March 2021 to April 2022", Link
[58] The King's Fund (2024) "What's Going on with A&E Waiting Times?", Link
[59] Sharma, N., Moffa, G., Schwendimann, R., et al. (2022) "The effect of time-varying capacity utilization on 14-day in-hospital mortality: a retrospective longitudinal study in Swiss general hospitals", BMC Health Services Research, 22:1551, Link

When hospitals operate above safe bed occupancy levels, the risk of death for patients can rise by around 2% for every additional day.

Figure 22. Extreme heat-related emergency admission rate per 100,000 (*left*) and absolute emergency admissions (*right*) across warming scenario and age band

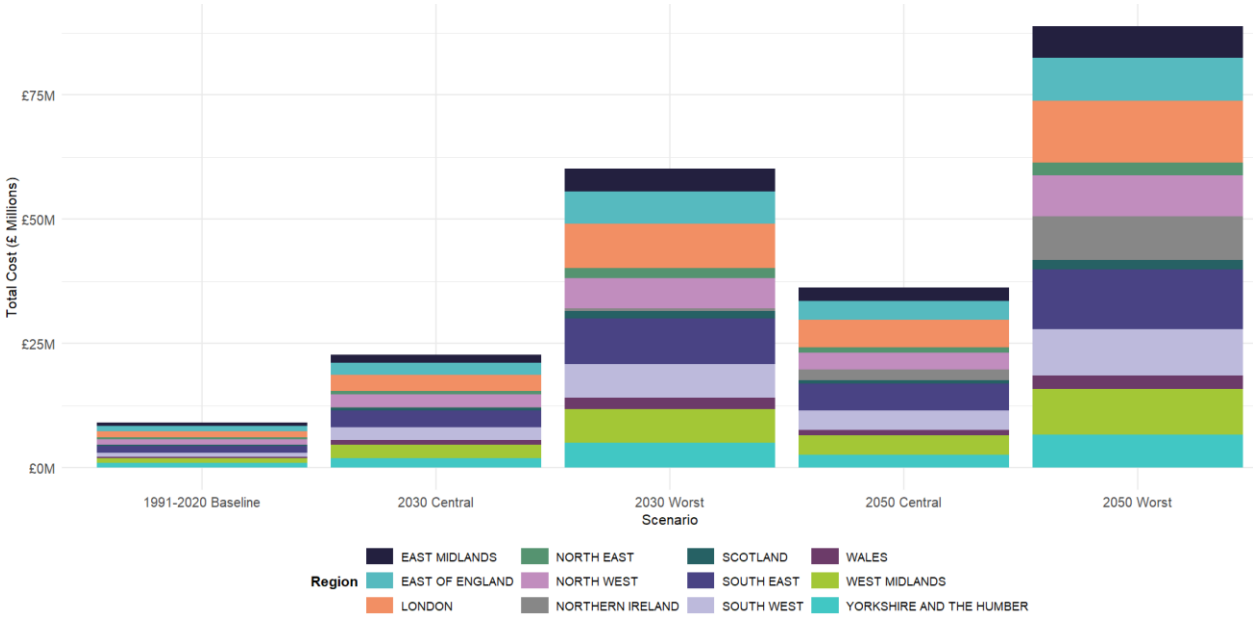


Source: Edge Health & Greencroft Economics. Note that this is directly taken from the main modelling results

Emergency admissions related to excess heat are projected to more than triple from 2,900 in the present-day baseline to 10,887 by the 2050s. This surge could push bed occupancy to levels that compromise patient safety. The above heat map (Figure 22) shows the projected impact of heat on emergency admissions, demonstrating that as heat events increase across future years and scenarios, A&E attendances will also increase. Notably, while attendances disproportionately affect young people, admissions disproportionately affect the elderly, who require longer and more resource-intensive inpatient stays.

In addition to the effects described above, increased bed occupancy has a significant cost to the NHS. The chart below (Figure 23) shows the estimated cost of increased bed occupancy as a result of heat events. There are four main extreme heat-related admission types: injury, respiratory disease, infectious disease, and metabolic disease. This chart looks at the expected admissions, the average length of stay, and the average bed day cost of these admission types.

Figure 23. What are the projected costs of bed days from excess heat events?



Source: Edge Health & Greencroft Economics

The impact on bed occupancy could lead to important financial implications. In the central scenario, total bed costs are projected to more than double from baseline by 2030 and almost quadruple by 2050. In the worst-case scenario, the increase is even greater. These projections assume that the average length of stay and cost of beds for injuries, respiratory disease, infectious disease, and metabolic disease remain constant, and that costs are uniform across regions. Given that the bed-day costs have historically increased over time, these figures are likely conservative.

Operational Disruptions

Infrastructure

Hospital buildings can be particularly vulnerable to overheating during heatwaves, increasing patient risk, reducing staff and system productivity, and potentially damaging equipment. Experts have found that as many as nine in ten hospital wards are at risk of overheating because of the design of buildings.[60]

With a third of the NHS estate built before 1965—more than 50 years before overheating incidents were recorded—many facilities were designed to retain heat rather than dissipate it. The UK Health Alliance on Climate Change reported that some hospital wards recorded indoor temperatures above 30°C even when outdoor temperatures were just 22°C in 2012/13.[61] NHS England recommends maximum ward temperatures of 28°C and 25°C in sensitive areas such as recovery or birthing rooms.

Serious impacts have already been evidenced during recent heatwaves. For example, in July 2022, when UK temperatures hit record highs of 40°C, computer systems at Guy's and St Thomas' Hospital in London, one of the NHS's biggest hospital trusts, failed.[62] Overheating has also caused refrigeration breakdowns affecting medicine storage, failures of essential hospital equipment, and crashes of IT systems holding patient information.

In 2022-23, there were over 6,800 recorded cases of wards or clinical areas exceeding 26°C, which the NHS says puts vulnerable patients at risk because they 'are physiologically unable to cool themselves efficiently'.[63] This was almost a quarter higher than the year before and more than double the 2,908 incidents recorded in 2016-17.[64] This is likely due to the record breaking heatwaves during that time period, and may hide fluctuation and report bias within the system. However, as these heatwaves are projected to become more frequent, these incidents will become more likely.

Cooling interventions that might help adaptation efforts in other buildings are often not feasible in hospitals: in some mental health wards, windows cannot be opened for safety reasons, and fans are often restricted to control infection.

The impact of overheating also extends to other health and social care settings. Research shows significant excess mortality in care homes and private homes during heatwaves, many of which lack air conditioning or effective ventilation.[65] Older people are especially vulnerable to heat

[60] Agency, UK Health Security (2023) "Written evidence submitted by the UK Health Security Agency", Link
[61] UK Health Alliance on Climate Change (n.d.) "Heat", Link
[62] Guy's and St Thomas' NHS Foundation Trust (2023) "Review of the Guy's and St Thomas' IT Critical Incident: Final Report from the Deputy Chief Executive Officer, January 2023", Link.
[63] Round Our Way (2023) "NHS overheating in the UK at its highest rate ever", Link.
[64] NHS England and UK Health Security Agency (2025) "4th Health and Climate Adaptation Report", Link
[65] Thompson R (2022) "Heatwave Mortality in Summer 2020 in England: An Observational Study", Link

because they are more likely to have chronic health conditions and tend to spend more time indoors. In domiciliary care, where practitioners visit a maximum of four times per day, it is harder to manage risks and monitor behaviour. Individuals may also adopt practices that exacerbate heat exposure, such as wearing excessive layers or keeping heating on, for reasons including reduced thermal sensitivity meaning they do not perceive themselves as overheated, cognitive impairment or dementia, or social isolation.

Impact and cost of staff absences

Increased heat events are linked to 2.2% additional workforce absenteeism.[66] The NHS already experiences higher sickness absence rates than other sectors. According to the Office for National Statistics, NHS absence is 27% higher than the public sector average and 46% higher than all the private sector.[67] Absences can lead to delays, cancellations, and safety concerns, making the prevention of avoidable absences a key NHS England priority.[68]

> Generally, NHS staff absenteeism rates are lower in summer than in winter. However, in July 2022, when there was the hottest week of the year, the NHS staff absenteeism rate was 6.06%, in comparison with an average 2022 absenteeism rate of 5.65%.

There is also likely to be an impact on staff productivity. A report produced by Round Our Way, a campaign group, reported the occupational health risk to NHS staff from high temperatures.[69] It cited evidence that the 'cognitive performance' of doctors and nurses decreased at high temperatures, or even mild temperatures of 24°C, lowering their productivity.[70] This is likely to affect different parts of the workforce in different ways, and staff working in controlled environments have limited capacity to amend their exposure when compared to other parts of the workforce.

As temperatures increase, there is a risk that staff absences will increase. In June 2025, a 'heat strike' motion was put forward by union members to demand that the Health and Safety Executive adopt a 'national maximum workplace temperature', which would allow all non-essential staff to walk out if the temperature rises any higher than that.[71] There is currently no threshold for this. There is no agreed threshold beyond which the NHS would cease to function effectively, but even one or two absences in critical departments, such as theatres, A&E, intensive care, or radiology, can cause immediate disruption, including:

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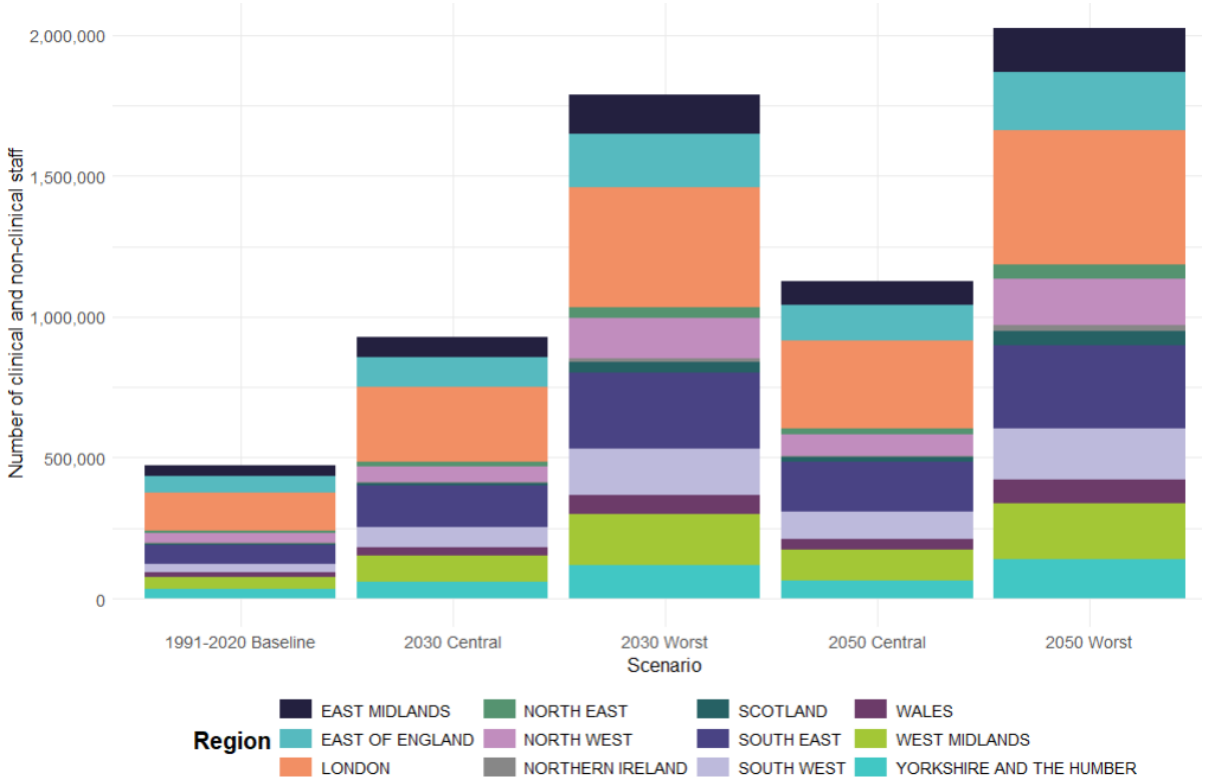
[66] Ananian, Sévane (2023) "Impact of Heat Stress on Labor Productivity and Decent Work", Link
[67] Bhatia, Tazeem (2015) "What will be the real cost of poor NHS staff wellbeing?", Nuffield Trust, Link
[68] In this analysis, the term "absence" is assumed to refer specifically to sickness-related absence rather than planned leave.
[69] Davey et al. (2024), Prevalence of occupational heat stress across the seasons and its management amongst healthcare professionals in the UK, Link
[70] Li Lan et al. (2022) "Cognitive performance was reduced by higher air temperature even when thermal comfort was maintained over the 24-28 °C range", Link
[71] Round Our Way (2023) "NHS Overheating in the UK at its Highest Rate Ever", Link

- Delayed ambulances
- Reduced elective activity, triaging of services, and reliance on bank staff (which can increase stress and error rates)
- Delays, cancellations, or safety concerns

Figure 24. Projected staff absences from excess heat events



Source: Edge Health & Greencroft Economics

Heat also disrupts surgical activity. Around 20% of hospitals cancelled operations during the 2022 heatwave.[72] While the impact of heat is not yet visible in theatre data, partly because a significant proportion of operations are cancelled for other reasons, rising temperatures are likely to increase extreme heat-related cancellations.

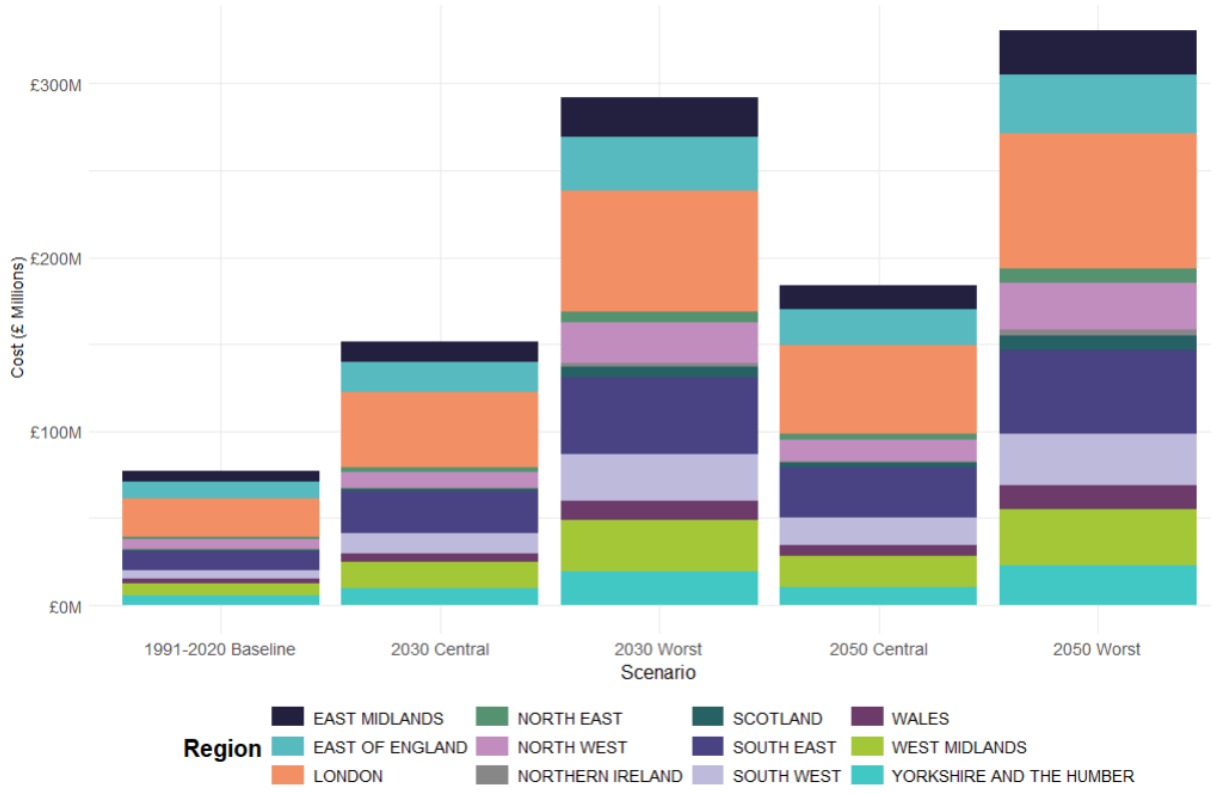
NHS staff absences are typically covered through three mechanisms: bank staff, overtime from existing employees, or redeployment from other service areas. Most sickness absences appear to be covered by bank staff. The NHS has capped agency staff use, with exemptions allowed

[72] University of Birmingham (2023) "2022 heatwave struck off surgery in fifth of UK hospitals", Link

only in limited circumstances, which are unlikely to include heat events. This policy was delayed by the COVID-19 pandemic, but in 2024–25, agency staff spend fell from 3.7% to 3.2%.[73]

The graph below (Figure 25) shows the projected cost of replacing NHS clinical and non-clinical staff with bank staff. By 2050, these staffing costs could increase more than fourfold. This analysis focuses on bank staff because they are the primary method for covering absences, both currently and in future NHS workforce planning. The average hourly wage for bank staff is £21.77, calculated using weighted grades and wages.

Figure 25. Projected cost of using bank staff to replace NHS staff absences due to excess heat events



Source: Edge Heath and Greencroft Economics

[73] Hopkinson, Emily (2024) "Summary of NHS operational planning and contracting guidance 2024/25", HFMA, April 2024, Link.

Longer-term Impacts

Social care and stroke

Heat events increase the risk of conditions such as stroke, which can lead to long-term healthcare needs.[74,75,76] Beyond the impact on quality of life, this creates costs for both individuals and the NHS, as well as greater demands on social care. Stroke was chosen for modelling because it is both strongly heat-sensitive and one of the few conditions with robust UK evidence linking extreme heat to increased hospital admissions and long-term care needs. As a result, the most significant social care impact of heat is likely to be an increased number of strokes, as many stroke patients require short- or long-term care and support.

In the present-day baseline, an estimated 136 additional people experience a stroke each year as a result of extreme heat (Appendix D3 – Supplementary Results).[77] In the worst-case scenario, this could rise more than 8x by 2050. However, a substantial proportion of these deaths is likely due to the "displacement effect," where individuals already in poor health die slightly earlier (by days to weeks) due to heat. Because these deaths do not meet the definition of "excess deaths," they have been excluded from the modelling. While UK-specific estimates are limited, studies suggest the displacement effect for stroke-related deaths could be around 80%.[78]

Table 15. Impact of Heat Events on Stroke Cases, Care Home Discharges, and Social Care Costs

	1991-2020	2030	2030	2050	2050
	baseline	central	worst	central	Worst
Stroke incidence due to heat events	136	353	940	517	1,197
Stroke patients discharged into care homes from heat events	10	27	72	40	92
Social care costs for patients discharged into care homes	£2,505,408	£6,509,148	£17,316,791	£9,530,376	£22,057,416

Source: Edge Health & Greencroft Economics

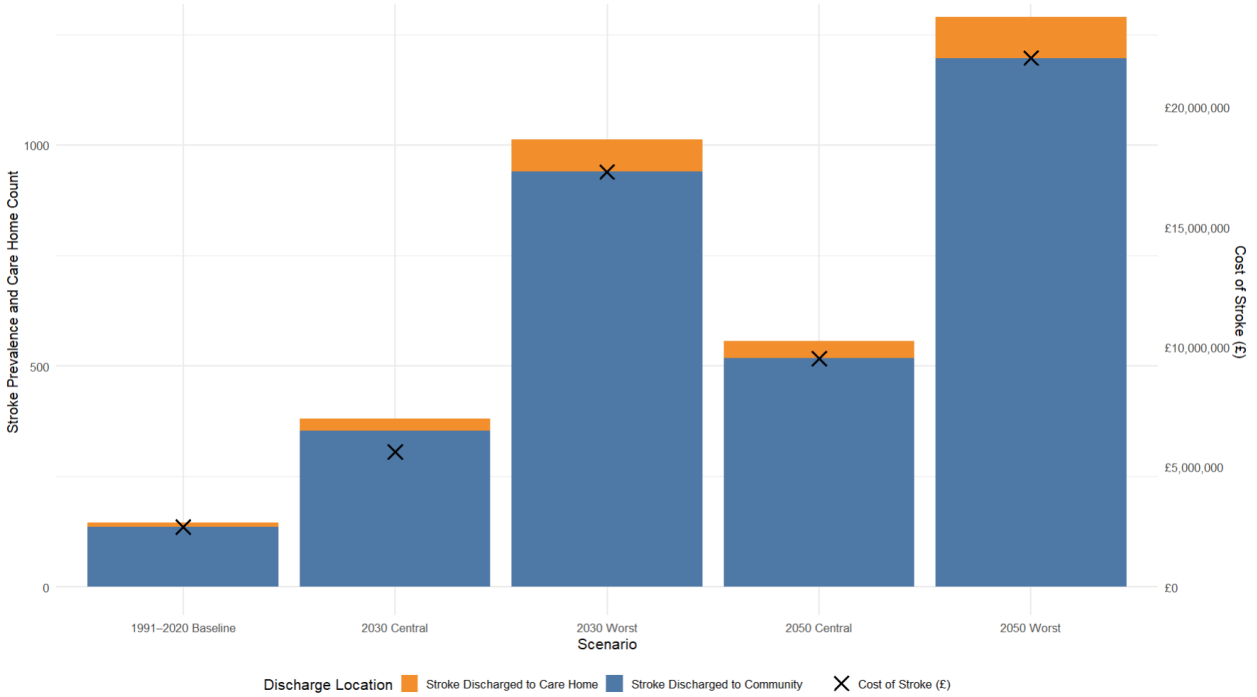
[74] Yang, C-L. et al. (2025) "Associations of compound hot extremes and heat waves with first-ever stroke morbidity in the context of climate change", Science of The Total Environment, Volume 964, Link
[75] Patel, M. D. et al. (2006) "Relationships between long-term stroke disability, handicap and health-related quality of life", Age and Ageing, Volume 35(3), 273–279, Link
[76] Anderson, G. B. et al. (2024) "Global effect of extreme hot and cold temperatures on cause-specific mortality", Stroke, Volume 55(2), Link
[77] For context, there are approximately 34,000 to 38,000 deaths from stroke in the UK each year, Link
[78] Hajat et al. (2005) Mortality Displacement of Heat-Related Deaths: A Comparison of Delhi, São Paulo, and London, Link

The projected number of strokes due to heat events is shown in the table above (Table 15). Only around 15% of strokes are fatal, meaning most heat-related strokes result in survival but often with significant care needs.[79] Around 1 in 10 people who experience a stroke will be discharged into a long-term care home.[80] For these patients alone, the lifetime social care cost could exceed £15m by 2030, assuming each patient lives for 5½ additional years and requires continuous care home residence.

Moreover, this cost is likely to be an underestimate. 65% of stroke survivors leave hospitals with a disability, and these are likely to also require social care.[81] Only 1 in 15 stroke survivors is reported to be cared for by family and friends, although there is often unreported support in the form of informal care and the voluntary sector supporting people and the healthcare system. Nevertheless, this leaves a significant number of people who will be reliant on some form of social care, many of whom will be at least partially paid for by the state.

[79] Lee, S., Shafe, A. C., & Cowie, M. R. (2011) "UK stroke incidence, mortality and cardiovascular risk management 1999–2008: time-trend analysis from the General Practice Research Database", Link
[80] Clery, A., Martin, F. C., Redmond, P., Marshall, I., McKevitt, C., Sackley, C., Manthorpe, J., Wolfe, C., & Wang, Y. (2021) "Survival and outcomes for stroke survivors living in care homes: a prospective cohort study", Link
[81] Public Health England & Brine, Steve (2018) "New figures show larger proportion of strokes in the middle aged", Link

Figure 26. Projected stroke impact by scenario



Source: Edge Health & Greencroft Economics

5.5 Distributional Impacts of Present-Day and Future Vulnerability to Extreme Heat

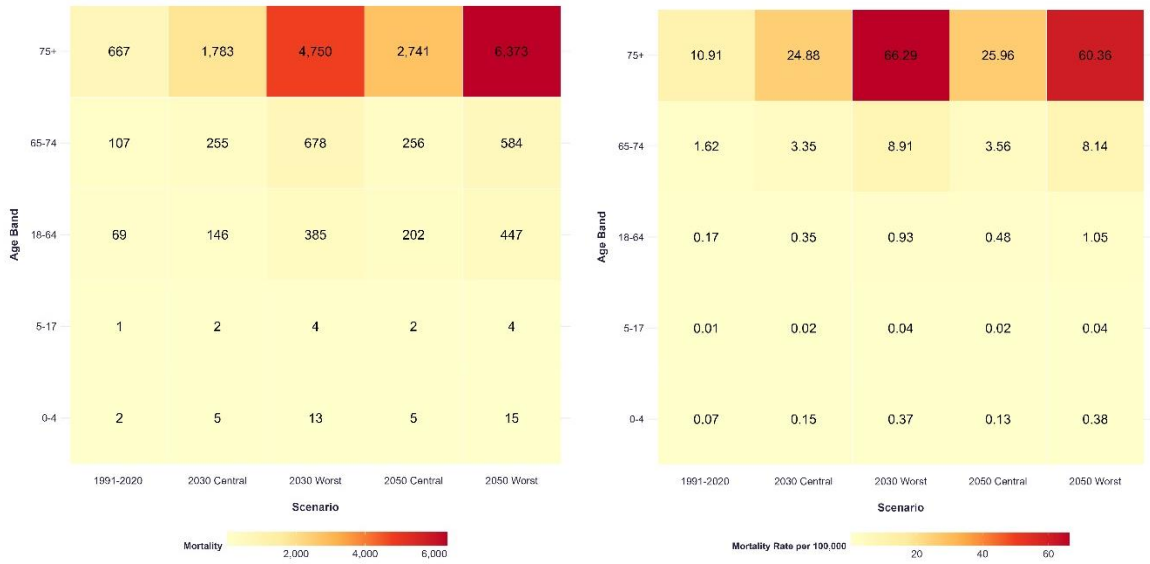
This section presents estimates of extreme heat-related health impacts under varying climate scenarios and evaluates how those impacts are distributed across population groups.

5.5.1 Mortality impacts

Distributional impact – age

Extreme heat-related mortality is most concentrated the oldest age groups. The 75+ age group is by far the most vulnerable, with a mortality rate eight times higher than other age groups. As a result, the 75+ age group accounts for 79% of heat-related mortality in the present-day baseline. Children under 18 were found to experience much lower heat-related mortality. However, this finding may be limited by the evidence, particularly the lack of UK-specific epidemiological studies for ages 0-4. It might also be indicative of the risk perception surrounding heat vulnerability that differs across age groups.

Figure 27. Heat-attributed mortality by scenario and age group - total (*left*) and rate per 100k (*right*)



Source: Edge Health & Greencroft Economics

In the central scenario, heat-related mortality is projected to nearly double compared to the present-day baseline. The largest relative increase in mortality is in adults aged 75+(+167% in 2030s and +311% in 2050s); this increase becomes more pronounced in the worst-case scenario

(+612% in 2030s and +856% in 2050s). However, it is worth noting that the relative increase is at least partly a result of a relatively low baseline mortality rate. The average annual mortality across the UK for people aged 75+ rises to around 2,741 by 2050s in the central scenario, up from 667 in the present-day baseline.

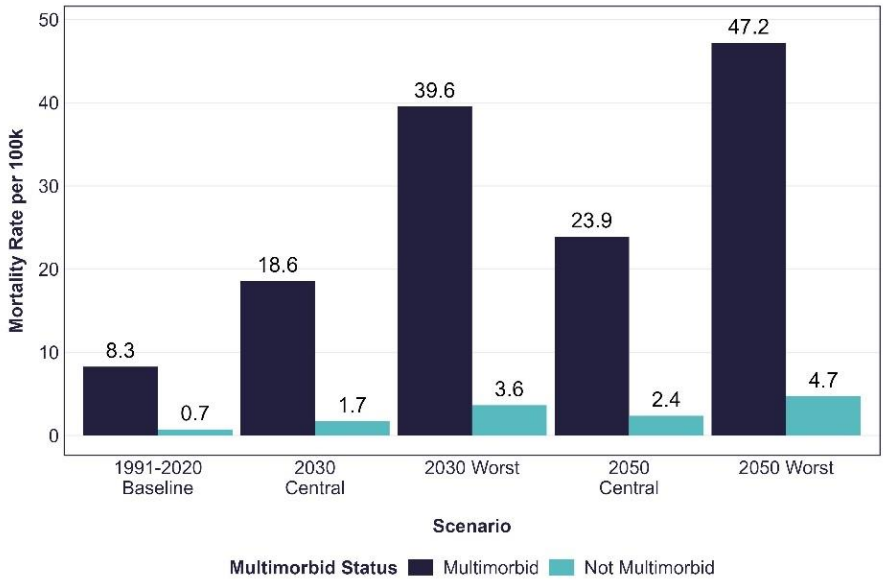
The largest absolute increase in mortality is also among those aged 75+ in the 2030s (*central*: +167%, *worst*: +612%). The average annual mortality across the UK for people aged 64 and above rises to around 2,997 by 2050 in the central scenario, constituting 93% of the mortality burden, up from around 774 in the present-day baseline. From a mortality perspective, the elderly will remain most at risk. For these older age groups, it is important to note that a substantial proportion of these deaths is likely due to the "displacement effect," where individuals already in poor health die slightly earlier (by days to weeks) due to heat. Because these deaths do not meet the definition of "excess deaths," they have been excluded from the modelling.

Distributional impact – multimorbidity

Multimorbidity refers to individuals living with two or more long-term health conditions. Currently, there is no UK-based cohort evidence that quantifies how multimorbidity affects the relative risk of mortality from heat exposure. Due to the lack of literature-based evidence on relative risks, the same age-specific mortality relative risk for individuals with and without multimorbidity was assumed in our model. This was a key limitation to the modelling results as the relative risks for these individuals likely differ from the general population.

Instead, we accounted for differences in underlying mortality rates between these groups. As a result, even with the same relative risk, individuals with multimorbidity are inherently more vulnerable, facing a higher absolute risk of heat-related mortality due to their elevated background risk of all-cause mortality.

Figure 28. Heat-related mortality impacts: multimorbid vs. non-multimorbid populations



Source: Edge Health & Greencroft Economics

Because individuals with multimorbidity have higher mortality rates than those without, most heat-related deaths are projected to occur within this group. In the present-day baseline, approximately 68% of the heat-related deaths are within the multimorbid population, who experience a mortality rate eight times higher than their non-multimorbid counterparts. This disparity is projected to grow, with the mortality rate in the multimorbid group reaching ten times that of the non-multimorbid population by the 2050s under the worst-case scenario. Notably, this elevated burden is concentrated within a relatively small segment of the population, as only 7-12% of the population are classified as multimorbid across regions.

Table 16. Number and percentage of heat-related deaths within multimorbidity group and age band in present-day baseline (number of deaths rounded to the nearest whole number)

Age Group	Multimorbid (%)	Not Multimorbid (%)
0_4	3 (98.8%)	0 (1.1%)
5-17	1 (93.0%)	0 (7.0%)
18_64	80 (82.7%)	0 (17.3%)
65_74	68 (45.5%)	81 (54.5%)
75+	265 (25.4%)	778 (74.6%)

Source: Edge Health & Greencroft Economics

Assessing these results with age, heat-related mortality falls within the 75+ group, which has the highest number of multimorbid individuals. In the present-day baseline, 60% of the 75+ population are multimorbid, where 74.6% of heat-related deaths in this age group occur among multimorbid individuals, suggesting multimorbidity- and age-driven vulnerability.

Distributional impact – deprivation

Nationally, the highest rates of heat-related mortality are observed in the least deprived decile. While this may seem unexpected given the typically higher vulnerability of more deprived populations at an individual level, the population-wide result closely tied to patterns of heat exposure.[82] Less deprived areas, often located in the South and urban centres like London, tend to experience more frequent and intense heat events. This higher exposure drives up the absolute number of heat-related deaths in these areas, despite potentially better access to healthcare and greater adaptive capacity.

Table 17. Mean heat-related mortality rate per 100,000 by the average number of heat occurrences and IMD deciles (IMD = 10: Least Deprived, IMD = 1: Most Deprived)

IMD Deciles	Average heat-related mortality rate per 100,000	Average number of heat occurrences
1	0.8	9.0
2	1.1	10.8
3	1.3	11.6
4	1.5	11.0
5	1.7	10.6
6	2.0	11.0
7	2.1	10.8
8	2.2	11.2
9	2.5	11.3
10	2.9	12.0

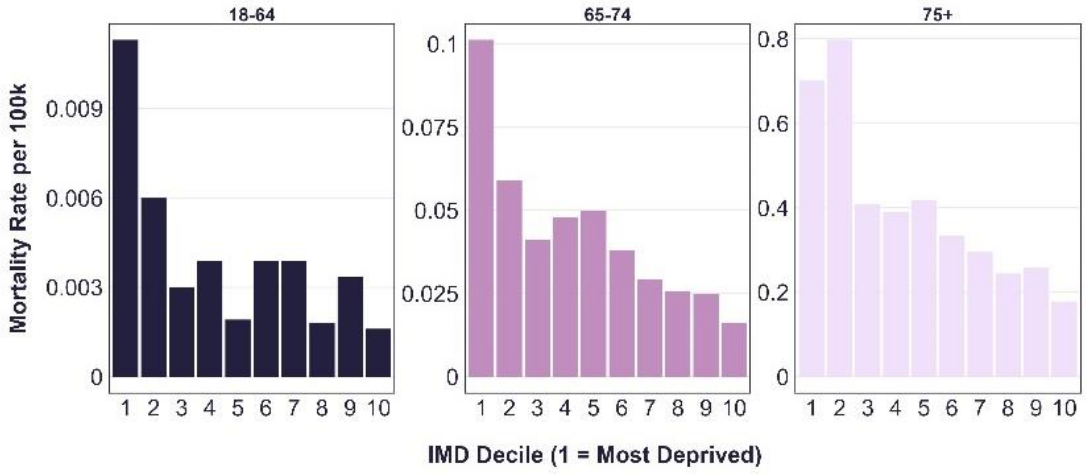
Source: Edge Health & Greencroft Economics

It's important to distinguish between exposure and vulnerability. Although current mortality is higher in less deprived areas, due to more frequent extreme heat days, more deprived populations may face greater risk per degree of exposure due to factors like poor-quality housing, existing health conditions, and limited resources.

At a national level, heat occurrence patterns and demographic factors outweigh deprivation as main drivers of heat-related mortality. However, when controlling for region and age (e.g., in South East), we see that this effect of deprivation largely disappears.

[82] Thompson et al. (2025), Social determinants of heat-related mortality in England: a time-stratified case-crossover study using primary care records, Link

Figure 29. Heat-related mortality rates by age across IMD deciles for the baseline in the South East (IMD = 10: least deprived, IMD = 1: most deprived)



Source: Edge Health & Greencroft Economics

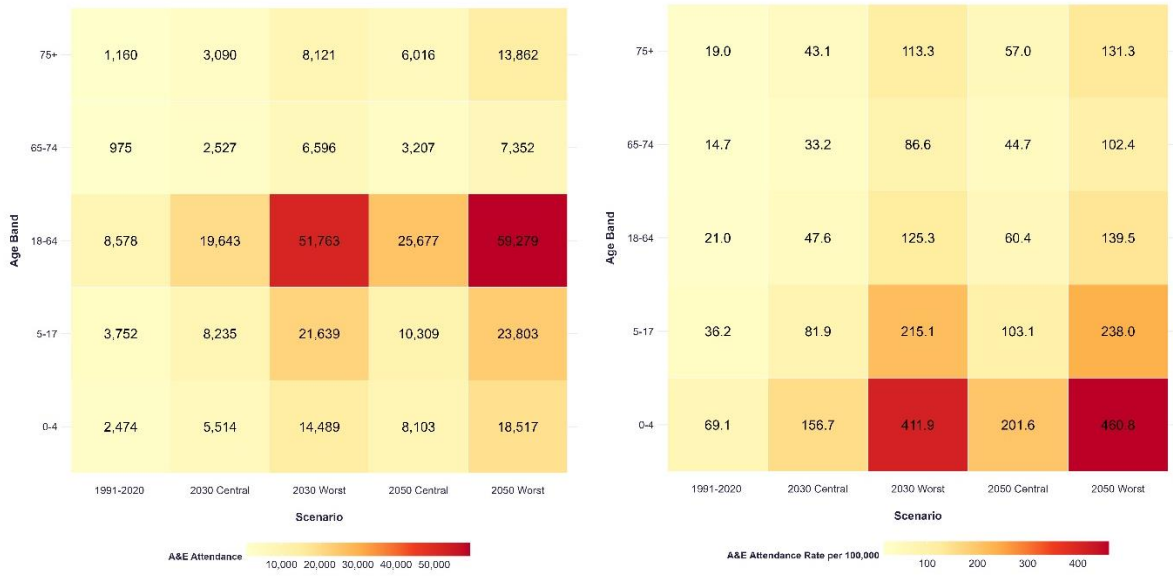
Currently, there is no consistent UK-based evidence quantifying a significant relationship between deprivation and heat-related mortality. Our results show that deprivation likely has a minor influence on mortality, though its relative importance is overshadowed by other factors. Further research is needed to fully understand the role of deprivation in heat-related health impacts.

5.5.2 A&E attendance impacts

Distributional impact – age

Most of the heat-related A&E attendances are concentrated in younger age groups. Children aged 0-4 experience the highest attendance rate (69.1 per 100,000), with rates twice as high as other age groups in the present-day baseline. When looking at the absolute number of attendances, the majority of the impact is concentrated in the 18-64 age group due to its large population size. In contrast, those aged 65-74 have the lowest heat-related attendance rate as well as the lowest absolute burden relative to other age groups.

Figure 30. Heat-attributed A&E attendance by scenario and age group - total (*left*) and rate per 100k (*right*)



Source: Edge Health & Greencroft Economics

In the central scenarios, the heat-related A&E attendance rate across all age groups is projected to be at least twice as high as the present-day baseline. The age group that experiences the largest increase relative to the present-day baseline are those aged 75+ in 2030s (+127%) and in those aged 65-74 in 2050s (+204%). This exacerbates further in the worst-case scenarios, where the projected increase in the 2050s is more than five times the present-day baseline estimate, with the largest relative increases observed in those aged 65-74 (+597%) despite having the lowest attendance rate. In terms of the absolute impact, while the 0-4 age group has the highest attendance rate, the relative increase for those aged 75+ in the 2050s worst-case scenario is also substantial, with the number of heat-related attendance projected to increase by almost eleven

times (+1,095%) its impact at the present-day baseline. This is likely driven by the ageing population.

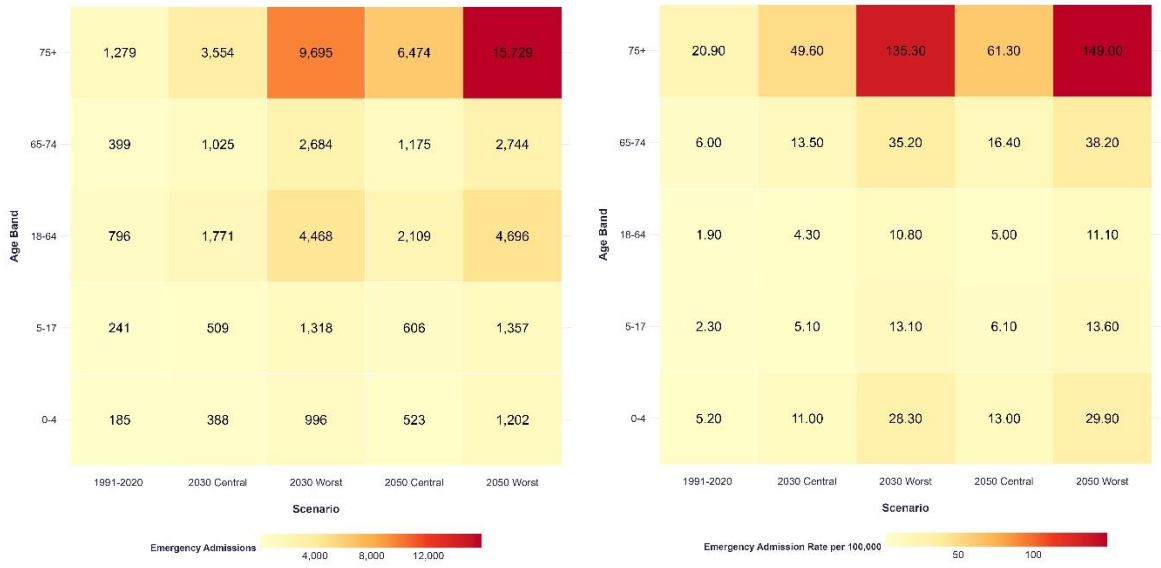
5.5.3 Emergency admission impacts

Distributional impact – age

Most heat-related emergency admission impact is concentrated in the oldest age group 75+, which has an admission rate (20.9 per 100,000)—more than three times as high as other age groups in the present-day baseline. When looking at absolute number of emergency admission impacts, the majority is within those aged 75+, despite a smaller population size than those aged 18-64.

Unlike the trend seen in A&E attendance impacts where those aged 0-17 are the most impacted, individuals aged 75+ are most likely to be admitted into hospital for emergency due to heat.

Figure 31. Heat-attributed emergency admission by scenario and age group - total (*left*) and rate per 100k (*right*)



Source: Edge Health & Greencroft Economics

In the central scenario, the heat-related emergency admission rate across all age groups is projected to be nearly three times as high as the present-day baseline in the 2050s. The age group seeing the largest relative increase are those aged 75+, with admissions rising by 102% in the 2030s and 193% in the 2050s. This exacerbates further in the worst-case scenarios, where the projected increase in the 2050s is over six times the present-day baseline estimate, with the largest relative increases also observed in the 75+ age group. In terms of the absolute impacts, the admission rate for those aged 75+ in 2050s worst-case scenario (149.00 per 100,000)

represents an increase of over 600% (+613%) compared to the baseline rat (20.90 per 100,000), likely exacerbated by an ageing population.

Distributional impact – disease category

We have modelled emergency admissions specifically for four specific disease categories: infectious diseases, injuries, metabolic diseases and respiratory diseases.[83] These diseases were identified in line with the source used to model emergency admission impacts.[84] For more details of these diseases, see Appendix – Health Impact Modelling.

In the present-day baseline, respiratory diseases (29%) and injuries (28%) account for the largest shares of heat-related emergency admissions. This shifts in the future scenarios. By the 2050s worst-case scenario, the contribution from injuries drops to approximately 19%, while the burden of admissions shifts towards respiratory diseases (32%) and infectious diseases (27%). During extreme heat days with daily maximum temperatures exceeding 30°C, the risk of injury-related admissions tends to level off, showing a plateau in relative risk. In contrast, the relative risks for respiratory and infectious diseases rise exponentially, indicating that these health outcomes are more sensitive to higher temperatures. This is amplified by demographic ageing: the 75+ group is projected to account for ~39% of the total excess emergency admissions, the majority of which (90%) are for respiratory and infectious diseases.

In the 2030s central scenario, we would expect to see double the number of emergency admissions overall, and in the 2050 worst-case scenario, we can expect to see almost seven times the number of emergency admissions overall.

Previous research has demonstrated that extreme heat may significantly increase the vulnerability of the population to infectious disease.[85] While this is not directly captured as the relative risk for infectious disease on the same temperautre day is assumed to be constant in future scenarios, the shift of the distribution of heat occurrences towards days above a daily maxmum temperature of 30°C would contribute to higher infectious disease burden due to heightened relative risks

The relative risks for emergency admissions due to infectious disease at 25°C and 30°C).

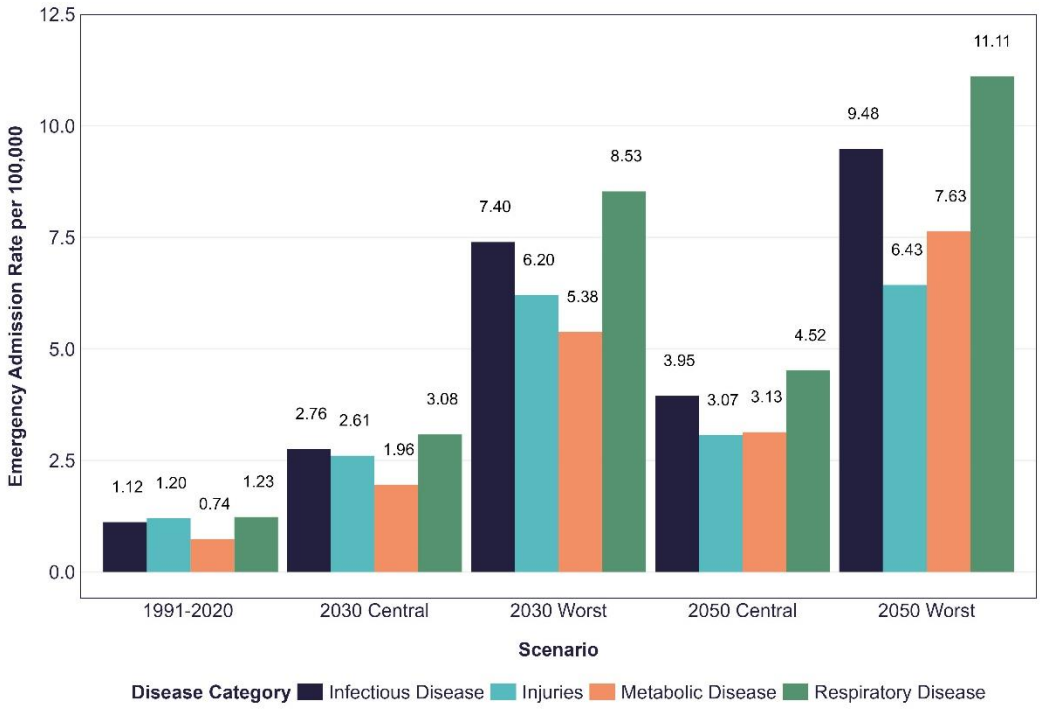
Age	25°C	30°C
0-4	1.05	1.08
5-17	1.08	1.30
18-64	1.06	1.08
65-74	1.07	1.14
75+	1.13	1.35

[83] Injuries include injuries to body parts (e.g. head injury), metabolic diseases include diabetes, obesity and hypoglycaemia, respiratory diseases include respiratory tract infection such as COPD, influenza, bronchitis. Note that this does not include cardiovascular admissions as this is limited by the source chosen for modelling Rizmie et al. (2021)

[84] Rizmie et al. (2021), Impact of extreme temperatures on emergency hospital admissions by age and socio-economic deprivation in England, Link

[85] Meher, Mirza Mienur; Afrin, Marya; Al Bayazid, Abdullah; Islam, Md Sayedul; Ali, Md Zulfekar (2025) "Deciphering the impact of heat wave in the global surge of infectious diseases", Link.

Figure 32. Heat-related emergency admission rate per 100,000 across warming scenario and disease category



Source: Edge Health & Greencroft Economics

5.6 Conclusion on Extreme Heat-Related Impacts on Health and Health System

Present-day baseline estimates indicate that extreme heat poses a significant and growing burden on the UK health and healthcare system, accounting for estimated 846 deaths, 16,938 A&E attendances and 2,901 emergency admissions annually.

The geographical distribution shows regional variation with London and southern England consistently experiencing highest heat-related impacts across all health outcomes in England, reflecting both higher heat exposures as well as demographic concentrations of vulnerable populations. Notably, while Scotland and Northern Ireland show lower absolute impacts, under the worst-case scenario they experience greater than average rates of increase overtime, suggesting that these historically cooler areas could face large adaptation challenges as they encounter increasing extreme heat levels.

Future projections demonstrate that extreme heat could amplify these health burdens, and it could be significant even in the central scenarios. By the 2030s central scenario, UK-wide heat-related outcomes are projected to more than double the impact at present-day baseline. By the 2050s central scenario, these are estimated to triple the impact of the present-baseline. These projections underscore that even under moderate warming scenarios, the UK faces substantial increases in heat-related health impacts, which could be further amplified by population changes.

The projected increases in heat-related mortality, A&E attendances, and emergency admissions represent a major challenge for the health system. While mortality represents the most severe outcome, A&E attendances constitute the largest volume impact, estimated at around 40% of the daily emergency department caseload. This highlights the operational pressures heat-event could place on healthcare services. Surges in demand during heat events could lead to longer waits in A&E, which are strongly linked to worst patient outcomes, including higher short-term mortality.

Furthermore, increased emergency admissions will raise bed occupancy to unsafe levels, delaying urgent care and increasing mortality risk. The resulting operational strain is likely to be compounded by heat-related impacts on NHS infrastructure. In parallel, the longer-term consequences of heat-related illness will drive up social care demand and costs, particularly for long-term residential care.

5.7 Validation & Sensitivity Analyses

To support the robustness of the results, a multi-step validation process was conducted. This process included sensitivity analyses that were undertaken to assess how the modelling results respond to changes in key assumptions and inputs that reasonably vary. This was done to show how dependent the findings are on these choices, particularly where the evidence base is limited.

The following sensitivity tests were carried out to internally validate the modelling results:

- **Relative risk inputs**:
    - Applying the upper and lower bounds of the 95% confidence intervals
    - Applying an England-wide mortality relative risk curve uniformly across all regions
- **Definition of an extreme heat day:**
    - Varying regional temperature thresholds
    - Altering the selection of climate model ensemble members
- **Population projections**:
    - Substituting the baseline projections with high-variant population scenarios
    - Substituting the baseline projections with low-variant population scenarios

Apart from sensitivity testing, the modelling results were also externally validated. This process included:

- **Expert engagement**: Sense-checking results with epidemiological experts in our Project Steering Group.
- **Literature and external sources:** A review of existing UK-based literature to benchmark the present-day baseline and future estimates, particularly for heat-related mortality, against published studies. It is important to note that external sources often use different methodologies, particularly in defining extreme heat thresholds and climate scenarios, which may limit direct comparisons.
- **Assess model results for a heatwave year**: Modelled mortality, A&E attendance, and emergency admission for the 2022 heatwave year. The results from this year were then compared with reported figures for that year to provide external validation.

5.7.1 Sensitivity analyses

The sensitivity analyses demonstrate that the relative risk inputs represent the greatest source of uncertainty, followed by the regional thresholds. The model is moderately sensitive to the population projection selected. Comparing across heat-related outcomes, emergency admissions and A&E attendance show greater methodological stability compared to mortality estimates.

Table 18. Summary of the sensitivity of the modelling results

Sensitivity Scenario	Heat-related Health Impacts Tested	Level of Sensitivity (Range of percentage change compared to main model)
Relative Risk Input – Upper and Lower Cis	Mortality, A&E attendance and Emergency Admissions	High Sensitivity (-15% to +78%)
Relative Risk Input – England-wide Curve	Mortality	High Sensitivity (-31% to +12%)
Temperature Threshold	Mortality, A&E attendance and Emergency Admissions	High Sensitivity (+25% to +86%)
Population Projections	Mortality, A&E attendance and Emergency Admissions	Moderate Sensitivity (-1.8% to +9.2%)

Source: Edge Health & Greencroft Economics

Relative Risk Input

Sensitivity to the relative-risk input was assessed by re-running the model with the reported upper and lower confidence limits for the relative risks of mortality, A&E attendance, and emergency admission, as provided in the source studies. Alongside this, mortality results were also tested using the England-wide mortality relative risk curves computed from Murage et al. (2022) to compare the sensitivity of the mortality results to the regional curves.

The model is highly sensitive to the relative risk input. Comparing the heat-related health outcomes, A&E attendance results are the least sensitive to the model input (-15% to +16%) despite having the highest absolute change. Mortality and emergency admissions are both highly sensitive to the relative risk input (ranging from -51% and +78%).

Table 19. Changes in heat-related outcomes, comparing the use of lower and upper confidence intervals of relative risks relative to main model results

	1991-2020 baseline		2030 central		2030 worst		2050 central		2050 worst	
Mortality	-495	-58%	-1,249	-57%	-3,323	-57%	-1,737	-54%	-4,183	-56%
	575	68%	1,512	69%	3,964	68%	2,053	64%	4,742	64%
A&E Attendance	-2,535	-15%	-6,241	-16%	-16,417	-16%	-8,609	-16%	-19,949	-16%
	2,683	16%	5,851	15%	15,391	15%	8,524	16%	19,702	16%
Emergency Admissions	-1,611	-56%	-3,986	-55%	-10,730	-56%	-5,722	-53%	-13,693	-53%
	2,271	78%	5,580	77%	15,904	83%	7,863	72%	19,576	76%

Source: Edge Health & Greencroft Economics

Sensitivity was also assessed by directly comparing results produced with the *regional* mortality RR curve to those produced with an *England-wide* RR curve. Across the warming scenarios, using the same mortality RR curve generally leads to a reduction of 0.3-1% in total mortality results, except for 2050s central, where 4 extra deaths were observed. This was driven by the increase in mortality impact in South East and South West. Across all scenarios, North West, Northern Ireland, West Midlands, and Yorkshire and the Humber see a reduction in the number of heat-related deaths. Northern Ireland is the most sensitive to relative risk input in terms of percentage decrease, which reaches -31% in 2050s worst-case scenario.

Table 20. Changes in heat-related mortality, comparing the use of England-wide mortality RR curve relative to main model results

	1991-2020 baseline		2030 central		2030 worst		2050 central		2050 worst	
EAST MIDLANDS	5	12%	-1	-1%	1	0%	-2	-1%	-9	-2%
EAST OF ENGLAND	-2	-2%	7	3%	-19	-3%	2	1%	-8	-1%
LONDON	-1	-1%	14	5%	15	2%	-16	-3%	7	1%
NORTH EAST	0	0%	3	7%	5	4%	-1	-3%	0	0%
NORTH WEST	-4	-6%	-6	-4%	-15	-4%	-3	-1%	-19	-4%
NORTHERN IRELAND	-1	-28%	-4	-29%	-9	-22%	-4	-23%	-25	-31%
SCOTLAND	0	-1%	0	-1%	6	6%	-4	-10%	0	0%
SOUTH EAST	7	3%	6	1%	-49	-3%	24	3%	9	0%
SOUTH WEST	4	4%	-15	-4%	9	1%	20	4%	-17	-1%
WALES	-4	-8%	3	3%	-2	-1%	-1	-1%	-7	-3%
WEST MIDLANDS	-5	-8%	-12	-7%	-12	-3%	-5	-2%	-20	-4%
YORKSHIRE AND THE HUMBER	-2	-4%	-10	-11%	-7	-3%	-6	-5%	-16	-5%
Grand Total	**-3**	**-0.3%**	**-22**	**-1%**	**-117**	**-2%**	**+4**	**+0.1%**	**-104**	**-1%**

Source: Edge Health & Greencroft Economics

Overall, the model was found to be highly sensitive to the relative risk inputs, especially when the upper and lower confidence limits were applied. Resulting estimates differed by up to 78% relative to the base case, indicating the results are substantially shaped by the chosen relative risk figures.

Temperature Threshold

In the main modelling results, extreme heat days are defined by daily maximum temperatures exceeding LSOA-based thresholds, ranging from 25°C to 29°C depending on the region, in line with the Met Office. To test the sensitivity of the modelling results to the application of thresholds, a single national threshold at 25°C is used.

With the application of the national threshold, the total number of heat occurrences is 30-48% higher across the warming scenarios. Furthermore, the application of a national threshold changes the ensemble member selected in the 2030s central scenario. London has the largest absolute reduction in heat occurrences across all the scenarios. There is no change to the

number of heat occurrences in Scotland and Northern Ireland during the present-day baseline, as their thresholds remain at 25°C daily maximum temperature.

The 2030s central scenario is the most sensitive to the application of the regional threshold, due to the selection of a different ensemble member. By the 2050s, the proportional differences are lower, suggesting that the choice of threshold matters slightly less in relative terms. Worst-case scenarios generally have smaller proportional differences than central scenarios, as both thresholds capture a similarly high number of heat days, as extreme heat days at higher temperatures become more common in worst-case scenarios.

Table 21. Changes in heat-related outcomes, comparing the use of regional thresholds relative to the main model results using national threshold

	1991-2020 baseline		2030 central		2030 worst		2050 central		2050 worst	
Mortality	+447	+53%	+1,446	+66%	+1,458	+25%	+1,479	+46%	+1,844	+25%
A&E Attendance	+12,339	+73%	+33,157	+85%	+36,939	+36%	+32,839	+62%	+41,231	+34%
Emergency Admissions	+2,474	+85%	+6,232	+86%	+7,473	+39%	+7,169	+66%	+9,215	+36%

Source: Edge Health & Greencroft Economics

Population Input

In the main modelling results, the main subnational population projections were used as the population input. In this sensitivity analysis, results are tested with high variant and low variant population projections for the 2030s and 2050s scenarios.

Table 22. Changes in heat-related health impacts in future scenarios, comparing population variants to main model results using the main projections

	Population Variant	2030 central		2030 worst		2050 central		2050 worst	
Mortality	High	+37	+1.7%	+23	+0.4%	+231	+7.2%	+447	+6.0%
	Low	+20	+0.9%	-105	-1.8%	+3	+0.1%	-135	-1.8%
A&E Attendance	High	+1,092	+2.8%	+2,873	+2.8%	+4,903	+9.2%	+10,745	+8.7%
	Low	-117	-0.3%	-513	-0.5%	-52	-0.1%	-382	-0.3%
Emergency Admissions	High	+123	+1.7%	+307	+1.6%	+777	+7.1%	+1,938	+7.5%
	Low	+6	+0.0%	-39	-0.2%	-119	-1.1%	-179	-0.7%

Source: Edge Health & Greencroft Economics

The model demonstrates minimal sensitivity to population input variations, with proportional changes generally remaining below 12% across all health impact categories. When high

population variants are applied, heat-related impacts increase modestly, with mortality showing changes between +0.4-7.2%, A&E attendance rising by 2.8-9.2%, and emergency admissions increasing by 1.7-7.5% compared to the main model results. Conversely, with the low population variant, results decreased across most warming scenarios and impact categories. Small increases were seen in a few cases because the population effect was smaller than the inherent variability between model runs.

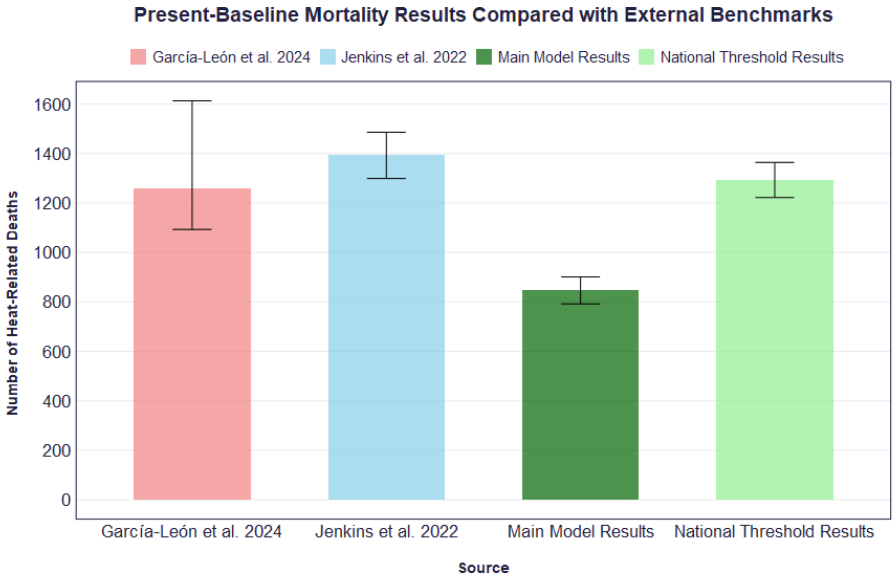
The 2050s scenarios show greater sensitivity to population variants than the 2030s, particularly for A&E attendance impacts, where the high variant produces increases of up to 9.2% in the central scenario, whereas the low variant leads to the largest reduction for mortality impacts. Central scenarios generally exhibit slightly higher proportional sensitivity to population variants than worst-case scenarios across most impact categories.

5.7.2 External validation

For mortality, A&E attendances, and emergency admissions, results were shared with external stakeholders for review and feedback. For mortality specifically, our estimates were validated against those previously modelled in the literature. However, due to a lack of published evidence, similar validation was not possible for A&E attendances and emergency admissions.

The graphs below outline validation of the mortality results against two external sources: García–León et al. 2024 (baseline defined as 1991-2020) and Jenkins et al. 2022 (baseline defined as 1990-2019). The main modelling results using regional threshold[86] were lower than the two external sources. This is due to the application of regional thresholds which reduces the number of heat occurrences compared to the national threshold. In contrast, the modelling results using the national threshold[87] were similar to the results from the two external sources, as shown by the overlapping confidence intervals.

Figure 33. Modelling results compared with external benchmarks derived from literature



Source: Edge Health & Greencroft Economics

Even though the definition of the central and worst-case scenarios would differ from previous estimates, comparison was still made for the modelling estimates of heat-related mortality for future scenarios to approximately understand where the results sit.

[86] Extreme heat defined as days with daily maximum temperatures equivalent to or exceeding 25C, 26C, 27C or 28C, defined in line with the Met Office regional temperature thresholds.
[87] Extreme heat defined as days with daily maximum temperatures equivalent to or exceeding 25C across the UK.

Time periods defined in the future scenarios in Jenkins et al. (2022) are most aligned with the time periods and global warming levels[88] used in our current study. Therefore, this study was used as the main comparator for the following scenarios:

Table 23. Scenarios used for comparison in Jenkins et al. (2022)

Jenkin's et al. (2022)	Current Study
2030s 2°C	2030s worst case
2050s 3°C	2050s worst case

Source: Edge & Greencroft

For the 2030s worst-case scenario, the current study estimated 5,830 heat-related deaths, which was higher than the 3,747 deaths reported by Jenkins et al. For the 2050s worst-case scenario, this study estimated around 7,423 heat-related deaths, which was lower than the 8,224 heat-related deaths reported by Jenkins et al., however the confidence intervals overlap, meaning that the difference is not statistically significant.

Table 24. Table comparing main model and national threshold results with two external sources

	Main Results	National Threshold
1991–2020 baseline	846 (792–901)	1293 (1222–1364)
2030s central	2192 (2093–2289)	3648 (3511–3783)
2030s worst	**5830 (5658–6001)**	7293 (7105–7481)
2050s central	3206 (3087–3325)	4685 (4548–4822)
2050s worst	**7423 (7234–7612)**	9267 (9052–9082)

	Jenkins et al. 2022	García–León et al. 2024
Baseline	1393 (1299–1485)	1258 (1093–1613)
1.5°C	2549 (2304–2794)	2383 (1669–3244)
2°C	**3747 (3280–4214)**	3378 (1886–4540)
2.5°C	–	7931 (4274–8833)
3°C	**8224 (7376–9072)**	11755 (8166–16928)

Table note: Time periods for each source is defined as follows

- *Jenkins et al. (2022) 1990-2020 baseline; 2020, 2030, 2050 for the respective warming scenarios (1.5°C, 2°C, 3°C)*
- *García–León et al. (2024), 1991–2020 baseline; 2100 for the respective warming scenarios (1.5°C, 2°C, 2.5°C, 3°C)*

Source: Edge & Greencroft

Heatwave Year Benchmarking

To further benchmark the mortality figures from the modelling, we ran a scenario for a previously recorded heatwave year in the UK. Specifically, 2022 is selected as it was the heatwave year most recent to the defined present-Day Baseline period (1991-2020). Two

[88] In this study, the global warming levels of each scenario are 1.5°C and 2°C for the central scenario, and 2°C and 2.5°C for the worst-case scenario, guided by CCC

heatwave scenarios were constructed, one based on the regional thresholds, which corresponds to the main modelling results scenario, and one based on the national threshold.

Table 25. Comparison of heat-related deaths modelled and reported by external sources

	Main Modelling	National Threshold	UKHSA[89]	ONS[90]
Mortality Results (England)	**2,197 (2,113–2,280)**	**3,035 (2,931–3,138)**	2,985 (2,258–3,712)	3,036
Mortality Results (England & Wales)	**2,332 (2,243–2,421)**	**3,185 (3,077–3,393)**	-	3,271

Source: Edge & Greencroft

There were two 2022 estimates for the number of heat-related deaths by the UKHSA and the ONS for England and Wales only. This ranges from 2,258 to 3,712 (UKHSA) for England and averaged at 3,271 (ONS) for England and Wales. Here, it is important to note that the case definition used to model the number of heat-related deaths for UKHSA is a L3 heat-health alert. Both the main modelling and national threshold results fall within the confidence intervals of these two estimates, meaning that the differences between the estimates are not significantly different.

5.8 Limitations and Future Research

This analysis is subject to several limitations that influence the precision and confidence of the results. Definitions of extreme heat vary between studies, and most rely on ambient air temperature rather than alternative measures such as Wet Bulb Globe Temperature, which restricts comparability. Furthermore, incorporating additional measures such as humidity could improve the representation of exposure.

The modelling results are sensitive to the RR curves used to estimate health impacts. Mortality projections were most sensitive (±67%), followed by emergency admissions (±72%), while A&E attendances were least affected (±16%). This uncertainty is especially significant for morbidity outcomes, where fewer robust studies exist. More recent UK-based studies, including post-COVID analyses, are needed to reflect potential changes in population health and healthcare use, and to determine the most appropriate methods for extrapolating RR curves to higher

[89] UKHSA (2025) Heat mortality monitoring report: 2022, Link
[90] ONS (2022) Excess mortality during heat-periods, England and Wales, Link

temperatures. Evidence gaps also remain for certain high-vulnerability groups, such as those with mental health conditions and pregnant individuals.

Geographical and demographic gaps in the evidence base persist, with most studies focused on London and the South East. There is limited recent research for Scotland and no quantitative evidence for Northern Ireland, and many existing studies are short-term or event-specific, limiting understanding of cumulative and long-term effects.

Data availability on healthcare system strain is also limited, including a lack of information on the condition and resilience of NHS estates and building stock. In addition, there is little UK-specific evidence quantifying the health benefits and cost-effectiveness of adaptation measures, which restricts the ability to prioritise interventions based on both health and economic outcomes.

To address these limitations, future research should:

1. Expand UK-specific analyses of morbidity outcomes across a wider range of indicators.
2. Re-estimate heat–health exposure–response functions using recent datasets, including post-COVID data, and develop methods for extrapolating to higher temperatures.
3. Undertake dedicated studies for Northern Ireland and Scotland to address regional evidence gaps.
4. Conduct targeted research on high-vulnerability groups, including those with mental health conditions and pregnant individuals.
5. Standardise definitions of extreme heat and incorporate additional metrics such as humidity or WBGT alongside air temperature.
6. Strengthen the UK evidence base on the health benefits and cost-effectiveness of adaptation interventions, including impacts on healthcare system capacity, infrastructure resilience, and operational efficiency.
7. Carry out further research on the current state of the NHS Estate, including how often overheating happens, and the prevalence of passive and active cooling measures, to prioritise retrofits based on a better baseline understanding of the current building stock.
8. Continue research into the most cost-effective ways to reduce the health impacts of heat in care home settings, in order to support prioritisation of low-cost measures such as natural ventilation and external shutters, and when to invest in active cooling such as air-to-air heat pumps.
9. Establish longitudinal datasets to assess cumulative and long-term health impacts.

6 Optimal Adaptation Response

6.1 Health Impacts of Adaptation in the Central Climate Scenario

This section describes the improvement in those outcomes compared to a no-adaptation scenario. The monetised outcomes described in Section 6.2 are based on avoiding the three heat-related outcomes (mortality, admissions, hospital attendances), compared to the expected health outcomes presented in Section 5.2.

The benefits of adaptation on mortality would be to reduce expected annual heat-related deaths from 3,206 across the UK by 2050, to 2,027 – a reduction of 1,179 deaths per year. This still results in a higher annual heat-related death-toll compared to the present-day baseline, in which on average 1,293 die from heat-related events each year. As would be expected the benefits are higher in regions which are most at-risk, which is where adaptation measures are implemented more intensively.

It is worth noting that while the assessment of the costs of adaptation is likely to be comprehensive, the assessment of benefits may be only partial – so the monetised benefits and resulting benefit-cost ratios presented in this section are likely to be conservative. The costs are complete in the sense that they include the full cost of implementing each measure, and there is relatively low likelihood of additional non-monetised costs (i.e. there is limited risk to outcomes such as biodiversity, or increased carbon emissions, which would be examples of further costs). However, the benefits only represent the value of the improved health outcomes on days of extreme heat. Whereas, implementing the adaptation measures would likely deliver additional benefits – in particular improved wellbeing and comfort, which is not valued here.

As an example, the benefits of public cooling stations are estimated on the basis of reducing risk of mortality, admission to hospital, or A&E attendance. While these are important benefits of public cooling stations – and the ones of relevance for this study – they are not the only benefits public cooling would deliver. Public cooling is likely to deliver improvements in public wellbeing, especially organised around major public events, and these benefits in wellbeing are not represented in the benefit-cost ratios presented in this section.

Table 26. Impact of the optimal adaptation package on health outcomes – central scenario

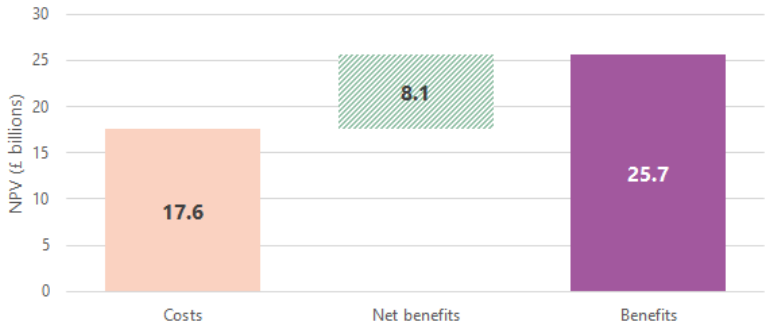
	2050 mortality – no adaptation	Reduction in mortality by adaptation	2050 admissions – no adaptation	Reduction in admissions by adaptation	2050 attendance – no adaptation	Reduction in attendance by adaptation
East Midlands	182	60	839	156	4,159	407
East of England	350	116	1,222	225	5,760	560
London	480	194	1,763	326	12,647	1,230
North East	58	17	320	53	1,196	116
North West	198	66	1,082	180	4,685	450
Northern Ireland	19	7	71	10	338	17
Scotland	43	13	188	25	614	22
South East	915	387	1,742	316	8,809	865
South West	520	180	1,258	224	4,523	445
Wales	104	31	335	55	1,510	134
West Midlands	211	65	1,229	207	5,687	536
Yorkshire and the Humber	126	42	840	142	3,384	325
Total – all regions	**3,206**	**1,179**	**10,888**	**1,917**	**53,312**	**5,106**

Source: Edge Health & Greencroft Economics

6.2 Implementing the Optimal Adaptation Package

Optimal adaptation could deliver net benefits of around £9.5 billion in Net Present Value (NPV), between 2025 and 2080. The optimal adaptation response maximises net benefits – i.e. the NPV of benefits delivered by adaptation measures, subtracting the NPV of costs associated with those measures. While the cost of adaptation would be around £17.6 billion in NPV, the benefits in terms of reduced mortality, hospital attendance, hospital admissions and health system benefits could be over £25.7 billion in NPV. Implementing the full package of adaptation options therefore delivers benefits 50% higher than costs (with a benefit cost ratio of 1.5).

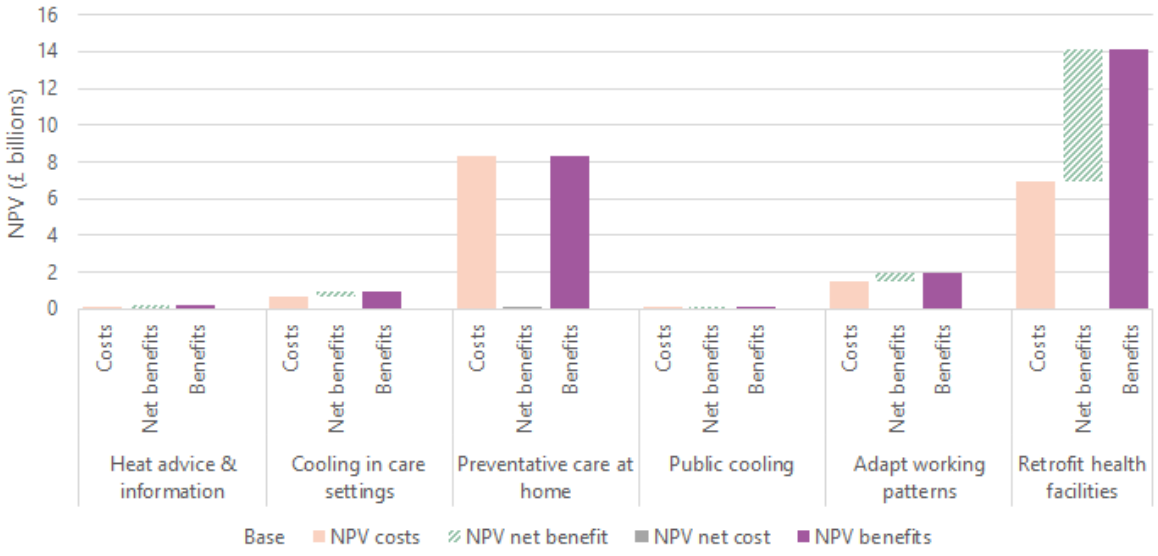
Figure 34. Total costs and benefits of the optimal adaptation package



Source: Edge Health & Greencroft Economics

The greatest overall benefits are delivered by retrofitting health facilities (both passive and active cooling, combined depending on the building context) to be better able to shield patients and staff against extreme heat, and preventative home visits to high-risk individuals on hot days (Figure 35). As set out in Section H, the cost of home health care visits have been costed on the basis of additional health visits during periods of extreme heat, while there may be opportunities to utilise existing contacts and reforms to decentralise health care provision, which would make this more cost effective.

Figure 35. Costs and benefits of the measures included in the optimal adaptation package



Source: Edge Health & Greencroft Economics

Some measures have consistently high benefit cost ratios, while others are more sensitive across regions and depending on underlying assumptions (Table 27).

Health advice and information services produce a very high benefit-cost ratio (BCR). This is because they are generally relatively low cost to set up and operate and can reach a large share of the population, although they need to be well designed to be accessible and to elicit behavioural change. Even with fairly modest assumptions around how effective they are in influencing behavioural change, they are likely to deliver benefits that outweigh their costs.

Investing in retrofitting existing health care facilities is likely to deliver high net benefits. Modelling that accounts for both active cooling (for this study, air-to-air heat pumps) measures and passive solutions (such as blinds and shutters) suggests that upgrading infrastructure could significantly reduce indoor temperatures, protect vulnerable patients, maintain critical services during heatwaves, and improve the occupational health and performance of health workers.

The total costs of retrofitting health care facilities to adapt to the risks of extreme heat would be costly, but within reasonable ranges given current NHS expenditure. For example:

- the CCC's advice on the UK's Seventh Carbon budget estimates a need for just over £30 billion in capital expenditure for non-residential buildings between 2025 and 2050, with an annual peak of £2.5 billion in 2031.[91]
- NHS capital expenditure has fluctuated around £10 billion per year (in 2025 prices) since 2009-10, with a spike to over £15 billion in 2020-21.[92]
- The NHS maintenance backlog has risen from £5.4 billion in 2022-23 to £12.5 billion in 2022-23.[93]

This study estimates a cooling capital investment need of £2.6 billion, if all at-risk hospitals installed heat pumps. To put this into context, that is equivalent to about 10% of all capital investment requirement for low-carbon heating capex for all non-residential buildings in the CCC's CB7 advice, or 30% of a single years' NHS capital investment.[94] However, an important implication of this study is on how quickly measures should be implemented; to respond to the risks posed by extreme heat may mean bringing forward some of the expenditure that may otherwise be planned, for hospitals most at-risk during heat events.

While adapting working patterns and staffing has a relatively low BCR – at 1.3 it delivers benefits 30% higher than costs – this finding is likely to be relatively robust and may be on the conservative end. This is because it is comparing increasing staff to meet excess demand (and

[91] Climate Change Committee (2025) "The Seventh Carbon Budget", Link
[92] Institute for Fiscal Studies (2024) "The past and future of UK health spending", Link
[93] Institute for Fiscal Studies (2024) "The past and future of UK health spending", Link
[94] On the basis of an average annual capital investment of £10 billion per year

reduced staff availability) during heat events, either using bank and agency staff, or through reform to staffing rosters.

Table 27. Costs and benefits of the optimal adaptation package

	Costs (NPV in £ million)	Benefits (NPV in £ million)	BCR
Heat advice and information services	8.0	249.	31.0
Preventative care at home	8,367.5	8,367.2	1.0
Public cooling	22.6	43.0	1.9
Cooling in care settings	711.3	927.3	1.3
Total - demand measures	**9,114.7**	**9,586.7**	**1.1**
Retrofit health facilities	6,934.2	14,140.2	2.0
Adapt working patterns and staffing	1,524.2	1,953.2	1.3
Total - supply measures	**8,458.5**	**16,093.4**	**1.9**
Total - all measures combined	**17,573.2**	**25,680.2**	**1.5**

Source: Edge Health & Greencroft Economics

The demand side measures provide an illustration of the trade-offs that will need to be balanced in a prioritised regional implementation approach.

While the optimal adaptation package builds in regional phasing, three of the demand side measures do not always produce benefits exceeding costs (i.e. a BCR greater than 1), especially in regions with a relatively lower extreme heat risk profile Table). This is likely because the approach to regional phasing cannot be perfectly optimised (see discussion in Section 3.6), with the BCRs suggesting that rolling out these measures would need to be carefully assessed and monitored within each region.

While health care visits at home for vulnerable patients can deliver significant benefits in terms of reducing risk of mortality, admissions, and attendance, they are also relatively costly, as it entails an increase in health care workers levels during heat events. In low relatively low risk regions, such as Northern Ireland, Scotland, and the North East, this may not be cost-effective or would need to be scaled back appropriately in line with the level of risks. It should also be noted that this is based on the current approach to delivering healthcare, while in future it is highly likely that healthcare evolves to place a stronger role on care in the community.[95] If this evolution were to happen in any case, then incorporating a more proactive role for community care workers during heat events would become much more cost effective. This could be integrated as part of an increasing broader role for community care, making every contact with

[95] For England, see for example the UK Government (July 2025) "FIT FOR THE FUTURE – 10 Year Health Plan for England", Link

patients count as part of a holistic approach to care in the community (including NHS health contacts, community care workers etc.).

For preventative care, the high variation in regional BCRs, to a large extent, results from relatively crude modelling assumptions. Once this adaptation measure is activated, the model implements a set number of healthcare visits are delivered over the course of summer months, irrespective of how many hot days there are, or how hot the days are. So, the modelled costs are essentially fixed and relative to the size of the vulnerable population in each region. However, the benefits reduction relates not only to the size of the vulnerable population in each region which benefits from health care visits, but also the magnitude of the risk – i.e. it is proportionate to the exposure to extreme heat. Therefore, the regional BCR variation tells us that the amount of proactive health care visits would need to be highly tailored on a region-by-region basis.

Public cooling stations show a wide range of benefit ratios. This is partly because their benefits are primarily related to improving wellbeing of people in public spaces, and less about directly improving the three health outcomes assessed in this study (see Section H for further discussion on the likely effectiveness of public cooling stations in terms of reaching people at risk of adverse health outcomes from extreme heat).

The cost effectiveness of investing in cooling in care home settings varies widely by region. This is because there is a large capex cost incurred once the adaptation measure is implemented, so its cost effective rises the higher the risk posed by extreme heat (as the fixed costs do not change, while the benefits rise in proportion with the risk). This means a targeted approach will need to be taken both across and within UK regions, to prioritise the right mix of cooling solutions. In general, cooling in care homes delivers relatively low benefit-cost ratios as its main impact is on avoiding mortality for at-risk care home residents, many of home are elderly, and will be likely to die of other causes within a relatively short time span. This is underscored by the much higher BCR in the Southeast, where there is both high exposure to extreme heat, and high vulnerability with a large and elderly population. However, staff within care homes will also need protecting from extreme heat.

Note that in the case of Scotland and Northern Ireland, there are no benefits shown for public cooling or for cooling in care settings. This is because the risk profile of these two regions remains low even by 2050 in the central climate scenario, so these two medium-term adaptation option are not activated. This is a result of modelling adaptation at large regional level (the 12 UK regions); in practice there may be sub-regions, or specific facilities, where passive and active cooling in care home settings, or where public cooling should be deployed.

Table 28. Benefit cost ratios (BCRs) for demand side adaptation measures by region

	Preventative care at home	Public cooling	Cooling in care settings
East Midlands	0.7	1.5	0.7
East of England	1.0	1.7	1.1
London	1.3	2.0	1.8
North East	0.5	4.1	0.3
North West	0.6	2.1	0.5
Northern Ireland	0.3	-	-
Scotland	0.2	-	-
South East	1.8	1.7	8.6
South West	1.5	1.3	1.9
Wales	0.8	3.6	0.3
West Midlands	0.7	2.4	1.4
Yorkshire and the Humber	0.5	1.7	0.6
Total – all regions	**1.0**	**1.9**	**1.3**

Source: Edge Health & Greencroft Economics

Note: there is no entry for Scotland and Northern Ireland for public cooling and cooling in care settings, as these are not activated since both regions remain "low risk". However, this is intended only to represent a reasonable estimate for the UK-wide needs, and especially in the reasonable worst-case climate scenario both Scotland and Northern Ireland would need to implement some of all measures (even if less than other UK regions)

6.3 Testing the Adaptation Package and Sensitivity Analysis

To test and refine the optimal adaptation package, the four alternative packages described in Section 3.5 are run. As shown in Table 29, As described in Section 3.5, the adaptation measures are implemented to a different degree depending on the extreme heat risk profile of each region. In general, front-loading capital intensive solutions would not increase net benefits. This is because benefits increase as the incidence of extreme heat hazards rises over time, so deferring capital costs can be advantageous where possible. Similarly, implementing a uniform adaptation strategy across all regions would decrease the overall net benefits (and the BCR), as it would not prioritise regions most at risk, while accelerating the adaptation measures also reduces the BCR.

The deferred adaptation package does produce a higher BCR, pointing to the potential trade-offs between maximising adaptation, and prioritising only the most beneficial options.

Table 29. Comparing BCRs of different adaptation packages

	A Optimal Adaptation	B Front-load capex	C No regional phasing	D Accelerated	E Deferred
Heat advice and information services	31.08	31.01	25.33	29.53	26.41
Preventative care at home	1.00	0.97	0.94	0.99	1.12
Public cooling	1.91	1.90	1.86	1.87	2.80
Cooling in care settings	1.30	0.82	0.82	1.02	1.50
Total - demand measures	**1.05**	**0.98**	**0.96**	**1.02**	**1.17**
Retrofit health facilities	2.04	2.02	1.89	1.82	2.02
Adapt working patterns and staffing	1.28	1.28	1.28	1.28	1.28
Total - supply measures	**1.90**	**1.89**	**1.78**	**1.72**	**1.91**
Total – all measures combined	**1.46**	**1.40**	**1.38**	**1.37**	**1.50**

Source: Edge Health & Greencroft Economics

6.4 Discussion of Other Adaptation Priorities

There are a range of other adaptation measures which have not been quantified due to a lack of evidence, but which would be recommended as near-term actions. These include targeted staff training and responsibilities on heat events, healthcare staff refreshment policies and guidance nationwide, building code or design for all new-built facilities, and heat and humidity monitoring in hospitals.

There are also adaptation measures which could deliver substantial well-being improvements during heat events, but which fall outside the scope of this study, or for which there is insufficient information to form recommendations at present and so are categorised as "longer term planning". These are discussed in the paragraphs below.

A key driver of heat-health related inequalities across the UK relates to deprivation and low-quality housing stock. Spatial inequality and deprivation are key drivers of heat-related health impacts. Over one in five houses across the UK already overheat in summer months,[96] while over half of English families in the poorest quintile live in homes at risk of overheating in future, with risks most acute for those living in social housing, in families with young children, and in ethnic minority families.[97] A study by Arup in 2022 assessed four different adaptation packages of different intensities, and assessed their effectiveness in reducing overheating in UK homes for current climate conditions, 2°C global warming levels, and 4°C global warming, requiring around £500 billion to £600 billion for adaptation expenditures.[98]

A major driver of adverse heat-related health outcomes is multimorbidity; that is the underlying health of the UK population. Influencing lifestyle changes and providing proactive health care to improve population health could reduce the risk of mortality, A&E attendance and hospital admissions during extreme heat. This is not assessed here, as both: (1) the benefits of improving the health of the UK population is a far broader issue than response to extreme heat, which is likely to be a small benefit relative to the overall health benefit, and (2) there is limited information on how best to tackle this issue, and how much it might cost.

Monitoring and reviewing heat stress protocols for at-risk professions can help ensure protective measures are in place and remain effective, reducing the likelihood of heat-related illnesses and safeguarding worker health during extreme events. This is not assessed here, as the main benefits are expected to be worker wellbeing (occupational comfort and safety), not on the health outcomes quantified in this study (mortality, A&E attendance, hospital admissions).

[96] UK BEIS (2021) "Energy Follow Up Survey: thermal comfort, damp and ventilation", Link
[97] Resolution Foundation (2023) "It's Getting Hot in Here", Link
[98] Arup (2022) "Addressing overheating risk in existing UK homes", Link

Implementing robust heat action plans and making related capital investments in schools and prisons could improve safety, comfort, and functionality during extreme heat events. In schools, programmes like London's Climate Resilient Schools initiative[99] show how tailored adaptation plans – backed by physical upgrades such as improved ventilation, solar shading, and green infrastructure – can protect learning environments while delivering long-term cost-efficiency and wellbeing benefits. Meanwhile, in the prison estate, the Ministry of Justice is beginning to build heat resilience into its Prison Estate Transformation Programme[100] through both passive design features (like solar shading and natural cooling) and mechanical systems (such as air-flow controls). Together, these measures show promise in reducing heat-related risks for some of the UK's more vulnerable populations but are not yet systematically deployed across all schools or prisons.

Green and blue spaces can deliver important health benefits, including in response to higher temperatures. These span both physical benefits – as they can reduce temperatures (e.g. green infrastructure such as street trees and parks that provide shading and cool spaces), and improved mental health and resilience, which tend to worsen during heat events.[101] Green and blue spaces are also associated with a range of co-benefits relevant to health impacts during heat events – such as contributing to reducing comorbidities and promoting a healthier population. The potential benefits of green and blue space are not quantified in this study, as they are not within the adaptation response options of the UK health care sector. Previous studies have found significant benefits to health from green and blue infrastructure. For example, the ONS Natural Capital Accounts estimate the value of green and blue spaces on health benefits from recreation at £489 billion in 2022,[102] while green and blue infrastructure was estimated to have resulted in £136 million in health care savings in 2015, due to reduced admissions related to respiratory and cardiovascular conditions, and reduced mortality and morbidity.[103]

Training community care workers could provide a cost-effective alternative to treatment in health care facilities. For example, given the elevated risk to pregnant women and infants, training midwives in emergency response to extreme heat through programmes such as Community PROMPT Wales,[104] could enhances ability of community care workers to manage extreme heat related health risks. This could reinforce practical skills and promote teamwork in non-hospital environments. Moreover, community care workers embedded in local communities are a trusted source of information and may be well placed reach out to vulnerable people

[99] Mayor of London (2023), "Climate Adaptation Plans for Schools", Link
[100] https://committees.parliament.uk/writtenevidence/88373/html/
[101] See for example WHO (2023) "Assessing the value of urban green and blue spaces for health and well-being", Link
[102] ONS (2021) "UK natural capital accounts: 2024", Link
[103] Kirby & Scott (2023) "Green Blue Infrastructure Impacts on Health and Wellbeing; A Rapid Evidence Assessment" , Link
[104] https://nwssp.nhs.wales/ourservices/welsh-risk-pool/welsh-risk-pool-programmes/maternity-and-neonatal-safety-and-learning-programmes/community-prompt-wales/

(elderly, postnatal women, newborns), identify signs of heat stress early, and provide timely education or referrals, which would help prevent avoidable complications and reduces pressure on hospitals.

At a UK health-system level, there are several options that could not be quantified in detail in Section 6.2 but which should be explored as potential high value:

- *Effective use of regional patient transfer and mutual aid.* As hospitals will see sharp increases in A&E attendance and in bed occupancy with more people admitted and for longer durations, making as much use as possible of the possibility to transfer patients between NHS Trusts. This is consistent with NHS guidance on surge planning and mutual aid during extreme demand.[105] However, this this can involve additional risks to patients and should be a last resort after all other internal capacity-boosting measures have been deployed. [106] Moreover, nearby hospitals tend to be affected simultaneously by heatwaves, which limits the effectiveness of inter-hospital transfers as a strategy to relieve pressure across the system.
- *Ensure availability of ambulances to respond during heat events.* One of the major bottlenecks in the health system that could cause challenges when attendances rise during heat events is availability of ambulances, and their ability to transfer patients to busy emergency departments.[107] There is evidence that ambulance dispatches are significantly higher during heat events,[108] and indeed that ambulance dispatches increase much more during hot periods than cold periods.[109] There is insufficient evidence to quantify how best to adapt ambulance availability during heatwaves; further information should be gathered in future heat events.
- *Reschedule elective procedures across the year.* As is done during flu season in the winter, non-elective procedures could be deferred during heatwaves. This may have a knock-on effect on quality of patient care and health outcomes by delaying treatments, but may also be offset by milder winters, which might result in less impact on deferring elective procedures during winter.
- *Reschedule elective procedures to cooler day-time periods.* With day-time peaks in temperatures more often reaching the high 30°Cs and going over 40°C it may be worth exploring, over the longer term, reforms to allow for some treatments planned in summer months to be moved to early mornings or overnight, when temperatures are lower. However, this is likely to be fairly marginal in terms of effectiveness compared to

[105] NHS England (2023) "Adult critical care surge plan guidance", Link
[106] South West Critical Care Network "Principles of capacity transfers", Link
[107] NHS England (15 July 2022) "Update on ambulance handovers in light of current heatwave", Link
[108] Xu et al (2023) "Heat, heatwaves, and ambulance service use: a systematic review and meta-analysis of epidemiological evidence", Link
[109] Janos et al (28 May 2025) "Short-term effect of temperature on cause-specific, sex-specific, and age-specific ambulance dispatches in Czechia: a nationwide time-series analysis", Link

the other adaptation measures discussed in this report and would also depend on acceptability for healthcare professionals to work in less regular shift patterns.

- *Enhance the resilience of critical infrastructure – including digital.* As hospitals increasingly rely on digital systems to operate, one of the major risks posed by extreme heat is its potential to cause outages in key infrastructure. For example, the 2022 heatwave increased the internal temperatures above 50°C at both data centres at Guys and St Thomas's NHS Foundation Trust, which caused major disruptions to electronic patient records and diagnostic services.[110] NHS England is working on exploring the risks of cybercrime and climate on digital infrastructure, as well as other systemic issues (such as points of failure of electricity supply networks during heat events).
- *Improve resilience of medical supply chains, and stock management of cold chains and heat-vulnerable supplies*: Improving NHS resilience through stronger medical supply chains and better management of cold-chain and heat-sensitive stocks could help maintain essential services during heatwaves. While NHS Supply Chain[111] has begun embedding disruption-management processes and clinical risk-based product segmentation, further work is needed to ensure these systems are consistently adopted and effective nationwide. Local inventory-management improvement pilots, such as those in North Central London[112], have shown potential for cost savings and better readiness to respond when temperature-sensitive supplies are urgently needed, but similar approaches are not yet standard practices across all regions. Strengthening national shortage-management frameworks[113] and ensuring real-time tracking and redistribution systems are in place, could further reduce the risk of disruption during periods of extreme heat.

6.5 Health Impacts of Adaptation in the Reasonable Worst-Case Climate Scenario

The discussion of adaptation above is all presented for the central climate scenario. Table 30 shows the results for the reasonable worst-case scenario, applying the same adaptation package as in the central scenario.

The residual (non-mitigated) health risk is much higher in the reasonable worst-case scenario. The adaptation package is implemented in the same way as in the central scenario, so these results show the health impacts that would occur if the same adaptation measures were

[110] Guys and St Thomas NHS Foundation Trust (2023), Review of the Guy' and St Thomas' IT Critical Incident – Final Report from the Deputy Chief Executive Officer, Link
[111] https://www.supplychain.nhs.uk/teams/resilience/
[112] https://www.supplychain.nhs.uk/programmes/in-trust-inventory-management-systems-ims/studies/
[113] https://www.england.nhs.uk/long-read/a-guide-to-the-systems-and-processes-for-managing-medicines-supply-issues-in-england

implemented, at the same intensity. In practice, the adaptation package could – and should – be revised as more information about the future climate scenario is revealed over time.

This could have two implications:

- Increasing the intensity of the adaptation measures selected in the central climate scenario: as described in Section 3.5, the adaptation measures are sequenced as a function of how the relative heat-health profile changes over time in each region. In the reasonable worst-case scenario, this would imply dialling-up the implementation of adaptation measures – both implementing them earlier and doing more of them.
- Prioritising other measures that are qualified as "watching brief", specifically adaptation measures that could carry substantial benefits, but for which there was insufficient evidence to include in this assessment; these should be prioritised to assess in greater detail, so that they can be added as complementary measures needed in the reasonable worst-case scenario.

To some extent, the residual risks (excess heat mortality, hospital admissions and A&E attendances) could be reduced to near-zero by ensuring active cooling is available. However, there are several challenges to this, which explain the significant residual risks estimated in this study. First, some people will be exposed to higher temperatures while outdoors, so the risk of higher air temperatures cannot be fully mitigated by (indoor) climate control measures. Second, in some settings the health benefits of implementing full climate control may not be large enough to justify the costs. For example, in care home settings, those most at risk of mortality are likely to be relatively vulnerable and would be at risk of death within a relatively short time period, so the expected life-years gained of reducing a mortality that may be likely to occur within, for example, the next six months, might be low.[114]

Table 30. Impact of the optimal adaptation package on health outcomes – worst-case scenario

	2050 mortality – no adaptation	Reduction in mortality by adaptation	2050 admissions – no adaptation	Reduction in admissions by adaptation	2050 attendance – no adaptation	Reduction in attendance by adaptation
East Midlands	432	141	2,021	377	9,659	938
East of England	770	255	2,731	512	12,599	1,223
London	1,025	415	3,958	737	27,196	2,637
North East	146	45	835	141	3,191	312

[114] Ibbetson et al (2021) "Mortality benefit of building adaptations to protect care home residents against heat risks in the context of uncertainty over loss of life expectancy from heat", Link

North West	493	166	2,612	454	11,742	1,126
Northern Ireland	79	26	258	39	1,303	65
Scotland	133	42	606	81	2,084	75
South East	1,998	838	3,831	706	18,841	1,848
South West	1,251	427	2,965	535	10,665	1,050
Wales	269	81	858	142	3,897	344
West Midlands	510	157	2,949	505	13,324	1,263
Yorkshire and the Humber	317	104	2,106	362	8,314	802
Total – all regions	**7,423**	**2,698**	**25,730**	**4,591**	**122,815**	**11,683**

Source: Edge Health & Greencroft Economics

7 Conclusion

Extreme heat already exerts a significant and uneven impact on health in the UK, with the highest risks observed among older adults and those with multiple long-term conditions. The greatest absolute burden is experienced in London and the South East, reflecting both higher temperature exposures and concentrations of vulnerable populations, specifically the elderly. While historically cooler regions, such as Scotland and Northern Ireland, show lower absolute impacts, they experience the steepest relative increases overtime; even UK's cooler regions today will face an adaptation challenge as they encounter increasing incidence of extreme heat. Across mortality, emergency admissions, and A&E attendances, temperature exposure is the dominant driver of variation in regional outcomes.

Extreme heat also places substantial strain on the health and care system. Increases in A&E attendances contribute to longer queues, which are linked to higher 30-day mortality rates. Additional emergency admissions increase hospital bed occupancy, raising patient mortality risk and adding significant costs to the NHS. Hospital buildings are particularly vulnerable to overheating during heatwaves, which can endanger patients, reduce staff productivity, and risk damaging sensitive medical equipment. Workforce absenteeism during extreme heat further reduces service capacity and efficiency, compounding operational and financial pressures.

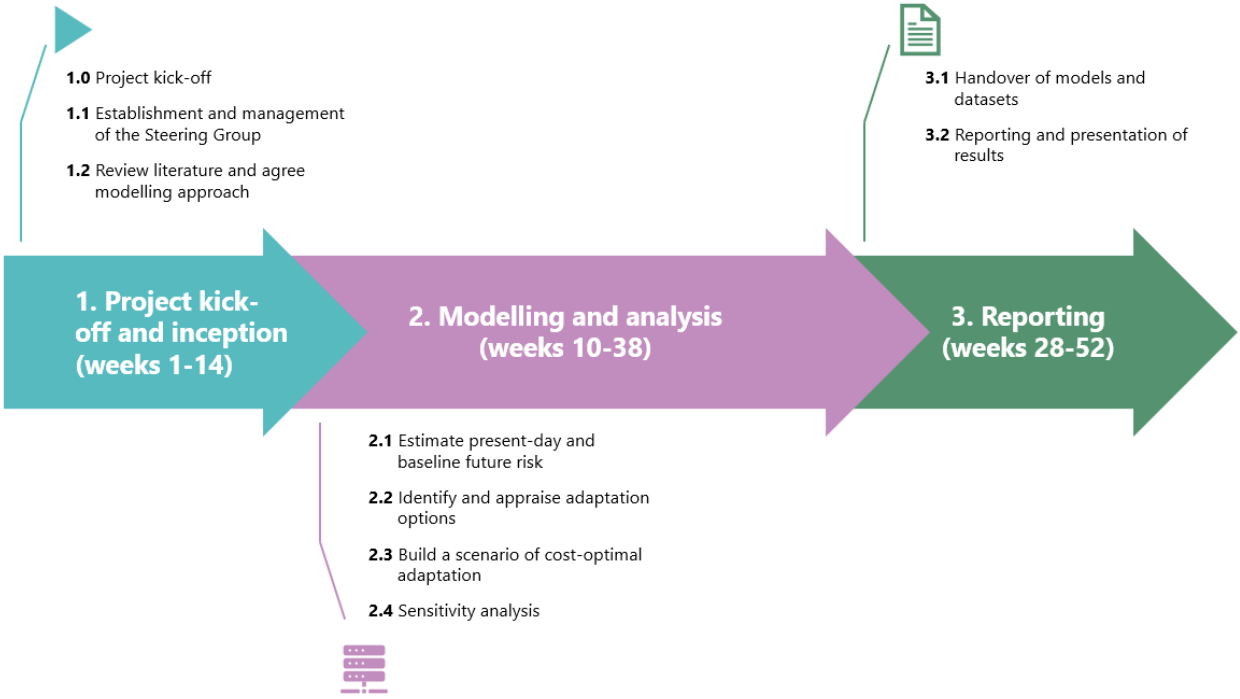
Evaluation of adaptation options indicates that a cost-effective bundle of interventions could yield net benefits of £8.1 billion in net-present value (NPV) by 2080. The optimal adaptation bundle costs £17.6 billion and incurs benefits exceeding £25.7 billion.

High-impact measures include retrofitting existing NHS facilities with active and passive cooling to protect patients, staff and critical services during heatwaves, and providing low-cost health advice and information services. Preventative home visits to vulnerable people can bring major health benefits but are costly and not cost-effective everywhere, so they need region-specific targeting. Adapting working patterns and staffing to meet excess demand during heat events offers modest net benefits with a benefit-cost ratio of 1.3 (although this is likely a conservative estimate). Public cooling stations and care home cooling are more cost-effective in high-risk areas, such as the South East, than as blanket measures. Overall, combining broadly applicable, high-return actions with targeted regional interventions maximises health benefits while controlling costs.

A Appendix – Overall Approach

The approach was structured into three phases. The first phase focused on project inception, including a rapid evidence review to identify key risks and gaps, and the establishment of a multidisciplinary Steering Group to guide the work. The second phase involved modelling and analysis: we carried out an initial risk assessment of temperature-health relationships, followed by scenario-based modelling of future health impacts and appraisal of adaptation options, including sensitivity analysis. The final phase focuses on reporting, synthesising findings to inform policy and support the CCC's Well-adapted UK report.

Figure 36. Three-phase research approach



Source: Edge Health & Greencroft Economics

A.1 Ways of Working

Throughout the project, we have engaged regularly with key stakeholders both within and beyond the CCC, establishing a consistent feedback loop to support and steer the work.

Project Working Group

The Project Working Group provided delivery oversight and reviewed progress. The team met every fortnight to coordinate timelines, ensure stakeholder engagement and facilitate necessary

feedback loops. In these meetings, interim results were shared to facilitate early-stage decision making.

CCC Adaptation Committee

The Adaptation Committee held a formal oversight role and reviewed progress at key project milestones. The CCC adaptation committee met with the project team three times throughout the project. Their feedback was key in determining the modelling scope and approving major methodological directions.

Steering Committee

There was also an established steering committee involved in the process, consisting of 21 members from the 4 UK nations. This group consisted of decision-makers and experts in climate adaptation, healthcare and urban design from governmental departments, delivery bodies and healthcare practitioners. Throughout the work, there were four dedicated advisory sessions for members to examine the methodology, assumptions and results, which have shaped the direction of work.

B Appendix – Literature Review

The literature review was guided by clear objectives and research questions to ensure it provided a strong foundation for the subsequent modelling work. These objectives and questions were designed to help assess what evidence is available to inform model inputs, identify gaps, and ensure the review could directly support the development of our analysis and adaptation strategies.

B.1 Objectives

1. **Establish Baseline Knowledge:** To develop an understanding of the current state of knowledge regarding heat-related health impacts, healthcare system strain, and adaptation measures in the UK and comparable regions.
2. **Identify Data Gaps:** To identify gaps in existing research that our project could address, particularly in relation to heat-related mortality and morbidity, healthcare and social care service impacts, and effective adaptation strategies.
3. **Inform Modelling Approaches:** To review and select the most appropriate modelling techniques for predicting future heat-related health outcomes and the efficacy of adaptation strategies.
4. **Support Policy Development:** To gather evidence for the development of data-driven, cost-effective adaptation policies, with a focus on public health protection and healthcare system resilience.

B.2 Key Questions

The following key questions guided the literature search, ensuring it would address the objectives outlined above:

Baseline Impact Assessment

Heat-Health Impacts

1. What are the direct and indirect health impacts of increased heat exposure in the UK?
2. How does heat exposure affect mortality and morbidity rates, and what population groups are most vulnerable?
3. What is a suitable modelling methodology? i.e. why the use of microsimulation modelling and the choice of the model and the trade-offs

These key questions have informed the following objectives for the next modelling phase:

- Determine the scope of modelling based on evidence availability and establish risk-exposure relationships that can be reliably inputted into the model
- Identify appropriate impact metrics for mortality and morbidity that should be captured
- Define key vulnerable populations for inclusion as distinct population archetypes in our simulation model

Heat-Health System Impacts

4. What are the impacts of extreme heat on healthcare system, specifically on the healthcare supply including workforce, infrastructure?
5. Have these impacts been previously quantified and if so, how are they quantified?
6. How might the impact on the demand of healthcare influence the resource availability from the healthcare system?

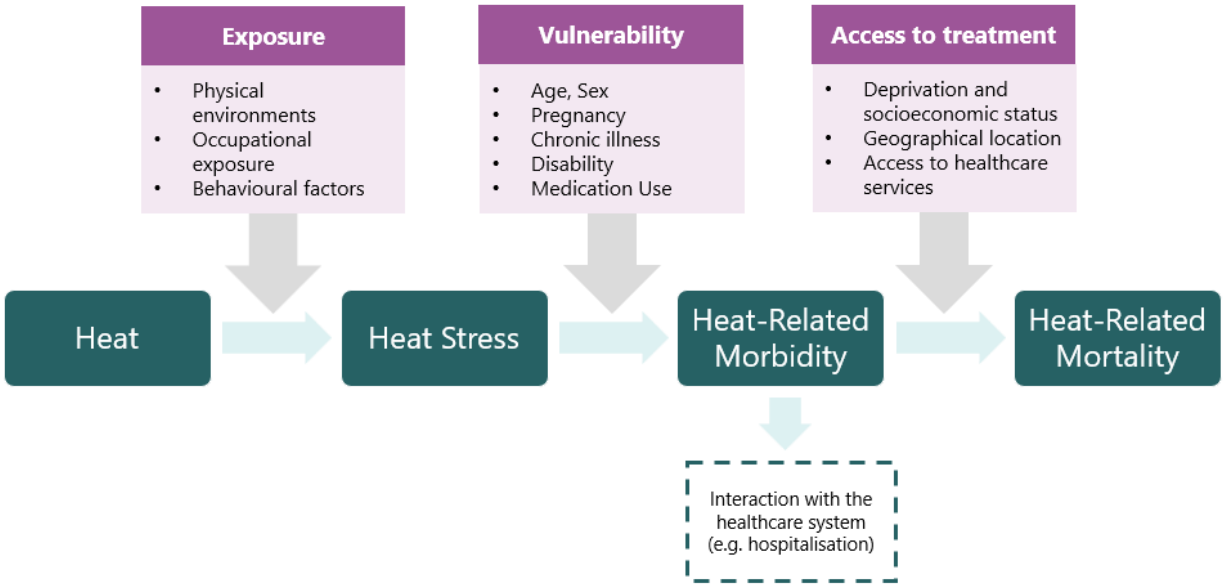
Adaptation

1. What adaptation strategies have been effective in reducing heat-related health risks, both within the UK and internationally?
2. What are the costs and cost-effectiveness of different adaptation options for the health sector?
3. How have other countries with habitual high temperatures adapted their healthcare systems to manage heat-related health risks?

B.3 Literature Review on Heat-Health Impacts

The relationship between exposure to extreme heat and adverse health outcomes involves a complex causal pathway, progressing from initial exposure through various intermediate stages to final health impacts, such as illness or death (Figure 37).

Figure 37. Heat-health causal impact pathways



Source: Edge Health & Greencroft Economics, based on Kovats and Hajat (2008) Link

B.3.1 Overview of heat and health

Most epidemiological literature on heat-health relationships have quantified the impact of heat on health outcomes by computing the relative risks (RR), which measure the increase in the likelihood of adverse health outcomes associated with heat exposure compared to baseline conditions. Relative risks are typically computed from time-series regression models that examine the statistical association between temperature variables and health outcomes overtime. For example, mortality for RR compares the observed mortality during periods of elevated temperatures (exposed periods) with mortality during reference temperature periods (non-exposed periods), then assess the percentage increase in mortality that are attributable to heat during the exposure periods.

Researchers typically use distributed lag non-linear models (DLNMs) to account for both the non-linear relationship between temperature and health outcomes and the delayed effects of

heat exposure.[115] Studies often define exposure thresholds based on percentiles of the local temperature distribution (e.g., 95th percentile) or absolute temperature values (e.g., >30°C), with RR representing the increased risk per degree of temperature rise above this threshold. Most papers use percentile-based approach to establish thresholds at the point where a health event begin to increase with temperature, and the RR represent the increased risk per degree of temperature rise above this threshold. For example, an RR of 1.021 for all-cause mortality means 2.1% increase in mortality risk per degree temperature rise above the threshold. These RR form the basis for the transitional probabilities that are used in our health impact assessments.

While the literature identifies a broad spectrum of risk factors for heat-related impacts, our modelling has focused on the most consistently evidenced and policy-relevant vulnerabilities to ensure clarity, feasibility. Therefore, this literature review adopts a bottom-up approach to establish the scope (e.g. mortality and morbidity metrics) and parameters for the subsequent modelling phase. The criteria for selecting studies to inform model input were based on the UK-relevance of the evidence, recency of publication, and the provision of quantified estimates, specifically RR, linking heat exposure to health outcomes.

B.3.2 Mortality impacts

The literature provides robust evidence that extreme heat has a significant impact on mortality. Extreme heat days and heatwaves are consistently linked to excess mortality worldwide; the 2022 summer alone was associated with 2,985 excess deaths in England and 61,672 across Europe.[116,117] The temperature-mortality relationship in the UK has been well-established, with studies covering a large range of time periods.[118,119,120] All sources have found an increase in all-cause mortality when air temperature increases.

There is significant geographical variation in all-cause and cause-specific heat-related mortality risks, with populations in the South East of England, particularly London, showing higher heat-related mortality risk, while populations in Scotland and Northern Ireland exhibit lower relative risks. One study found that the majority of excess mortality in Northern Ireland during the 5% deadliest summer days came from "cold-related" mortality, i.e. days cooler than the regional optimal.[121]

[115] Gasparrini (2011), Distributed Lag Linear and Non-Linear Models in R: The Package dlnm, Link
[116] UK Health Security Agency (2022), Heat mortality monitoring report: 2022, Link
[117] Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R.F. et al. (2023), Heat-related mortality in Europe during the summer of 2022, Nature Medicine, Link
[118] Hajat, S., et al. (2002), Impact of hot temperatures on death in London: a time-series study, Occupational and Environmental Medicine, Link
[119] Wan, K., et al. (2022), Temperature-related mortality and associated vulnerabilities in Scotland, 1974–2018, Environmental Health, Link
[120] UK Health Security Agency (2025), Heat mortality monitoring report, England: 2024, Link
[121] Huang, Wan Ting Katty, et al. (2020), Weather regimes and patterns associated with temperature-related excess mortality in the UK: a pathway to sub-seasonal risk forecasting, Link

The biggest driver of the geographical variation in extreme heat related mortality is the extent of exposure of the populations. The higher heat-related mortality rates in the South East and around London is predominantly driven by higher temperatures in these regions, compared to the relatively cooler temperatures in northern regions, and in particular in Scotland and Northern Ireland (see Section 5.1).

There may also be variation in the vulnerability of populations exposed to extreme heat by region. This could be driven by a range of factors, including deprivation, housing quality, health status etc. Four key sources of mortality estimates are summarised in Table 31, each of which providing evidence of heat-related mortality in the UK, over the baseline period used in this study (1991-2020), with regionally varying relative risks for mortality. The two most relevant sources include Murage et al. (2024) and the 1988-2022 climate-related mortality analysis by the ONS.

For modelling, we assume that the exposure-risk relationships between heat and mortality remain stable, so we can apply previously established relative risks in our current model. This was based on a finding from a 1996-2013 time-series analysis across Greater London, West Midlands, and Greater Manchester, which found no significant change in heat-related relative risks over time.

Table 31. Mortality research sources within the UK

Mortality Sources	Regions	Time period	Demographic breakdown	How were the heat-health relationships quantified?
ONS climate-related mortality analysis[122]	England and Wales	1988 to 2022	18-64, 65 and above	Regional relative risks by daily mean temperature reported
Murage et al. (2024)[123]	UK 4 nations	2007-2018	0–64, 65–74, 75–84, 85+	Regional relative risks by daily mean temperature reported
Gasparrini et al. (2012)[124]	England and Wales	1993–2006	0–64, 65–74, 75–84, 85+, chronic illnesses	Percent increase for 1°C rise above the regional heat threshold, attributable

[122] Office for National Statistics (2023), "Climate-related mortality, England and Wales: 1988 to 2022", Link
[123] Murage, Peninah; Macintyre, Helen L.; Heaviside, Clare; Vardoulakis, Sotiris; Fučkar, Neven; Rimi, Ruksana H.; Hajat, Shakoor (2024), "Future temperature-related mortality in the UK under climate change scenarios: Impact of population ageing and bias-corrected climate projections", Link
[124] Gasparrini, Antonio; Armstrong, Ben; Kovats, Sari; Wilkinson, Paul (2012), "The effect of high temperatures on cause-specific mortality in England and Wales", Link

				deaths, raw RR values not reported
Hajat et al. (2007)[125]	England and Wales	1993-2003	0–64, 65–74, 75–84, 85+, male, female	Percent increase for 1°C rise above the regional heat threshold, attributable deaths, raw RR values not reported

Source: Edge Health & Greencroft Economics

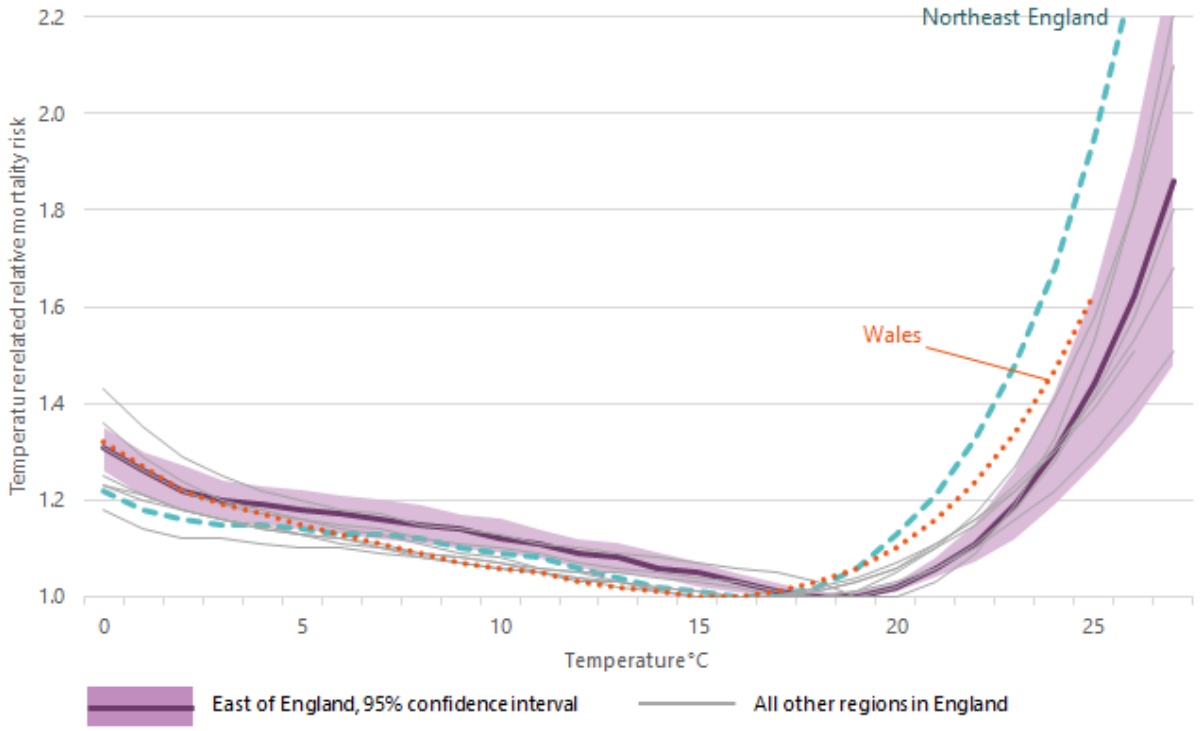
However, it should be noted that the strength of evidence on the extent to which people living in different regions of the UK might have different vulnerability to extreme heat is limited. Taking the ONS climate-related mortality dataset as an example, while it presents different relative risk curves for 10 regions (excluding Scotland and Northern Ireland), the difference between the curves is in many cases not significantly different. As an illustration, seven of the other regions lie within the 95% confidence interval of the East of England, as shown by the purple area in Figure 38. The only exceptions are Wales and the North East of England.

Furthermore, looking at the regional ONS curves, it is not immediately obvious what drives the variation in vulnerability. While the North East appears to have significantly higher relative mortality risk at higher temperatures than the East of England, the North West has lower risk. Conversely, the West Midlands appears to have higher vulnerability than the East of England, while the East Midlands appears to have lower risk than the East of England.

While we have used region-specific relative risk curves in this study, this would be an area that merits further research to understand the extent to which, and why, populations in different regions of the UK are more or less vulnerable when exposed to the same extreme heat events.

[125] Hajat et al. (2007), Heat-related and cold-related deaths in England and Wales: who is at risk? Link

Figure 38. Comparing the ONS regionally variant heat related relative mortality risk curves



Source: Edge Health & Greencroft Economics, based on ONS "Climate-related mortality, England and Wales: 1988 to 2022", Link

B.3.3 Morbidity impacts

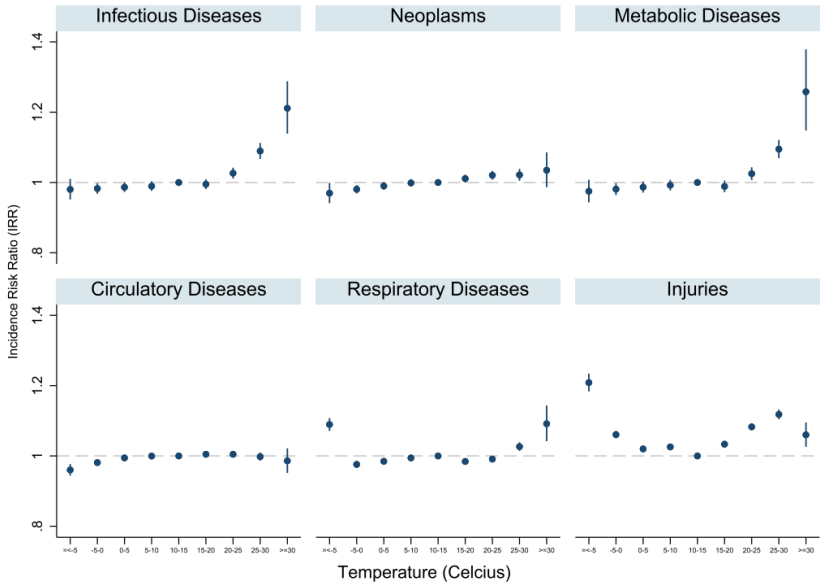
While the relationship between extreme heat and mortality is well-established and consistently evidenced across the literature, evidence for morbidity outcomes is comparatively limited, with fewer studies and generally weaker or less consistent associations. Extreme heat-related events also demonstrate a more significant impact on mortality than on hospital admissions, as evidenced by a time-series analysis which found a non-significant 2.5% increase in admissions, but a significant 10.8% increase in mortality.[126] In the UK, most studies quantifying relative risks have focused on hospital-related outcomes, particularly emergency admissions and A&E attendances. As a result, the modelling of heat-related morbidity is constrained to hospitalisations, which represent only one dimension of the broader health burden associated with extreme heat.

There is no clear evidence on the impact of extreme heat on all-cause emergency admissions, but extreme heat can increase the risk of being admitted for specific diseases. Rizmie et al.

[126] Kovats et al. (2004), Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, UK, Link

(2022) found respiratory disease, infectious diseases, metabolic disease, respiratory diseases and injuries show significant associations with extreme heat, while admission for cardiovascular demonstrate less pronounced impact compared to the other disease types within this study.[127] This distinction has important implications for understanding how heat affects different disease pathways.

Figure 39. Risk ratio by disease type

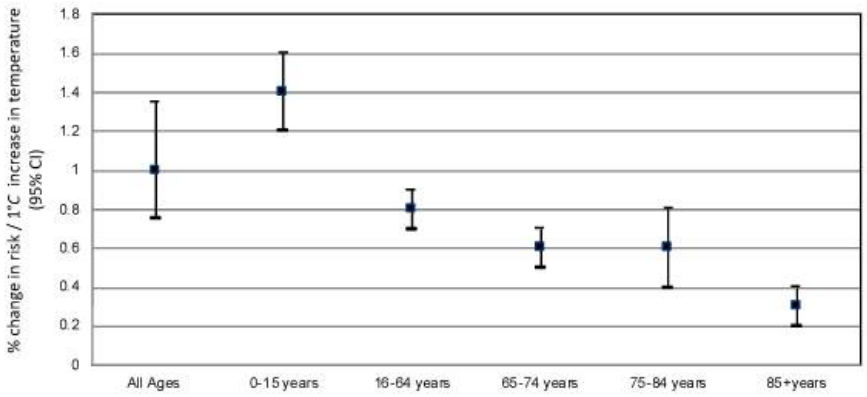


Source: Rizmie et al

There is one UK study on the impact of heat on A&E attendance, focusing on the population in London. Heat does not significantly increase the A&E attendance for all ages 1.0% (95% CI 0.8, 1.4), as shown by confidence intervals overlapping zero, but the relative risks are the highest in the younger age groups (Figure 40). This suggests a difference in age-specific relative risks in heat-related attendance compared to heat-related mortality.

[127] Rizmie et al. (2021), Impact of extreme temperatures on emergency hospital admissions by age and socio-economic deprivation in England, Link

Figure 40. Percentage change in risk for all-cause A&E attendances by age group



Source: Edge & Greencroft

Table 32. Morbidity research sources within the UK

Morbidity Sources	Time period	Demographic breakdown	How were the heat-health relationships quantified?
Rizmie et al. (2022)	2001–2012	<5, 5-14, 15-24, 25-34, 35-44, 45-54, 55-64, 65-74, >74	Relative risks computed for daily maximum temperature bands (25C-30C, and >30C)
Hotz et al. (2020)	2007-2012	0-15, 16-64, 65-74, 75-84, 85+	Percentage change in risk per C for daily mean temperature above 16C

Source: Edge Health & Greencroft Economics

Based on an assessment of the available literature, we selected Hotz et al. (2020) to derive relative risks for the impact of extreme heat on A&E attendance, and Rizmie at al. (2022) for relative risks related to emergency hospital admissions.

B.3.4 Vulnerability factors

Age

Age emerges as the most critical vulnerability factor, with well-documented evidence of increased risk at both ends of the age spectrum. Most of the heat-related mortality occurs in those aged 65 and above, with the highest relative risk observed in the 85+ age group due to impaired thermoregulation, preexisting health conditions, and medication use that affects heat response.[128,129] Similarly, for heat-related emergency admissions, those over 65 are most likely to be admitted. This concentration means that a significant portion of health impacts during heat events will be focused within older age groups.

Children under five years, particularly neonates, were shown to be at risk.[130] However, most studies do not quantify mortality relative risks for children under the age of five, likely due to the low incidence of heat-related deaths in this age group and limited data availability in the UK. Research on children over 5 also remains sparse, with no consistent findings of elevated relative mortality risk compared to adults. In terms of morbidity, the Hotz et al. (2022) study has shown that younger children are more likely to be admitted to A&E departments.

The evidence supports granular age categorisation adopted in the model, especially those aged over 65, with a continued increasing risk even within older age groups.

Sex and demographics

Research has found females, particularly older females, showing slightly higher relative mortality risk during heat events; however, this is not consistently shown in all UK-based literature, and might be confounded by age-related effects.[131,132] This elevated risk may result from physiological and socioeconomic factors, as well as the larger share of elderly population among females.

Due to the inconsistent findings around the impact of sex on heat, we have not included this as a vulnerability factor for our modelling.

Deprivation

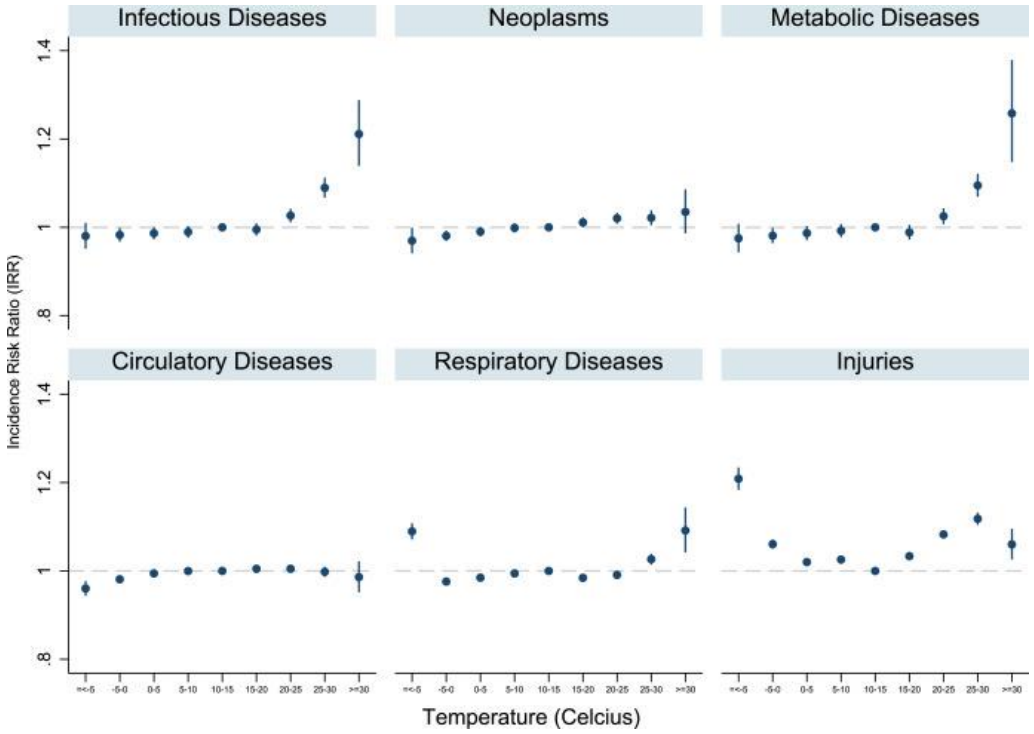
The relationship between socioeconomic status and heat-related health impacts shows important geographic and outcome-specific variations. Unlike patterns observed in the United

[128] 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, Link
[129] UK Health Security Agency (2025), Heat mortality monitoring report: England 2021, Link
[130] A. Dimitrova et al. (2024), "Temperature-related neonatal deaths attributable to climate change in 29 low- and middle-income countries, Link
[131] 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, Link
[132] 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, Link

States, where heat exposure varies significantly by race and is linked to differential access to air conditioning, evidence for such disparities in European cities, including the UK, is less clear.

Studies examining deprivation effects on heat-related mortality have generally found minimal impact. The 2003 European heatwave showed little effect of deprivation on heat-related mortality, with time-series analyses in England & Wales and Scotland finding no significant effect of deprivation (Index of Multiple Deprivation) on heat-related mortality. Only one study shows that deprivation could significantly impact morbidity, specifically emergency hospital admissions for injuries.[133]

Figure 41. Temperature effects on disease-specific incidence by deprivation level



Source: Rizmie et al. (2022)

As a result, deprivation is included as a vulnerability factor, but since the relative risks are not well established, this factor will be investigated through distributional analysis instead of as a population archetype.

[133] Rizmie, D., de Preux, L., Miraldo, M. & Atun, R. (2022), Impact of extreme temperatures on emergency hospital admissions by age and socio-economic deprivation in England, Soc Sci Med, Link

Pregnancy and maternal health

There has been international evidence supporting significant heat-related risks during pregnancy; however, UK-specific literature remains limited. A comprehensive meta-analysis of 198 studies across 66 countries found that exposure to high temperature and heatwaves increases risk for pregnancy-specific medical disorders (such as gestational hypertension and cardiovascular events), obstetric complications (including preterm birth), and pregnancy loss (including stillbirths).[134]

Heat exposure also significantly affects neonatal outcomes, with evidence from India showing every 1°C increase exceeding 42°C associated with a 43% increase in neonatal intensive care unit admissions.[135] Notably, environmental interventions such as relocating maternity wards to lower floors reduced NICU admissions by 64%, highlighting the importance of environmental factors in maternal and neonatal heat vulnerability.

Due to the lack of UK-based evidence, the impact of heat on populations with maternal health needs will be done via a supplemental analysis to show indicative impacts of heat on maternal health and associated outcomes.

Mental health

Populations with mental health conditions represent a particularly vulnerable group for heat-related health impacts. Meta-analyses and systematic reviews demonstrate that every 1°C increase in temperature is significantly associated with a 2.2% increase in overall mental health-related mortality and 0.9% increase in morbidity, with heat significantly increasing both hospital admissions and emergency department visits.[136]

UK-specific evidence, while focusing primarily on mortality risk with limited morbidity data, reveals that suicide and violent suicide risk increased by 3.8% and 5.0% respectively, per 1°C increase in mean temperature above 18°C.[137] [138] Among individuals with diagnosed mental health conditions, a 4.9% increase in mortality risk per 1°C increase was observed between 1998 and 2007, particularly affecting those with psychosis, dementia, and substance misuse, and

[134] Lakhoo, D.P., Brink, N., Radebe, L., Craig, M.H., Pham, M.D., Haghighi, M.M., Wise, A., Solarin, I., Luchters, S., Maimela, G., Chersich, M.F.; Heat-Health Study Group; HIGH Horizons Study Group (2025), A systematic review and meta-analysis of heat exposure impacts on maternal, fetal and neonatal health, Nature Medicine, Link

[135] Principi, N., Campana, B.R., Argentiero, A., Fainardi, V., Esposito, S. (2025), The Influence of Heat on Pediatric and Perinatal Health: Risks, Evidence, and Future Directions, Journal of Clinical Medicine, Link

[136] Liu, J., Varghese, B.M., Hansen, A., Xiang, J., Zhang, Y., Dear, K., Gourley, M., Driscoll, T., Morgan, G., Capon, A., Bi, P. (2021), Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis, Environment International, Link

[137] ONS (2025), Suicides attributable to extreme heat, England and Wales - Office for National Statistics Link

[138] Page, L.A., Hajat, S., Kovats, R.S. (2007), Relationship between daily suicide counts and temperature in England and Wales, The British Journal of Psychiatry, Link

those prescribed antipsychotics, antidepressants, and hypnotics.[139] Notably, within this population, individuals under 65 were at higher risk of death, contrasting general population patterns.

B.3.5 Research gaps

Despite the significance and growing impact of extreme heat on health, our review identified several critical evidence gaps that constrain our ability to fully characterise risk and design targeted adaptation strategies.

- **Data availability on health impacts**:
    - Heat-related mortality relationships are more established than morbidity. Most research focuses on heat-related deaths, with fewer studies on morbidity, leading to potential underrepresentation of the full burden of heat on healthcare systems.
    - Lack of UK-based literature examining the quantitative impact of extreme heat on a wide range of morbidity outcomes, such as morbidity indicators such as A&E attendance, emergency admissions, or other health outcomes like medication effects, exacerbations of chronic conditions.
    - Heat-health relationships are not the most updated. It will be appropriate to redo the analysis on the relative risk exposure-response functions on post-COVID populations, as it is suspected that the population health status might have changed significantly post-COVID.
- **Geographical variation in data availability**: No new evidence for Northern Ireland on the impact of extreme heat on health.
- **Impact on vulnerable populations**: No UK-based evidence on populations with varying maternal status. We know that there is ongoing research in Newcastle on the impact of heat on individuals with maternal health status.
- **Lack of evidence on the costs and benefits of the impact of adaptations on health:** Recently, there have been emerging literature on adaptations within care homes specifically,[140] but generally there is a lack of literature on cost-effectiveness of adaptations for extreme heat in health, likely due to the lack of data and evidence on the implementation of adaptations.

[139] Page, L.A., Hajat, S., Kovats, R.S., Howard, L.M. (2012), Temperature-related deaths in people with psychosis, dementia and substance misuse, The British Journal of Psychiatry, Link
[140] Ibbetson A et al. Cost-benefit analysis of interventions to protect care home residents in England against heat risks, Link

B.3.6 Limitations in heat-health outcome evidence

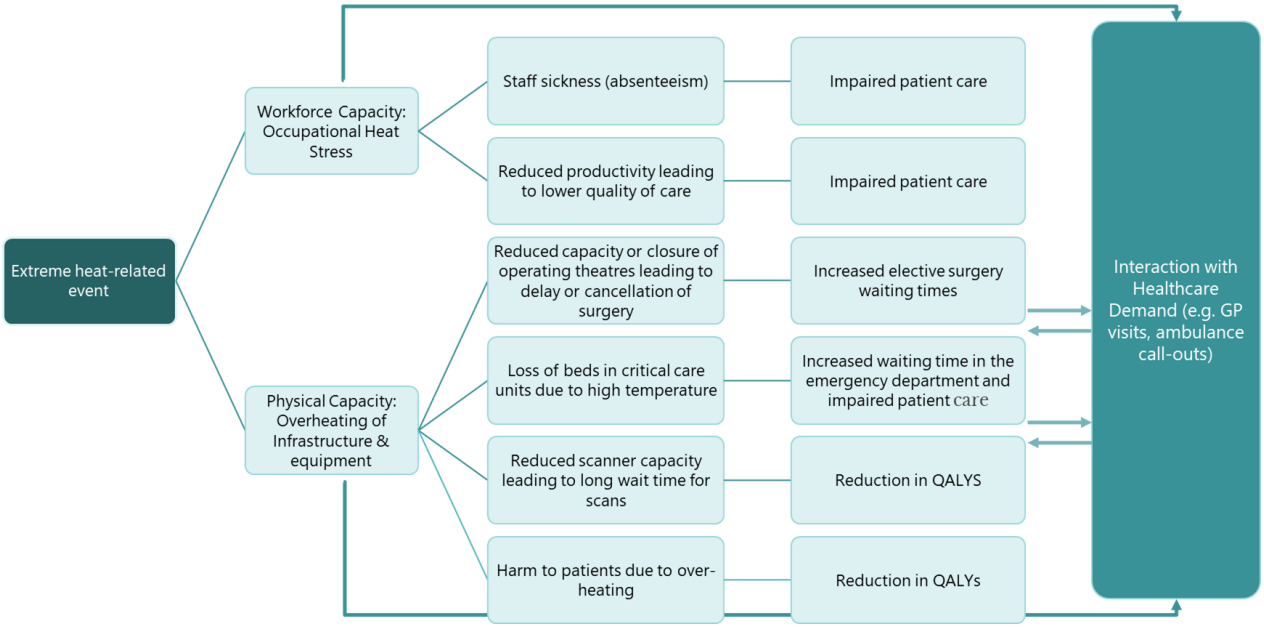
Many of the research gaps outlined above also represent limitations to the present evidence base. In particular, the following methodological and contextual issues constrain the interpretation of existing findings:

- **Focus on mortality over morbidity**: Most research focuses on heat-related deaths, with fewer studies on morbidity (e.g., hospital admissions), leading to potential underrepresentation of the full burden of heat on healthcare systems.
- **Inconsistent definitions of heat exposure**: Different definitions of "heat exposure" (e.g., daily max temperature, heat index) lead to inconsistent estimates of heat-health impacts across studies. Varying metrics could make comparison and generalisation difficult.
- **Heat exposure is usually represented as air temperatures**: Limited literature examining the relationship between WBGT and health. Instead, most used air (ambient) temperatures as heat exposure.
- **Underrepresentation of UK context**: Existing literature on heat and health primarily comes from regions with historically higher temperatures, limiting its relevance to the UK. Differences in climate, healthcare infrastructure, and population characteristics mean findings may not fully reflect UK's unique challenges or vulnerabilities under future warming scenarios.
- **Limited longitudinal studies**: Much of the literature relies on short-term or event-specific data (e.g., heatwaves), lacking the longitudinal studies needed to understand cumulative and long-term health impacts of rising average temperatures.

B.4 Literature Review on Heat and Health System

The impact of extreme heat on the health system is more multifaceted and can occur via multiple pathways (Figure 42). There are two ways of looking at the impact of health on the health system, firstly the impact of heat directly on the healthcare **supply**, which is the availability of resources within the healthcare system. Secondly the impact via the increased healthcare **demand** because of extreme heat, which is the level of healthcare services utilised by the population based on their needs. It is also important to note the interaction between demand and supply; during periods of extreme heat, the increased demand can create further pressure on the health system thus adding pressure on the healthcare supply.

Figure 42. Healthcare system impacts of heat events



Source: Edge Health & Greencroft Economics

Our literature review focused on the impact of heat on the healthcare supply. We found that there is significantly less evidence on the impact of heat on the healthcare supply in the UK, importantly most literature is qualitative. As a result, for evidence completeness, we also searched grey literature including news articles and governmental reports to collate these case studies.

B.4.1 Physical Capacity

There is a wealth of evidence demonstrating a high rate of overheating in health facilities. Hospital ward overheating is common, as shown by primary data on indoor temperature monitoring. At Addenbrooke's hospital in Cambridge, 46 days of monitoring in 5 spaces (nursing stations and beds in wards) from July to August 2010 found that most spaces exceeded nighttime overheating guidance.[141] A 35-day study at Royal Berkshire Hospital in 2018 showed all examined areas (receptions and scan rooms) breached overheating guidelines for indoor temperatures.[142]

Our analysis of the yearly NHS England Estates Returns Information Collection (ERIC) datasets shows that increasing number of overheating occurrences in NHS buildings over time. The number of overheating occurrences increased by 23% in 2022/23 compared to the previous year; more than doubling since 2016/17.[143] There are also regional variations in overheating occurrence, which are consistently highest in hospitals in North West and Midlands, but these patterns do not align with geographical variation in heat exposure, indicating that these might be contributed to by the conditions of NHS buildings.

Overheating is also prevalent in care homes. London-based care homes were consistently shown to overheat regardless of the overheating metrics used.[144] In this study, interviews with staff and residents have also revealed a culture of warmth and conflicts between measures that ensure the safety of residents and effective management of heat.

The evidence of impacts on healthcare supply due to overheating however is scarce. A cross-sectional survey of 271 surgeons, anaesthetists, and critical care doctors during the 2022 UK heatwave revealed significant summer pressures due to extreme heat:[145]

- 85% said their hospitals lacked summer pressure plans to maintain elective surgical safety and capacity.
- 35% reported making adaptations to sustain routine surgical activity during the heatwave, with delayed discharge being the most common (Table 33).

Delayed discharge has important implications for healthcare supply and patients and could strain health demand. It reduces bed availability, prolongs A&E/ambulance waiting times, and

[141] Lomas, Giridharan (2012), Thermal comfort standards, measured internal temperatures and thermal resilience to climate change of free-running buildings: A case-study of hospital wards, Link
[142] Gough et al. (2019), Assessment of Overheating Risk in Gynaecology Scanning Rooms during Near-Heatwave Conditions: A Case Study of the Royal Berkshire Hospital in the UK, Link
[143] An overheating occurrence is defined as an occupied ward or clinical area having a daily maximum of over 26˚C: This definition excludes incidents in areas defined as non-clinical space (e.g. medicine cabinets in central storage areas away from wards). The 26˚C threshold is set by the Heatwave Plan for England.
[144] Gupta, Barnfield, Gregg (2021), Examining the magnitude and perception of summertime overheating in London care homes, Link
[145] GreenSurg Collaborative (2023) Elective surgical services need to start planning for summer pressures, Link

lengthens hospital stays, which can negatively affect patients (e.g. risk of infections, loss of mobility and cognitive function).[146]

Table 33. Strategies adopted during the heatwave

Strategy	n (%)
Delayed discharge of high-risk patients	35 (36.5%)
Changes to surgical teams	26 (27.1%)
Selected lower risk patients to have surgery	23 (24.0%)
Restricted surgical activity to day-case	22 (22.9%)
Other*	23 (24.0%)

**Other: longer staff breaks, administration of extra fluids to the patients admitted, starting surgeries earlier in the morning*

Source: GreenSurg Collaborative (2023), Link

Despite the lack of quantified impacts, a 2022 qualitative assessment of perspectives from frontline healthcare staff has shown that these indicative impacts on the capacity of the healthcare supply. Some of these impacts, such as power cuts, are less frequent but occur in extreme conditions, while others, like equipment malfunctions, may be more common during heatwaves.

Theatres and critical care units

- High indoor temperatures have led to the closure of operating theatres and MRI rooms and the loss of critical care beds. These disruptions contribute to surgery cancellations and increase backlogs, reducing the healthcare system's capacity to deliver timely care.[147]

Impact on electrical equipment and IT system

- The 2022 heatwave increased the internal temperatures above 50°C at both data centres at Guys and St Thomas's NHS Foundation Trust, which caused disruptions to electronic patient records and diagnostic services.[148]

[146] Health Foundation (2023), Why are delayed discharges from hospital increasing? Seeing the bigger picture, Link
[147] Brooks et al (2022), Heatwaves, hospitals and health system resilience in England: a qualitative assessment of frontline perspectives from the hot summer of 2019, Link
[148] Guys and St Thomas NHS Foundation Trust (2023), Review of the Guy' and St Thomas' IT Critical Incident – Final Report from the Deputy Chief Executive Officer, Link

Efficacy of drugs

- Heat has caused fridges to break down, especially impacting medications requiring specific temperatures, like antipsychotic drugs. During the 2003 heatwave in England, the temperatures in drug cupboards and doctor's bags were reported to increase to 35 to 40°C.[149]

B.4.2 Workforce Capacity

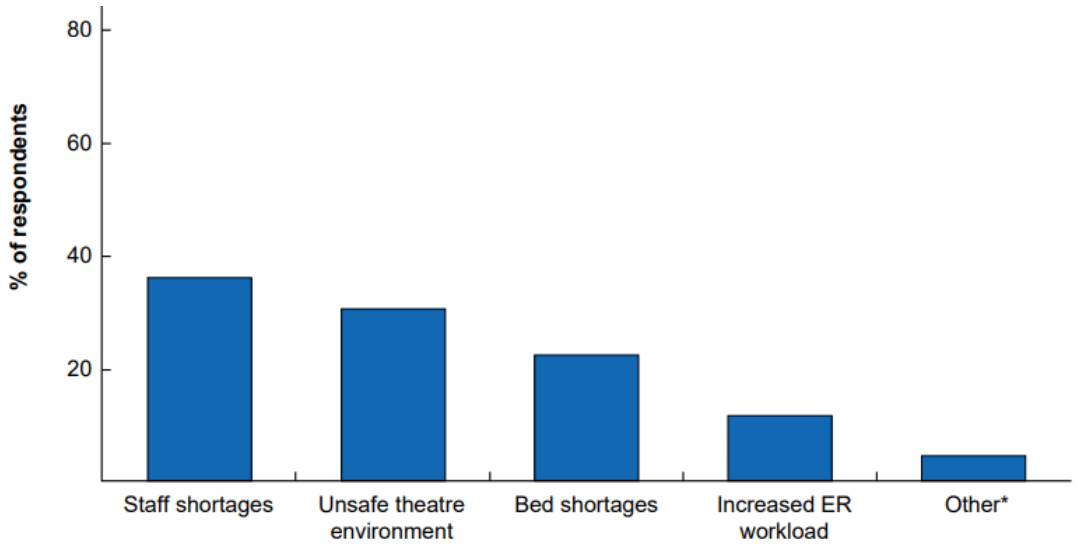
Like the impact on physical capacity, the evidence base on the effect of extreme heat on workforce capacity is scarce in the UK and are largely qualitative.

Occupational heat stress and heat-related absenteeism might be prominent, based on a survey of 1,014 healthcare professionals.[150] This survey showed that 90% reported perceiving occupational heat stress as impacting their physical and cognitive performances, 20% of which have reported heat-related absenteeism, averaging **2.2 days** due to experiencing symptoms of heat illness or exhaustion. When these were extrapolated to the current NHS workforce, this led to an estimate of an annual cost of ~£23 million (£17 per person).

Staff shortages were the main cause of surgery cancellations during heatwaves (Figure 43). 1 in 5 healthcare professionals reported cancellations of surgeries in UK hospitals, as shown by a survey of 271 healthcare professionals during the 2022 heatwave.[151]

[149] Carmichael (2012), Overheating and Hospitals - What do we know? Link
[150] Davey et al. (2024), Prevalence of occupational heat stress across the seasons and its management amongst healthcare professionals in the UK, Link
[151] GreenSurg Collaborative (2023) Elective surgical services need to start planning for summer pressures, Link

Figure 43. Factors contributing to heatwave-related cancellations of elective surgery: % of respondents. ER: emergency room



Source: GreenSurg Collaborative (2023), Link
Note: Others includes IT problems caused by the heat, and patients unwilling to have surgery owing to the heatwave

B.4.3 Interactions between healthcare demand and health supply

Heatwaves significantly increase primary care demands. For example:

- Surveillance data during a 2013 heatwave in England showed an increased demand on GPs and emergency departments for heat illness, with 2.5 times more cases of heat illnesses compared to non-heatwave years.[152]
- Highest GP demand was among children aged 4-14 and people aged 75 and above, with a 3.2-fold increase in cases for the latter age group compared to non-heatwave years.[153]
- Recent surveillance data (18 to 24 July 2022) also indicate large increases in reported symptoms of heat stroke and heat exhaustion.[154]

[152] Smith and Elliot (2016), Estimating the burden of heat illness in England during the 2013 summer heatwave using syndromic surveillance, Link
[153] From Smith and Elliot (2016), IRR = 3.2 (−7.0 to 13.5) for aged 75+, Link
[154] GOV.UK, Syndromic surveillance summary: 28 July 2022 week 29, Link

Table 34. Estimated number of general practitioners in hours (GPIH) heat illness consultations during summer (1 June to 15 September) 2012–2014

	GPIH percentage population coverage of England	Actual Consultations	Estimated total population consultations (95%CIs)
2012	39%	135	345 (287, 403)
2013	43%	500	**1166 (1064, 1268)**
2014	53%	326	616 (549, 683)

Source: Smith and Elliot et al. (2015), Link

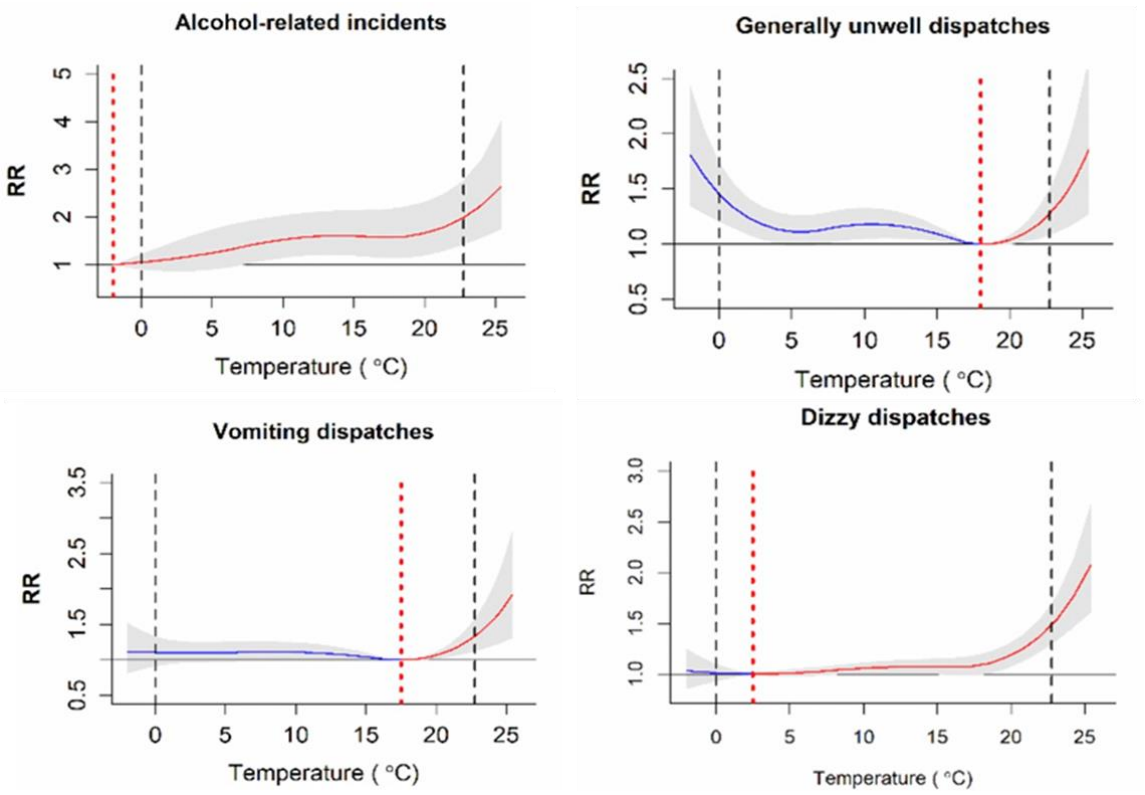
Increase in ambulance callouts for specific health risks shown by a time series analysis in London (2010-2014):[155]

- Conditions such as Chronic Obstructive Pulmonary Disease (COPD), chest pain, dizziness, alcohol-related vomiting, and 'generally unwell' presentations contributed to the rise.
- Alcohol-related ambulance dispatches showed the highest relative risks during high temperatures, likely linked to increased alcohol intake and dehydration.
- Among cardiovascular-related dispatches, only chest pain dispatches showed a significant increase with high temperatures.

The increase in alcohol-related ambulance callouts aligns with previous findings of a higher risk of injuries-related admissions due to extreme heat.

[155] Sangkharat, Kamolrat; Mahmood, Marliyyah A.; Thornes, John E.; Fisher, Paul A.; Pope, Francis D. (2020) "Impact of extreme temperatures on ambulance dispatches in London, UK", Link

Figure 44. Cumulative association between daily mean temperature and London ambulance dispatches over lag 0–21 days with 95% CI



Source: Graphs from Sangkharat, Mahmood et al. 2020, Link

B.4.4 Case Studies

To illustrate the real-world consequences of extreme heat on health and healthcare systems in the UK, we selected case studies capturing both acute impacts and longer-term system pressures. These examples highlight how heatwaves have disrupted health service delivery, strained infrastructure, and exacerbated existing challenges within the NHS.

The first case study is on the impact of 2003 heatwave on health service infrastructure in the UK:[156]

Context: The 2003 heatwave was one of the worst pan-European heatwaves, causing 2,091 excess deaths from 4th to 13th August 2003. A number of incidents on how heatwaves are affecting UK hospitals were reported in the press. This has driven the subsequent development of the UK Heatwave Plan in 2003.

Reported effects of 2003 heatwaves in the UK:
• *Loss of samples*: A freezer malfunctioned which led to the loss of human specimen samples
• *Staff health issues*: Excessive heat caused staff members to fall ill and experience severe discomfort, affecting their ability to work. Some nurses and administrative staff walked out in protest.
• *Patient dehydration*: Patients suffered from dehydration and swelling due to the high temperatures and inadequate cooling measures.
• *Cancelled surgeries*: Numerous surgeries were cancelled because essential equipment failed in the extreme heat.
• *Laboratory disruptions*: Laboratory operations were halted as machines malfunctioned under the high temperatures.
• *Electrical overload*: The use of portable air conditioning units by staff overburdened the hospital's electrical system.

[156] Chemical Hazard and Poisons report: issue 4, (May 2005), Link

The second study outlines an analysis by the Royal College of Nursing (RCN):[157]

Context: The 2018 summer saw record-breaking temperatures in June and July,[158] which led to a surge in A&E attendances, particularly those with chronic. The RCN looked at the impact of increased demand during summer and how that subsequently affected existing winter pressures.

The impact on NHS demands:

• *Rising trolley waits*: The number of patients waiting more than 4 hours for a hospital bed after an A&E decision doubled from 64,898 in 2014 to 153,895 in 2018—a 137% increase.
• *Extended delays*: Patients waiting over 12 hours for a bed rose sharply from 32 cases in 2014 to 508 cases in 2018, despite such extended waits being against NHS guidelines.
• *Declining bed availability*: The number of available overnight hospital beds fell from 135,754 in summer 2014 to 128,448 in summer 2018, despite increasing admissions.

• *Decreasing A&E performance*: Only 90% of A&E patients were seen within the 4-hour target in summer 2018, down from 95.1% in 2014, marking the lowest performance over the past five summers.

"…what our analysis demonstrates is that trolley waits have now become a summer problem too, with over 150,000 patients waiting more than four hours for a hospital bed this summer once staff had said they needed to be admitted…."

"This increased strain on the Health Service this summer will inevitably have a knock-on effect on services this winter, and means that the NHS is going into winter on the back foot. This, coupled with the relentless rise in the number of nursing vacancies, means that it's unlikely that an extra 900 beds can be freed up this winter… beds are more likely to be cut than created this winter"

B.4.5 Research Gaps

Despite growing recognition that extreme heat stresses the healthcare system itself (not just individual outcomes), this review found very limited quantitative evidence on system-level impacts, particularly for the UK, constraining robust risk appraisal and targeted adaptation planning.

- **Very limited quantitative evidence on heat's impact on the healthcare system (especially in the UK):** Most studies track patient outcomes (in particular, mortality) rather than system performance. There is little quantified evidence on heat-related

[157] Sources: (1) Royal College of Nursing (2018), On the Back Foot: An analysis of NHS performance in England in recent summers, Link, (2) Royal College of Nursing (2018), College warns bed numbers unlikely to increase this winter without extra nurses, Link
[158] Met Office Press Office, (2018), Was summer 2018 the hottest on record? Link

effects such as theatre cancellations and delays, bed/ICU capacity reductions, ED crowding and ambulance handover delays, equipment and IT failures, staff absenteeism/productivity loss, infection control incidents, or energy/cooling failures. Where incidents are documented, they are typically anecdotal, event-specific, and non-comparable, with minimal causal attribution or counterfactuals.

- **Data availability on healthcare system strain**: There is no comprehensive, routinely collected dataset on the thermal performance and resilience of NHS estates (e.g., ward-level temperature logging, HVAC/cooling coverage and redundancy, solar gain/shading, building fabric and retrofit status, backup power and chiller capacity, overheating exceedances). Estates, facilities, and procurement data are fragmented across trusts, lack common definitions/KPIs (e.g., "overheating event", "heat-related outage"), and are rarely linked to operational metrics (admissions, length of stay, flow) or near-real-time weather data. This limits comparability, modelling, and evaluation of adaptation measures.

B.5 Implications for Modelling

Based on the literature review on the effect of extreme heat on health demand and supply impacts, these are the implications for the modelling phase.

Literature insights	Implications for Phase 2 Modelling
More qualitative than quantitative evidence is available in the literature on the impact of heat on health; this highlights a need quantify impacts on the health system from the increased demand and from other non-heat-related extreme events	Quantify the impact of heat on healthcare supply with a focus on the impact on demand, and the subsequent impact of demand on healthcare supply. Impacts on services will also be quantified from other non-heat related events (e.g. flu seasons, pandemic)
Variation of overheating incidents in NHS estates differs from the geographical variation in heat exposure – i.e. inadequate infrastructure, not just regional temperature differences, is a driver of overheating in hospital sites	Further analysis of the building stocks of NHS estates to establish the baseline building preparedness of NHS hospitals
The literature and ERIC analyses highlight increasing risks to NHS capacity from overheating, staff shortages, and equipment failures. Therefore, the impact of heat on healthcare supply is expected to worsen over time, exacerbated by deteriorating NHS infrastructure and a growing maintenance funding gap	Assess healthcare supply impacts due to heat over time (e.g., surgery cancellations, workforce strain) with consideration of the NHS building stock and maintenance gap going forward
Mortality vulnerability over time: The relative risks for heat-related mortality, for a given change in temperature, remain stable overtime in the UK context	Relative risks for mortality and morbidity derived from previous literature can be used in our model without adjustments.

Morbidity Measure: Most evidence on morbidity focuses on hospitalisations	Use hospitalisations as the primary measure of morbidity, given the greater availability of data and stronger evidence base compared to other morbidity outcomes, such as milder illnesses, recognising that hospitalisations are only one aspect of morbidity
Age: Relative risks of heat-related deaths and admissions increase significantly in ages above 65 and below 5	Different heat-health relationships will be modelled for four age categories: (1) 0-4, (2) 5-17, (3) 18-64, (4) 65-75, (4) 75+, driven by evidence showing that age-correlated increase in risk even in the older age group.
Sex: Females have a higher risk of heat-related mortality than males, but unclear from evidence whether this is due to age distribution	Inconsistent evidence suggesting a direct link between sex and heat-related health impacts, so sex will not be modelled as an archetype.
Pregnancy status: Pregnant women have a higher risk for health adverse events such as pregnancy specific disorders, obstetric complications and pregnancy loss. However, there is no UK-based quantitative evidence available to incorporate maternal health as an archetype	Examine the impact of heat on populations with maternal health needs in a supplemental analysis to show indicative impacts of heat on maternal health and associated outcomes
Deprivation: Deprivation (IMD) does not have a significant effect on mortality; one study shows that deprivation could significantly increases the risk of hospital admissions for injuries	Deprivation will be investigated as a vulnerability factor through distributional analysis and won't be included as an archetype in the main model.

Chronic Illnesses: Heat disproportionately increases morbidity and mortality risks for individuals with certain underlying chronic conditions. For example, extreme heat does not significantly increase cardiovascular admissions but is strongly linked to higher cardiovascular-related deaths	Subdivide the emergency admission states into specific disease categories (respiratory diseases, metabolic diseases, infectious disease, injuries) due to varying susceptibilities based on comorbidity profile

C Appendix – Health Impact Modelling

C.1 Simulation Model Input

C.1.1 Population input

Population input covering the UK 4 nations was constructed at all modelled time periods: 1991-2020, 2030s and 2050s. These populations were created by:

- Building representative baseline populations at LSOA/data zone-levels using mid-year estimates by single year age and sex
- Projecting future populations (2030s and 2050s) by applying local authority-level growth rates from national population projection datasets
- Calculating growth factors by age and sex from official projections and applied to baseline populations to estimate future distributions
- Producing the outputs of population sizes by our desired age bands

C.1.2 Health outcome rates

Mortality, attendance and emergency admission rates were used as health state transition probabilities within the model. They were calculated using the following guidelines:

Mortality rates

- Mortality rates by single year of age and sex were used for each UK nation
- These were applied to LSOA-level baseline and projected populations to estimate expected deaths
- Local mortality rates were adjusted using age-standardised ratios to account for regional variation
- An annual mortality improvement of 1.1% was applied to future estimates of mortality rates, in line with long-term trends in background mortality improvement

Attendance rates

- A&E attendance rates were obtained from publicly available data sources
    - *Note*: We don't have the attendance number for Type 2 attendance in Scotland. Assumption is that the English ratios apply to Scotland and that the relationship between Type 1, Type 2, and Type 3 is stable.
- After data cleaning and processing, yearly A&E attendance rates were computed by nation and desired age bands for each nation

- We have assumed that future scenarios have the same attendance rate as 1991-2020 for future scenarios. According to historical data, there is a general growth in the number of A&E attendances overtime, but there is no reliable data to project how attendances might change in the future

Emergency admission rates

- Emergency admission rates in England for respiratory diseases, infectious diseases, metabolic diseases and injuries were obtained from Hospital Episode Statistics (HES).
- We have assumed the same admission rates apply in Wales, Scotland and Northern Ireland, due to the lack of data available on disease-specific emergency admission rates
- We have assumed that future scenarios have the same emergency admission rate as 1991-2020 for future scenarios. According to historical data, there is a general growth in the number of A&E attendances overtime, but there is no reliable data to project how attendances might change in the future

C.1.3 Multimorbid populations

To model populations in 1991-2020, 2030s and 2050s with multimorbidity status, we used the following assumptions:[159]

- **Mortality rates adjustment for individuals with chronic illness**: Using adjusted hazard ratios from the UK Biobank cohort study to modify the baseline all-cause mortality rates by number of long-term conditions. Multimorbidity is defined by two or more long-term conditions.[1]
- **Chronic illness prevalence**: Age-weighted prevalence of multiple long-term conditions from an England-wide population study based on GP data.[2]

C.1.4 Relative risks

Risk-exposure relationships between heat, mortality and morbidity from the literature. The relative risks do not usually match our desired age bands. Hence, we aggregated relative risk inputs from to match our desired age bands through population weighting.

Mortality

Based on the data reported in Murage 2024, we computed the relative risks that are inputted into our model:

[159] Note: The prevalence and hazard ratios are assumed to be constant for future scenarios in 2030s and 2050s, due to lack of data for future multimorbidity.

1. Compute the exposure-response coefficient (b) based on the difference between the 99th and 93rd percentile temperature thresholds, assuming a linear log-risk increase per degree Celsius above 93rd percentile temperature

$$b = log(RR)/(t\_99 - t\_threshold)$$

2. Compute relative risks at **each daily mean temperature** (temperature_degrees_celsius) above the threshold temperature (t_threshold) for the region for each age group

$$RR = exp(b * (temperature\_degrees\_celsius - t\_threshold))$$

3. Aggregate these relative risks to match our desired age bands (0-4, 5-17, 18-64, 65-74, 75+). The 0-64 RR is applied uniformly for ages 0-4, 5-17 and 18-64, and 75+ is computed by aggregating 75-84 and 85+ RR using population weighting

A&E attendance

1. Hotz et al. (2020) study on the London population gives us a percentage change in risk for A&E attendance for each 1°C above the identified threshold of **daily mean temperature** of 16°C
2. We extrapolate the A&E attendance relative risks above 16°C to 30°C linearly to compute the relative risks for each age band
3. Aggregate these relative risks to match our desired age bands (0-4, 5-17, 18-64, 65-74, 75+)

Emergency admissions

1. Rizmie et al. (2022) study on the impact of heat on hospital admissions by comparing the effect of heat exposure on a day relative to a day at the 10-15°C range per day per hospital based on the **daily maximum temperature**
2. These relative risks were reported for each temperature interval below, and the relative risks relevant to our study are those computed on 25-30°C and >30°C (Table 35)
3. Aggregate these relative risks to match our desired age bands (0-4, 5-17, 18-64, 65-74, 75+)

Table 35. The daily max temperature intervals reported in Rizmie et al. (2022). Our study selects relative risks from two specific daily maximum temperature bands.

Temperature Interval	
$30 \leq$ Max Temp	
$25 \leq$ Max Temp<30	
$20 \leq$ Max Temp<25	
$15 \leq$ Max Temp<20	
$10<$Min Temp & Max Temp <15	Reference Group
$5<$Min Temp ≤ 10	
$0<$Min Temp ≤ 5	
-5 $<$Min Temp ≤ 0	
-5 $\geq$ Min Temp	

Source: Rizmie et al. (2022), Impact of extreme temperatures on emergency hospital admissions by age and socio-economic deprivation in England, Link

C.1.5 Maternal health modelling

Literature Review

The outcomes reported in the meta-analysis were rated using the following criteria:

- Clinical importance of this outcome (the prevalence and level of burden on the health system)
- Statistical significance (based on the confidence intervals reported)
- Health system dependency (whether the outcome is affected by current healthcare context therefore less extrapolatable to the UK).

The following table provides a summary of the review.

Table 36. Summary of the literature review

Outcome Reported	Odds Ratio (OR) Per 1°C increase	95% Confidence Interval	Statistically Significant?	Number of Studies	How important is this outcome? Would it be affected by the regional health system? (Rating 3/3)
Gestational diabetes	1.07	1.01-1.54	Y	3	1/3, managed mostly through outpatient care
Hypertensive disorders of pregnancy	1.12	1.03-1.21	Y	2	2/3, relatively common cause for maternal admissions, but hard to extrapolate to the UK

Maternal admission: Emergency Visits & Hospital Admissions	1.01	1.00-1.01	N	1	1/3, non-UK studies and is affected by local health system
Infections	1	1.00-1.03	N	1	2/3, some might escalate to admissions
Prelabour rupture of membranes	1.08	1.07-1.09	Y	1	1/3, may lead to admission or induction but varying outcome
Mental Illness	1.29	0.99-1.67	N	1	2/3, increases demand for perinatal mental health services
Antenatal bleeding	1.16	1.03-1.40	N	1	2/3, might lead to admission
Cardiovascular events	1.11	1.06-1.15	Y	1	2/3, serious but rare outcome
Stillbirths	1.14	0.99-1.32	N	5	3/3, serious outcome, requires clinical reviews
Congenital anomalies	1.13	0.95-1.34	N	4	1/3, impact depends on type and severity
Non-reassuring fetal status	1.21	1.12-1.32	Y	1	1/3, can lead to emergency delivery
Preterm Birth	**1.04**	**1.03-1.06**	**Y**	**12**	**3/3, strong driver of neonatal ICU admissions**
Low birth weight	1.06	1.03-4.26	Y	5	2/3, would require further monitoring but lower in clinical importance
Small for gestational age	1.1	1.02-1.18	Y	1	2/3, would require further monitoring but lower in clinical importance
Neonatal admission	1.22	1.02-1.43	Y	2	1/3, non-UK studies and is affected by local health system
Neonatal morbidity	1.04	1.03-1.06	Y	1	1/3, a composite outcome

Source: Edge Health & Greencroft Economics

Methodology

Illustrative impacts of heat exposure on preterm births were estimated across the four nations using the following methodology:

1. **Calculate the daily preterm birth rates by nation**: This was estimated by multiplying the incidence rates for preterm birth (6.8%–7.9%) with number of live births per day for the daily preterm birth rates. The rate of preterm births is multiplied with the number of hot days in each nation to estimate the average observed number of preterm births on those days.
2. **Model the odds ratios on hot days**: Assuming that meta-analysed odds ratio per 1°C at 1.04 is computed for a baseline temperature of 16°C,[160] linearly extrapolate the odds ratio to estimate the odds ratio for 16-30°C.
3. **Approximate the attributable fraction of preterm births on from the odds ratio**: Convert the average odds ratios for preterm births to attributable fraction using the following equation. The excess heat-related relative risks for preterm birth for each temperature band were calculated by multiplying the average number of heat occurrences per nation across time and scenarios.

$$AF_e = \frac{OR - 1}{OR}$$

4. **Calculate Heat-related Excess Cases using estimates from 1 and 3:** Estimate the number of preterm births that are related to heat by multiplying the number of preterm births on hot days and the attributable fraction to estimate number of excess preterm births due to heat.

Noted that we assume the same number of live births in the 2030s and 2050s as in 1991-2020, meaning that it is likely an underestimate for future scenarios.

[160] Baseline temperature assumed at 16°C: Note that the per 1°C increase in each study included in the meta-analysis estimate is derived from models estimating a continuous effect of temperature on risk, but the exact baseline temperature (i.e., the reference point from which increases are measured) is often not explicitly specified or standardised across studies. We assume a 16°C as a conservative reference point based on typical UK temperatures.

C.2 Simulation Model Mechanisms

C.2.1 Simulation model input data

The following outlines the core inputs used in the model, including population characteristics, baseline health outcome rates, relative risks, and projected heat occurrences under different climate scenarios:

1. **Population input**: Population inputs for the UK's four nations are constructed for three time periods (1991-2020, 2030s and 2050s). For each time period, population sizes are estimated by age bands (0-4, 5-17, 18-64, 65-74 and 75+), distinguishing between people with multimorbidity, at the LSOA/data zone level.
2. **Health outcome rates**: Mortality, attendance and emergency admission rates at regional level based on UK baseline in 2022 that were used as health state transition probabilities within the model
3. **Relative risks**: Risk-exposure relationships between heat, mortality and morbidity from the literature
4. **Climate hazard data**: Input data on the number of heat occurrences for each period and climate scenario

C.2.2 Simulation flow and process

The following steps outline the daily simulation process used to estimate changes in mortality and morbidity under different climate and population scenarios:

1. **Probability conversion**: Annual mortality, attendance and admission rates were converted to daily event probabilities
2. **Population initialisation**: A representative population of 1,000,000 individuals is constructed for each region or MSOA, stratified by demographic characteristics (age bands and multimorbidity status). This scaled population maintains the demographic proportions of the actual population for each warming scenario while providing computational efficiency.
3. **Heat day processing**: For each heat day exceeding 25°C daily maximum temperature threshold:
    a) **Excess risk calculation**: For each health outcome, (mortality, A&E attendance, emergency admissions), excess relative risks are multiplied by baseline daily event probabilities on the day based on the daily mean temperature of the heat occurrence.

$$Excess\ Risk\ =\ Baseline\ Daily\ Health\ Outcome\ Rate\ \times\ (Relative\ Risk\ -\ 1)$$

- **For mortality**: Baseline daily health event rates are first adjusted by multimorbidity status using literature-based multipliers, then temperature-specific relative risks are applied.
- **For A&E attendance and emergency admissions**: Age-specific relative risks are applied directly to baseline daily health event rates without multimorbidity adjustment due to limited evidence on how multimorbidity could affect A&E attendance or emergency admission rates.

b) **Binomial sampling**: The representative population is sampled using binomial distribution,[161] based on the calculated excess probabilities for each heat-related health outcome. Each healthy individual can experience one of two states: *remain healthy* or *experience a specific health event due to heat* (mortality, A&E attendance, or emergency admission).

c) **Fractional heat day adjustment**: When heat occurrences contain decimal values (e.g., 0.2 heat days), the model assumes that the fractional proportion of the population (20% in this example) experiences exposure to one additional heat day. Health outcomes for that day are multiplied by the fractional exposure (0.2) to reflect partial population exposure.

d) **Population scaling**: Health events generated from the representative population at each warming scenario are scaled up to actual population size by applying regional population scaling factors.

4. **Output generation:** Model produces heat-related excess health events at both MSOA and regional levels, with results representing additional health burden attributable to heat exposure above the defined temperature threshold.

[161] R Documentation: Binomial distribution, Link

C.3 Data Sources

Table 37. Data Sources with Descriptions and Links

Geographies	Data Type	Year	Description	Link
England	Population Projection	2018-based	Population projections – local authorities, England	Link
Wales	Population Projection	2020	Population projections - local authorities, Wales	Link
Scotland	Population Projection	2020	Population projections - council areas, Scotland	Link
Northern Ireland	Population Projection	2018	Population projects - sub-national, Northern Ireland	Link
England and Wales	Mortality Rates - National	Oct-24	Mortality rates (qx), by single year of age, England and Wales	Link
Scotland	Mortality Rates - National	2020	Mortality rates (qx), by single year of age, Scotland	Link
Northern Ireland	Mortality Rates - National	2020	Mortality rates (qx), by single year of age, Northern Ireland	Link
UK (4 nations)	Mortality Rates - LSOA	2021	Deaths registered by area of usual residence, UK	Link
England and Wales	LSOA Age Distribution	mid-2022	Estimates by single year of age and sex for 2021 Lower layer Super Output Areas, mid-2022 estimates	Link
Scotland	LSOA Age Distribution	mid-2022	Estimates by single year of age and sex for 2011 data zones, mid-2022 estimates	Link
Northern Ireland	LSOA Age Distribution	2021	Estimate by single year of age and sex for health and social care trusts	Link
England	A&E Attendances	FY2022/23	Hospital Accident and Emergency Activity: National Report Tables - 2022-23	Link
Scotland	A&E Attendances	FY2022/23	Monthly A&E attendances and rates per 100,000 by department type and age group for NHS Scotland.	Link
Northern Ireland	A&E Attendances	FY2022/23	Attendances per 1000 population by age group - NI (unplanned only)	Link
Wales	A&E Attendances	FY2022/23	Number of attendances in NHS Wales emergency departments by age band, sex and site	Link
England	Deprivation	2019	Statistics on relative deprivation in small areas in England	Link
Wales	Deprivation	2019	The Welsh Index of Multiple Deprivation (WIMD)	Link
Northern Ireland	Deprivation	2017	SOA deprivation measures released on 23rd November 2017	Link
Scotland	Deprivation	2020	Scottish Index of Multiple Deprivation 2020	Link

Source: Edge Health & Greencroft Economics

C.4 Validation of Output

We validate the outputs of the model internally, by checking them against the model's assumptions and working through example cases, and externally, by comparing result with previous research and estimates developed by experts:

Internal Validation

- Manual probability calculations compared against model outputs for selected scenarios
- Testing model on smaller geographical scope to verify simulation mechanics
- Sensitivity analysis of key parameters to assess model stability

External Validation

- With our project working group, steering group members, and the adaptation committee
- With previous sources that have modelled heat-related mortality effects
- We have selected four validation sources based on their alignment with our methodology, considering both their time periods and geographical scope

Table 38. Mortality estimates by data source

	ONS[1]	Gasparrini et al. 2022[2]	Jenkins et al. 2022[3]	García-León et al. 2024[4]
Baseline Period	1988-2022, 2018-2022	2000–2019	1990–2019	1991–2020
Future Scenarios?	No	No	Yes (1.5°C, 2°C, 3°C and 4°C warming 2020, 2030, 2050 and 2100)	Yes (1.5°C, 2°C, 3°C, 4°C, 2100)
Geographical Scope	England and Wales (Regional)	England and Wales (Regional)	UK, England and Wales (Regional)	UK

- More recent baseline periods
- Regional estimates to provide validation at a more granular level

- Earlier decades in baseline periods
- Projected estimates for future scenarios

Source: Edge Health & Greencroft Economics

C.5 Economic Valuation of Health Impacts Assumptions

Mortality

- We use Statistical Life Years (SLY) to estimate the economic impact of mortality, following UK Green Book guidance. SLY consists of two components:

    - **Years of Life Lost (YLL):** The estimated number of years a person would have lived had they not died, based on their age and life expectancy. To calculate YLL, we match each age at death to corresponding life expectancy estimates from ONS, which reflect the expected remaining years of life for individuals of that age.
    - **Value per YLL:** Each year of life lost is valued at £60,000, as per the UK Green Book guidance.
- Assumptions and limitations:
    - Individuals will live out their full life expectancy for the calculation of YLL for mortality
        - This might overestimate the economic impact of mortality as those affected by heat-related mortality may be disproportionately impacted by other vulnerabilities, such as underlying health conditions, that reduce life expectancy

A&E Attendance

- We use NHS Payment Scheme Prices Workbook 2024-25 (Pay Award Update) to estimate the economic impact of A&E attendance, based on the health resource groups (HRG) for emergency medicine
- Assumptions and limitations:
    - Assume a set proportion of A&E attendances in each HRG category of emergency medicine (75% in Category 2, 15% in Category 3 and 10% in Category 1)
    - Assume that all heat-related A&E attendance falls within Types 1 & 2 Emergency Care
        - To note, the A&E attendance data does not account for other healthcare system costs, such as hospital admissions, extended stays, or long-term care. These costs, particularly in regions like London and South East, could add substantially to the total economic impact.

Emergency Admissions

- We use estimates of the average length of stay and costs per bed day by disease conditions (injuries, infectious disease, metabolic disease and respiratory diseases) to calculate the inpatient costs incurred from emergency admissions. Length of stay for metabolic conditions is not available for admissions due to metabolic disease, therefore, an average length of stay of 9.1 days is used instead.
- Assumptions and limitations:
    - Assume that the length of stay and cost per bed day stays constant in the future.

D Appendix – Supplemental Health Impact Analyses

D.1 Heat-related Mortality by Causes

Estimated number of heat-related mortality by causes of death, using assumptions from Gasparrini et al. (2012).[162]

Table 39. Estimated number of heat-related mortality by causes of death

Disease Categories	1991-2020	2030 central	2030 worst	2050 central	2050 worst
Cardiovascular diseases	**287**	**743**	**1976**	**1087**	**2516**
Stroke	102	265	705	388	898
Ischaemic heart diseases	134	346	921	507	1173
Atrial fibrillation	8	20	52	29	67
Atrio-ventricular conduction disorders	0	0	0	0	0
Arrhythmias	5	13	35	19	45
Pulmonary embolism	4	11	29	16	37
Heart failure	24	61	163	90	208
Sudden cardiac death	0	0	0	0	0
Pulmonary heart diseases	2	4	12	6	15
Respiratory	**209**	**541**	**1440**	**792**	**1834**
Chronic obstructive pulmonary disease	65	169	449	247	572
Asthma	5	13	35	19	45
Respiratory infections	114	296	787	433	1002
Other	**350**	**905**	**2408**	**1324**	**3066**
Endocrine diseases	16	42	111	61	141
Diabetes	13	33	87	48	111
Genitourinary system	26	68	181	99	230
Urinary system	26	68	181	99	230
Mental health disorders	28	72	192	106	245
Nervous system disorders	40	103	274	151	349
Extra-pyramidal disorders	14	35	93	51	119
External causes (includes accidents, injuries, intentional self-harm)	37	96	257	141	327

Modelled using the number of deaths from modelling. Source: Gasparrini et al. (2012) Mortality risk attributable to high and low ambient temperature: a multicounty observational study, Link

D.2 Maternal and Neonatal Health Outcomes

Due to a lack of quantitative evidence on neonatal and maternal heat-related health outcomes within the UK, those populations are not explicitly examined within the core microsimulation

[162] Gasparrini et al. (2012) Mortality risk attributable to high and low ambient temperature: a multicounty observational study, Link

model. However, a recently published analysis has shown that heat exposure can significantly increase the likelihood of a series of neonatal and maternal health outcomes.[163]

To provide an illustrative view on the potential impacts of heat exposure on the UK populations, we followed a review process to shortlist outcomes that could be reasonably modelled for the UK context (Section C.1.5).

On this basis, preterm birth was shortlisted as the outcome most suitable for modelling, given its relatively strong evidence base, its prevalence in the UK, and its role as a key driver of neonatal intensive care admissions. It is important to note that other outcomes are still clinically important (e.g. stillbirths, cardiovascular events), but our assessment of the evidence suggests that more research might be needed to establish the heat-related impacts.

Table 40. Illustrative impact of heat exposure on maternal and neonatal outcomes - preterm births attributable to heat

	1991-2020	2030		2050	
	baseline	central	worst	central	worst
England and Wales	271	573	1,090	659	1,195
Scotland	2	3	12	6	19
Northern Ireland	1	1	5	2	9

Source: Edge & Greencroft

During the present-day baseline (1991–2020), an estimated 271 excess preterm births were linked to heat. By 2030s, this number is projected to more than double at 573 under the central scenario and 1,090 under the worst-case scenario. These estimates were found to be broadly consistent with the expected magnitude of heat-attributable preterm births. For example, in the worst-case scenario for the 2050s, heat-related preterm births account for 2.6% of all preterm births annually in England and Wales.

Assumptions: Number of pre-term births is calculated based on the same number of live births in the 2030s and 2050s as 1991-2020.

[163] Lakhoo, Darshnika P., et al. (2025) "A systematic review and meta-analysis of heat exposure impacts on maternal, fetal and neonatal health", Link

Limitations: This likely underestimates the impacts for future scenarios as number of births will increase overtime.

D.3 Impact of Strokes on the Health System

Table 41. Estimated cost on the social care system from excess strokes as a result of extreme heat

Category	1991-2020	2030 central	2030 worst	2050 central	2050 worst
Deaths from stroke[164]	102	229	650	388	898
Excess deaths from stroke (accounting for displacement effect)[165]	20	46	130	78	180
Excess stroke prevalence[166]	136	305	867	517	1197
Excess care home admissions[167]	10	23	66	40	92
Average weeks spent in a care home[168]	286	286	286	286	286
Cost per week of care home (£)[169]	842	842	842	842	842
Cost of care home for excess stroke patients	£2.5 million	£5.6 million	£16.0 million	£9.5 million	£22.1 million

[164] Gasparrini et al. (2012) Mortality risk attributable to high and low ambient temperature: a multicounty observational study, Link
[165] Hajat S, Armstrong BG, Gouveia N, Wilkinson P (2005) "Mortality Displacement of Heat-Related Deaths: A Comparison of Delhi, Sao Paulo, and London", Link
[166] Lee S, Shafe ACE, Cowie MR (2011) "UK Stroke Incidence, Mortality and Cardiovascular Risk Management 1999–2008: Time-Trend Analysis from the General Practice Research Database", Link
[167] Clery A (2021) "Survival and Outcomes for Stroke Survivors Living in Care Homes: A Prospective Cohort Study", Link
[168] Vandergriendt C (2024) "Outlook and Life Expectancy After a Stroke", Link
[169] NHS England Digital (2024) "Adult Social Care Activity and Finance Report, England, 2023-24", Link

E Appendix – Extreme Heat Hazard Modelling

This appendix sets out how the historical baseline and future climate scenarios were developed to estimate occurrences of extreme heat across the UK. It includes a discussion of the data and models used, the spatial granularity modelled, and heat metrics selected. The methodology described closely aligns with the "Proposed Methodology for the Fourth Climate Change Risk Assessment" framework.[170]

E.1 Historical Extreme Heat Occurrence (Baseline: 1991-2020)

A baseline for heat hazard occurrence is constructed from HadUK Grid data downloaded from CEDA Archive. The baseline is constructed using daily maximum air temperature across the UK, at 5km blocks (or "pixels" below), for the period 1991-2020.[171]

This data is then shaped to LSOAs using shapefiles for England and Wales from the Office for National Statistics, and Data Zone boundaries for Scotland and Northern Ireland from Spatial Data Scotland and NISRA.

The spatial NetCDF files are then converted into one long dataset, with a specified observed maximum temperature for each pixel (longitude x latitude) and day during 1991-2020 using the British National grid.

Extreme heat days are identified as any day where the temperature exceeds an LSOA-specific threshold (25°C to 29°C depending on the LSOA), in line with the definition of a 'summer day' and the lower bound of Met Office regional heat alert thresholds. From this cleaned dataset, extreme heat events are classified as where temperature exceeds the regional threshold and categorised into 1°C intensity bins.

The modelling here uses the same approach as the Met Office, but thresholds are calculated for each LSOA, based on the 90th percentile of baseline temperatures in July, rounded to the nearest 1°C, and above a minimum of 25°C.[172]

Heat occurrences are then normalised across the baseline period (of 30 years). For each pixel, the number of heat days is counted per 1°C bin (as per above). This count is then divided by 30, the number of baseline years, to obtain average annual heat occurrences. Heat occurrences are aggregated to LSOAs using a spatial averaging function.

[170] https://www.theccc.org.uk/publication/proposed-methodology-for-the-ccra4-advice/?chapter=1-introduction-to-the-uks-climate-change-risk-assessments#1-introduction-to-the-uks-climate-change-risk-assessments

[171] while maximum daily temperature is used to define heat events, minimum daily temperature is also available and used to derive average daily temperature (mean of minimum and maximum), which are maintained as additional variables throughout this modelling to obtain the aggregate number of minimum and average temperatures during heatwaves at LSOA level for baseline and climate scenarios.

[172] McCarthy et al (2019), "A new heatwave definition for the UK", Link

Finally, heat day percentiles are constructed from the historical data. For each 1°C temperature increment between the national threshold and the maximum observed temperature, the historical percentile rank is calculated. This is estimated for use in "bias correction" in the projected data (see Section E.2). For example, 25°C could be the 97th percentile during 1991-2020, while 26°C and 27°C could be the 98th and 98.5th percentiles, etc.

E.2 Projected Heat Hazard Occurrences

Projected temperature data was obtained from UKCP18 Local (data downloaded from CEDA Archive). This provides daily maximum and minimum air temperature across the UK, at 5km blocks (or "pixels" below), for the period 1981-2080. The scenario used is RCP8.5, for all 16 ensemble members.

As for the baseline data, the heat projections are then converted from spatial NetCDF files into one long dataset per ensemble member, specifying the projected maximum temperature for each pixel (longitude x latitude) and day during 1981-2070 using the British National Grid.

To acquire temperatures equivalent to the historical percentiles described in Section E.1, for each ensemble member, the years are filtered within the 30-year time slice that corresponds to a global warming level of 0.9C (equivalent to historical baseline period 1991-2020). From these, the equivalent absolute temperature figures are matched to the historical baseline percentiles derived in Section E.1. This is used later for bias correction (see below). In the example above, the 97th, 98th and 98.5th percentiles (equivalent to 25°C, 26°C and 27°C in historical data) could be 25.8°C, 26.6°C and 27.4C for ensemble member 1, and 23.8°C, 25.1°C and 26.2°C for ensemble member 2, etc.

The above temperature mapping between historical and projected data does not capture temperatures higher than those observed in the historical baseline. However, this is needed since future heat events will increasingly fall in ranges outside historical experience. Therefore, for each ensemble member, the temperature mapping is extended to capture all projected temperature values using an extrapolation approach.

For each of the 16 ensemble members, the years are filtered within the 20-year time slice that correspond to the global warming levels of each scenario: 1.5°C and 2°C for the central scenario, and 2°C and 2.5°C for the worst-case scenario. The start and end years of these time slices for each ensemble member were provided by the CCC.

For each ensemble member, only observations exceeding the temperature that is equivalent to the historical percentile of the national threshold are retained. Continuing the example given above, this means keeping only observations above 25.8C for ensemble member 1 and above 23.8°C for ensemble member 2. Temperatures are then assigned into according to intensity steps, equivalent to the historical percentiles of 1°C bins. In the example above, for ensemble

member 1, observations of 25.8-26.6°C would fall into 25-26°C bin, 26.6-27.4°C into the 26-27°C bin, etc.

For each pixel and ensemble member, the number of observed occurrences in total and in each 1°C bin is then counted. This is divided by 20 (the number of years in each time slice), to obtain annual projected heat occurrences (total and in each 1°C bin). For the four 'new' ensemble members, further scale these numbers by the factor $\frac{360}{365}$ to correct for the difference in time dimensions (the old members use a 360-day year while the new members use a 365-day year or the Gregorian calendar).

Finally, for each of the central and worst-case scenarios and decade of interest (2030s and 2050s), a representative ensemble member is selected. In line with guidance from the CCC:

- For the central scenario, the two median ensemble members are shortlisted (since there is no single median member), and the member closest to the average number of heat occurrences chosen.
- For the worst-case scenario, the member with the largest number of heat occurrences is chosen (i.e. the "maximum" worst case within the ensemble members is used).

For the main analysis, selecting the median and most extreme ensemble members is performed using total number of heat occurrences across the country. However, a sensitivity analysis is conducted in which higher temperature occurrences are assigned more weight due to their disproportional impact on health. The weights are defined based on the relative risk associated with every 1°C temperature step above the national threshold. In this sensitivity analysis, the median and 'maximum' ensemble members are selected after computing the risk-adjusted weighted average of heat occurrences.

For each scenario and decade, the number of annual heat occurrences (total and in each 1°C bin) are aggregated to LSOAs using a spatial averaging function.

F Appendix – Days of Extreme Heat by Scenario

Table 42. Days of extreme heat per year – present day baseline (1991 – 2012)

	25°C to 29°C	30°C to 35°C	Over 35°C	Total days
London	20.4	3.2	0.2	**23.8**
East of England	15.9	1.9	0.1	**17.9**
South East	13.9	1.6	0.0	**15.6**
East Midlands	11.5	1.2	0.0	**12.7**
West Midlands	10.4	0.9	0.0	**11.3**
South West	7.7	0.6	0.0	**8.3**
Yorkshire And the Humber	7.1	0.3	0.0	**7.4**
North West	4.9	0.2	0.0	**5.2**
Wales	4.5	0.2	0.0	**4.7**
North East	2.9	0.0	0.0	**2.9**
Northern Ireland	1.5	0.0	0.0	**1.5**
Scotland	1.3	0.0	0.0	**1.3**
Total (average)	**8.5**	**0.8**	**0.0**	**9.4**

Source: Edge Health & Greencroft Economics

Table 43. Days of extreme heat per year – central scenario

	2030				2050			
	25°C to 29°C	30°C to 35°C	Over 35°C	Total days	25°C to 29°C	30°C to 35°C	Over 35°C	Total days
London	38.3	6.7	0.2	**45.2**	43.8	8.2	1.0	**53.1**
East of England	27.4	3.9	0.1	**31.4**	31.7	5.3	0.5	**37.5**
South East	27.5	3.6	0.1	**31.2**	31.3	5.4	0.6	**37.3**
East Midlands	21.7	2.9	0.0	**24.6**	23.9	3.7	0.4	**28.0**
West Midlands	20.1	2.4	0.0	**22.5**	22.6	3.5	0.3	**26.5**
South West	17.7	1.7	0.0	**19.4**	21.3	3.2	0.2	**24.7**
Yorkshire And the Humber	11.1	0.9	0.0	**12.0**	13.6	1.3	0.1	**15.0**
North West	6.8	0.5	0.0	**7.3**	9.5	0.7	0.0	**10.2**
Wales	7.6	0.5	0.0	**8.1**	10.5	1.0	0.0	**11.5**
North East	3.6	0.1	0.0	**3.8**	5.8	0.2	0.0	**6.0**
Northern Ireland	1.8	0.0	0.0	**1.8**	3.5	0.0	0.0	**3.5**
Scotland	1.0	0.0	0.0	**1.0**	2.0	0.0	0.0	**2.1**
Total (average)	**15.4**	**1.9**	**0.0**	**17.4**	**18.3**	**2.7**	**0.3**	**21.3**

Source: Edge Health & Greencroft Economics

Table 44. Days of extreme heat per year – reasonable worst-case scenario

	2030				2050			
	25°C to 29°C	30°C to 35°C	Over 35°C	Total days	25°C to 29°C	30°C to 35°C	Over 35°C	Total days
London	54.9	19.3	0.6	**74.8**	59.2	21.2	1.1	**81.6**
East of England	44.3	11.8	0.4	**56.5**	47.0	13.8	0.7	**61.6**
South East	45.2	12.9	0.4	**58.6**	49.1	14.8	0.8	**64.8**
East Midlands	37.6	9.0	0.3	**46.9**	39.4	11.5	0.6	**51.6**
West Midlands	36.5	8.6	0.4	**45.5**	39.1	11.3	0.7	**51.1**
South West	33.8	8.3	0.3	**42.3**	37.3	10.8	0.7	**48.8**
Yorkshire And the Humber	24.9	3.9	0.1	**28.9**	26.6	5.9	0.2	**32.7**
North West	17.3	2.3	0.1	**19.6**	20.3	3.7	0.2	**24.1**
Wales	19.5	3.0	0.1	**22.6**	22.4	4.8	0.2	**27.4**
North East	12.1	1.1	0.0	**13.2**	14.7	2.1	0.0	**16.8**
Northern Ireland	8.2	0.4	0.0	**8.6**	11.9	1.0	0.0	**12.9**
Scotland	4.7	0.3	0.0	**5.0**	6.7	0.6	0.0	**7.3**
Total (average)	28.2	6.7	0.2	**35.2**	31.1	8.5	0.4	**40.1**

Source: Edge Health & Greencroft Economics

G Appendix – Full MCA Scoring Results

Table 45. Full MCA scores

x	Measure	Result 1	Result 2	Result 3	<< Result 4[173]	Sequencing
1.0	Heat-Health Action Plans (Local Authorities)	4.3	4.6	4.1	4.4	Immediate
1.1	Preventative contact with care-at-home	3.8	3.9	3.3	3.7	Immediate
1.2	Heat advice and information services	3.3	3.6	2.8	2.8	Near-term
1.3	Public cooling spaces	2.3	2.6	2.7	2.8	Medium-term
1.5	Train community care workers	2.3	2.6	2.1	2.3	Watching brief
1.6	Invest in improving health on key co-morbidity factors	1.5	1.3	2.4	2.4	Other – not assessed for this study
1.9	Improve heat-preparedness of care homes	3.5	3.3	3.5	3.6	Near-term
2.1	Improve resilience of medical supply chains	2.3	2.2	2.1	1.9	Watching brief
2.2	Adapt working patterns and staffing across the system	3.3	2.8	2.8	2.7	Medium-term
2.3	Building code / design for all new build facilities	3.5	3.3	3.2	3.2	Immediate
2.4	Retrofit policy for at-risk health centres	3.5	3.7	3.2	3.2	Immediate
2.5	Targeted staff training / responsibilities on heat events	3.5	4.1	3.2	3.1	Immediate
2.6	Introduce staff refreshment policies and guidance nationwide	2.5	2.7	3.1	2.5	Medium-term
2.7	Increase availability of rapid response and ambulances during heat events	2.3	2.2	2.4	2.4	Watching brief
2.8	Protocol for regional patient transfer	2.0	2.4	2.3	2.5	Watching brief
3.1a	Low intensity cooling (e.g. low-cost passive cooling)	3.0	3.0	3.0	3.0	Immediate
3.1 b	High intensity cooling (e.g. full climate control with A2A heat pumps)	2.5	2.7	2.5	2.6	Medium-term
3.2	Medium intensity cooling (e.g. dedicated cooling stations)	3.0	3.0	2.7	2.8	Near-term
3.3	Improve cooling / storage / backup of at-risk equipment, including digital infrastructure	3.3	2.8	2.5	2.6	Medium-term
3.5	Health Facility Heat and humidity monitoring	4.3	3.8	2.9	3.3	Immediate
3.6	Health Facility Heat management policies	4.3	3.8	2.9	3.6	Immediate
3.8	Increase maintenance and facilities management during heat alerts	3.0	3.0	2.7	2.9	Near-term
1.7a	Monitor and review heat stress protocol for at-risk professions	1.8	2.3	2.5	2.2	Other – not assessed for this study
1.8a	Develop heat action plans for prisons and schools, and invest in any capital requirements to limit risks	2.0	1.6	2.3	2.2	Other – not assessed for this study

[173] Results are derived based on different weightings of the eight criteria; result 1 only considers costs and risks, result 2 additionally accounts for implementation feasibility, result 3 also considers co-benefits, and result 4 weighs up all eight criteria including scalability, flexibility and distributional effects.

1.8 b	Improve housing stock in key deprived / heat exposed regions	2.5	1.9	2.5	2.4	Other – not assessed for this study

Source: Edge Health & Greencroft Economics

H Appendix – Quantifying Adaptation Costs and Benefits

This section sets out how the costs and benefits of each shortlisted adaptation measure are estimated. The objective is to provide reasonable unit cost benchmarks for the required capital expenditure (capex), recurring capital maintenance expenditure (repex) and operating expenditure (opex) for each measure.

Representative estimates of unit costs and unit benefits of implementing adaptation measures are build-up typically at a patient or hospital level. The output is used to arrive at reasonable estimates of the order of magnitude of adaptation costs and benefits at regional levels and is not intended for facility- or intervention-specific design. It reflects limited information on both the current baseline level of adaptation built into the UK health and social care system, and on exactly how much each adaptation measure might be expected to cost. As an example, illustrative costs of implementing active cooling measures are used in care home settings to represent the likely order of magnitude of investment and ongoing expenditure that might be required across the UK, but in practice a range of active and passive cooling measures could be implemented, as appropriate and as representing best value for money on a per-facility basis.

H.1 Demand Side – Cooling

H.1.1 Overview of rationale

These measures are about cooling body temperature on extreme hot days, to reduce the need for health care, i.e. reducing mortality, A&E attendances, or hospital admissions. There is only limited evidence on the effectiveness of each measure, in terms of (1) how measures can best be targeted to those who are most at-risk, (2) effectiveness in terms of reducing risk of mortality or morbidity, and (3) how the costs and effectiveness per unit may change as intervention is scaled up.

A major co-benefit of these measures may be in improving comfort and wellbeing during periods of extreme heat.

Interventions may be more or less effective across two key dimensions:

- *the type of population reached:* mapped to the archetypes used in this study
- *the type and extent of risk reduction:* in reducing mortality rates, attendance / admissions to health care facilities, or both during heat events.

Some measures are more likely to address certain population groups. Preventative care-at-home is most likely to be more effective for elderly people and those identified as high risk for other

reasons (e.g. co-morbidities, pregnant women). However, it will be less effective for other groups, such as the general population aged 5-65, and people in care home settings.

In terms of the type of type of risk reduction, it is likely that the main benefit of, for example, heat-preparedness in care homes will be on reducing mortality, and to some extent on attendance of urgent health care. Whereas providing heat advice and information services and public cooling is perhaps more likely to reach a relatively more active population, so may have a larger impact on attendance than it does on mortality.

H.1.2 Included in this bundle

#	Measure	Costs and benefits estimated
1.0	Heat-health action plans (local authorities)	Yes – set out below
1.2	Heat advice and information services	Yes – set out below
1.1	Preventative contact with care-at-home	Yes – set out below
1.3	Public cooling spaces	Yes – set out below
1.9	Improved heat-preparedness of care homes	Yes – set out below

#1.0 Heat-health action plans (local authorities)

Description: Regional authorities (as relevant in each of the devolved administrations, e.g. Local Authorities in England, Health Boards in Wales etc.) develop Heat-Health Action Plans, integrating urban planning, public health, and social services, which includes bringing together relevant groups to establish local risks and vulnerabilities, design of locally tailored policies, and implementation of plan.

A plan in and of itself is of course only effective if the actions within it are implemented. Nonetheless, the literature review and stakeholder interviews suggest locally developed plans are a highly valuable pre-requisite to increase the effectiveness of implementation tailored to the local environment, vulnerabilities and risks, and recognising the community and institutional factors involved.

UK approach: There are national Adverse Weather and Health Plans for England,[174] and Scotland,[175] both of which provide plans for how to respond to higher temperatures. There is a Heat Strategy for Wales,[176] focussed on decarbonisation and the use of heat in buildings, and

[174] UK Health Security Agency (2024) "Adverse Weather and Health Plan", Link
[175] Public Health Scotland (2024) "PHS adverse weather and health plan 2024–2027", Link
[176] Government of Wales (2024) "Heat Strategy for Wales", Link

there is guidance for health and social care professionals during extreme hot weather.[177] There is a Severe Weather Plan for Northern Ireland,[178] although this does not cover extreme heat. Local plans are in some instances available across the UK regions, but we have not been able to identify a comprehensive catalogue. For example, a plan is currently under development by Greater London Authority. More localised plans exist, such as in the Borough of Haringey.[179] Other plans would require allocation of responsibility and resource within authorities.

International examples and evidence: A wide range of global plans exist[180], for example in Madrid, Spain, and Toronto, Canada. These plans typically focus on early warning systems, public awareness and education, and preparedness in health systems, cooling centres, and targeted support for vulnerable populations. Recent assessments of plans have shown strong effectiveness for reducing mortality, with estimates ranging from 2-23%, and weaker effectiveness on morbidities and hospital attendances[181]. These impacts are from implementing (components of) the plan, rather than the plan alone. A recent meta-analysis showed evaluated plans worldwide have been shown to be cost effective and low regret/immediate action policies.[182] The variation across plans means the individual components are typically harder to assess, and so the impact of implemented plans can only act as a guide to the potential scope of total impact of the typical sub-components. The literature shows that while they are seen as effective, and that it is accepted that the measures within typical plans work, the nature of their typical implementation means individual components have not been effectively evaluated[183]. However, having a plan enables local tailoring of many individual policies, adapting to local risk and population types. In this report, many of the potential individual actions are documented as separate measures.

#1.2 Heat advice and information services

Description: Provision of specific heat information services and contact centres, such as hotlines or apps, during periods of expected extreme heat.

UK approach: In England, Heat Health Alert Guidance has been updated in June 2024,[184] providing various information services, while in other UK nations similar plans exist, such as

[177] Public Health Wales, Link
[178] Northern Ireland Direct (2017) "Household severe weather plan". Link
[179] https://www.local.gov.uk/case-studies/london-borough-haringey-joint-strategic-needs-assessment-heatwaves
[180] See for example the Global Heat Health Information Network "Heat Action Plans and Case Studies", Link
[181] See for example Dwyer et al (2022) "Evaluations of heat action plans for reducing the health impacts of extreme heat: methodological developments (2012-2021) and remaining challenges", Link, and Rao et al (2025) "Evaluating the socioeconomic benefits of heat-health warning systems" Link
[182] Rao et al (2025) "Evaluating the socioeconomic benefits of heat-health warning systems" Link
[183] For example this review: Dwyer et al (2022) "Evaluations of heat action plans for reducing the health impacts of extreme heat: methodological developments (2012–2021) and remaining challenges", Link
[184] UK HAS (June 2024) *"User guide – Weather-health alerting system"*, Link

guidance for health and social care professionals during extreme hot weather in Wales,[185] and the Severe Weather Plan for Northern Ireland.[186]

International examples and evidence: Previous work for the CCRA3 reviewed evidence and found a benefit-cost ratio of over 10:1 for heat alert and heat event planning.[187] In general, there is a wide range of cost-benefit analysis evidence, that show the potential benefits are large compared to relatively modest costs. For example, the costs of the French National Heatwave Plan for year 2005 were estimated at approximately €741k (opex of €454k plus system costs of €287k).[188]

#1.1 Preventative contact with care-at-home

Description: Additional visits by health care workers to people on an at-risk register on (or shortly before expected) heat events. Frequency and intensity would vary depending on needs. The advantage is it can be reasonably highly targeted to high-risk archetypes, who are also less likely to be reached by other individual cooling measures.

One of the challenges to this approach is how to register people onto priority registers and to agree to health care visits – with self-registration likely to result in low usage.

UK approach: There are existing examples across the UK's health system, including some NHS Trusts in England where heatwave plans include identifying vulnerable people that will need daily contact.[189]

International examples and evidence: New York City uses a community-led preparedness approach including climate risk training for Home Health Aides, and checks on at-risk neighbours through "Be a Buddy NYC". In Ottawa, a multi-stakeholder extreme weather prevention and response strategy exists to maximize capacity for public protection, especially for those most vulnerable (e.g. elderly, homeless). In France, there is a heatwave register for those who wish to be helped in case of heat events, which is a free and confidential service. Vulnerable people are then contacted regularly by their city during heat alerts; in case they need help and to offer advice. In the case of a non-response, the police can be contacted to attend.

[185] Public Health Wales, Link
[186] Northern Ireland Direct (2017) "Household severe weather plan". Link
[187] Paul Watkiss Associates (2021) "Monetary Valuation of Risks and Opportunities in CCRA3", Link
[188] Adelaide et al (2021) "Health effects from heat waves in France: an economic evaluation", Link
[189] See for example Sheffield Health and Social Care (2022) *"Heatwave plan"*, Link

#1.3 Public cooling spaces

Description: Dedicated infrastructure available to the public to cool down during heat events. This is most likely used by people that are relatively active, and arguably not the most at-risk groups who may be at home and in some cases isolated.

UK approach: London has a Cool Spaces map live between June and September.[190] These are not primarily public health interventions, and are social and community-based interventions.[191] In Wales, community centres offer fans and cooling and encourage people to visit if they need a place to cool down.[192] In general, the current UK approach uses existing infrastructure to offer cool spaces. The marginal cost is therefore very low. The main (intended) benefit of these types of spaces is to improve comfort, not to reduce acute heat stroke demands on health care provision. This differs from examples that have been evaluated elsewhere in the world.

International examples and evidence: New York[193] and Toronto both map locations of cooling centres alongside heat vulnerability indexes. Paris, Athens, and Rotterdam have launched the EXTREMA app in their cities, which assesses users' heat vulnerability and directs them to the nearest cooling centre.[194] There is evidence that the mortality risk for people who attend public cooling centres can be reduced by as much as 66%, although the same paper also notes that utilisation of these facilities is low, and *"there seems to be a discrepancy between the enthusiasm of public health officials to open cooling centres during periods of extreme heat and a decided lack of enthusiasm or ability by the public to take advantage of these resources"*.[195] Stakeholder engagement suggests that such infrastructure may have benefits if very targeted, for example, in areas with considerable overcrowding or homeless populations. However, more broadly, cooling centres do not reach the isolated or elderly populations who are most vulnerable to heat events.

#1.9 Improved heat-preparedness in care homes

Description: Implementing cooling measures in care home settings to reduce health risk to elderly populations. Active cooling measures include air-to-air heat pumps that can serve as heating in winter and cooling in summer, or built-in and portable air conditioning units and fans. Examples of passive cooling measures are shutters, blinds, and insulation of external walls. The optimal combination of these measures will need to be determined on a site-by-site basis, and will depend on both implementation cost, and performance in terms of cooling, especially at higher external temperatures.

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[190] Mayor of London / London Assembly "Cool Spaces", Link
[191] Kafeety et al (2020) "Social connection as a public health adaptation to extreme heat events", Link
[192] BBC News (15 August 2025) "'Cool spaces' provide help as Wales faces heatwaves", Link
[193] https://www.nycgovparks.org/about/health-and-safety-guide/cool-it-nyc
[194] C40 Cities (2019) "EXTREMA – Emergency Notification System for Extreme Temperatures", Link
[195] See for example Bedi et al (2023) "The Role of Cooling Centers in Protecting Vulnerable Individuals from Extreme Heat", Link

UK approach: There is very limited data available about the current readiness of care homes across the UK, or on how these could best be adapted. The ClimaCare project has been collecting heat and humidity data for 50 care homes,[196] and is developing a building stock model of UK care provision to help understand overheating risk. The Greater London Authority conducted a *"Care Home Overheating Audit Pilot Project"*,[197] which produced recommendations and a best practice checklist to help care homes reduce the risk of overheating. Previous studies have looked at a small number of care homes,[198] but there remains limited information on the current vulnerability of care settings and their residents to hear events, or on how best to adapt to rising temperatures in these settings. The Joseph Rowntree Foundation and researchers from three universities found high levels of risk,[199] but that building design for overheating is not commonplace, overheating is not prioritised, and cooling measures can be in conflict with occupant needs (for example opening windows posing security/safety threats).

There is growing evidence that overheating can pose a significant challenge in care home settings. A study of two London heat homes found that during the hot summer of 2019, they overheated (reaching above 26°C) on almost half of the days measured, with indoor temperatures reaching over 24°C in July 2019.[200]

International examples and evidence: In Quebec (Canada) all residents in long-term care settings have the right to request an individual air conditioning unit, which has seen air conditioning rise from just 8% of bedrooms to more than 60% over the last decade.[201] On Prince Edward Island (Canada) the provincial government is upgrading long-term care homes to install cooling systems (at an estimated cost of $3.6m for seven homes). However, there is limited evidence on the link between temperatures and mortality rates in care home settings.

H.1.3 Benefit estimation and parameters

To estimate the benefits of demand-side cooling interventions, a hypothetical scenario with amended relative risk factors is developed before health outcomes are quantified through a separate run of the microsimulation model. To estimate reductions to relative risk due to demand-side cooling interventions, a three-step process is followed (set out below).

Step 1 is to define the reach of each measure, i.e. what share of each archetype is (or could be) affected. Our proposed values for reach are set out in Table 46, noting that these are

[196] https://www.ucl.ac.uk/bartlett/engage/informing-policy/bartlett-research-supports-uk-policy-address-climate-change-risks-overheating-care-homes
[197] Greater London Authority (July 2020) "Care Home Overheating Audit Pilot Project", Link
[198] For example, Oikonomou et al (2020) "Assessing heat vulnerability in London care settings:
case studies of adaptation to climate change", Link
[199] Gupta et al (2016) "Care provision fit for a future climate", Link
[200] Tsoulou et al (2021) "Assessing the Current and Future Risk of Overheating in London's Care Homes: The Effect of Passive Ventilation",
Linkhttps://www.jrf.org.uk/care/care-provision-fit-for-a-future-climate
[201] TVA Nouvelles (29 July 2024)" Amélioration notable: tous les résidents de CHSLD peuvent désormais réclamer un climatiseur", Link

heavily assumption based. The objective is to allow modelling to get to reasonable ranges of the potential benefits – acknowledging each entry in itself debatable.

- **Local heat-health action plans,** effectively assumes these "reach" all of the population, as these are plans affect all people in the region. However, the impact of these plans varies by archetype (as set out in Table 47).
- **Heat-health advice services.** While heat-health advice services would be openly available, it is assumed there is a decline in the reach to elderly who are typically less easy to reach and influence through public communications. For example, only 55% of over 65-year-olds use a smartphone.[202] While there are alternatives, such as SMS or telephone outreach, the ability to convey information and influence behaviour nonetheless likely declines for the elderly.
- **Preventative outreach** would be targeted to a subset of working age population with comorbidities (10%), and for the elderly.
- **Public cooling** would be open access and in public spaces, but according to interviews with academics and experts, it is likely that attendance of these spaces is low as a share of the population, and most likely used by people who are outside and active, and less by people who are less mobile and largely at home.
- **Cooling in care homes,** is based on a mapping of care home residents as a share of the population, by age group, from the 2021 census in England and Wales,[203] and the 2021 Scottish care home census.[204] Data for Northern Ireland is more limited, so is proxied by combining existing evidence,[205] with UK-wide averages.

Table 46. Reach of adaptation measures

	#1.0 – Local heat health action plans	#1.2 – heat advice and information	#1.1 – preventative outreach	#1.3 – public cooling spaces	#1.9 cooling in care settings
0-4	100%	60%	0%	7%	0%
5-17	100%	60%	0%	7%	0%
18-64	100%	60%	0%	7%	0%
18-64 – comorbidities	100%	60%	10%	7%	0%
65-74	100%	50%	25%	3%	2%
75+	100%	40%	40%	0%	5%

[202] BBC News (25 June 2021) "Digital divide: Older people in the West left 'lonely'", Link
[203] Office for National Statistics (2021) "Older people living in care homes in 2021 and changes since 2011", Link
[204] Public Health Scotland (2021) "Care home census for adults in Scotland", Link
[205] COPNI (2024) "At the centre of government planning – The Programme for Government and preparing for an ageing population", Link

Source: Edge Health & Greencroft Economics

Step 2 is to define the "treatment effect" (effectiveness) on the population reached. The treatment effect of each measure may differ by impact on mortality, and on attendance or admissions (morbidity). This matters, as the optimal adaptation package will consist of measures that can act on each of these risk types. Moreover, the type of risk varies by population archetype; while extreme-heat-related mortality is highly concentrated in the elderly, attendances and admissions are more spread across the population, with concentration amongst those with co-morbidities and among the very young.

Table 47 sets out the estimated reduction in heat-related excess risk of each measure. The maximum reduction in relative risk of mortality is 60% as per evidence from academic literature.[206] The maximum risk reduction factor is then adjusted based on our assessment of each measure's likely effectiveness in reducing mortality, and separately for hospital attendance and admissions[207], as follows:

- *For local heat-health action plans,* the same 5% effectiveness for both mortality and attendance/admissions is assumed. This is on the basis that local heat-health action plans are pre-requisites for the effective implementation of other measures (both demand and supply side), so the effectiveness is the same for both risk types.
- *For heat advice and information services,* a higher degree of effectiveness for attendance and admissions than for mortality is assumed. This is on the basis that while providing information can help people reduce their heat-related health risk, it is more likely to be effective for people at risk of being unwell, and less in affecting the outcomes of those who struggle most with extreme heat and are at risk of mortality.
- *Preventative care* is likely to have a high treatment effectiveness on both mortality and on attendance/admissions due to its high potential to target at-risk groups.
- *Public cooling stations,* based on the literature and on consultations, are expected to be much more effective in reducing hospital attendance and admissions, and have only a relatively marginal impact on mortality.
- *Cooling in care home settings,* could be highly effective in reducing mortality, which would otherwise have occurred in the care home. It may be less effective in reducing hospital attendance and admissions, as care home residents are less likely to be

[206] Bedi et al (2022) "The Role of Cooling Centers in Protecting Vulnerable Individuals from Extreme Heat", Link. Source states 66%, but report uses 60% to account for potential that cooling solution doesn't always work reliably

[207] A key challenge in assessing the likely effectiveness of measures is that the vast majority of the evidence in the UK and elsewhere focusses on mortality; there is a very limited evidence base to draw on for how adaptation measures may reduce attendance and admissions. Therefore, effectiveness of reducing admission/attendance was evaluated based on assumptions and expert judgement.

transferred to acute hospital care during heat events, as they are treated within their care setting.

While the relative risk reduction associated with each adaptation measure is assumed to be the same for all archetypes, the effectiveness of each adaptation measure varies by archetype because of variation in:

1. The pre-adaptation extreme-heat relative risk, which varies significantly by archetype.
2. The "reach" of each measure by archetype – some adaptation measures will be more effective at reaching (treating) a larger share of some archetypes (Table 46).

Table 47. Effectiveness of adaptation measures on treated population[208]

	Local heat-health action plans	Heat advice and information	Preventative care at home	Public cooling	Cooling in care settings
Mortality	5%	5%	50%	10%	60%
Attendance/admissions	5%	10%	50%	50%	10%

Source: Edge Health & Greencroft Economics

Step 3 is to combine treatment 'reach' and the treatment 'effect' to estimate the reduction in risk of mortality in a heat event. Multiplying the percentages in Table 46 (treatment reach) and Table 47 (treatment effect) gives the population-wide expected reduction in excess risk of mortality during a heat event. This percentage is therefore the difference between the estimated increase in mortality in a baseline with no adaptation, and the scenario where adaptation is implemented. These population (and UK-wide) estimates are shown in Table 48.

Table 48. Treatment effectiveness at population level of adaptation measures

	#1.0 – Local heat health action plans	#1.2 – heat advice and information	#1.1 – preventative outreach	#1.3 – public cooling spaces	#1.9 cooling in care settings	Max risk reduction per archetype
0-4	5%	6%	0%	3.5%	0%	14.5%
5-17	5%	6%	0%	3.5%	0%	14.5%
18-64	5%	6%	0%	3.5%	0%	14.5%
18-64 – comorbidities	5%	6%	5%	3.5%	0%	19.5%

[208] Note – some of these numbers are currently illustrative.

65-74	4%	5%	20%	1.5%	1.2%	25.2%
75+	3%	4%	20%	0%	3.0%	32.0%

Source: Edge Health & Greencroft Economics

H.1.4 Cost estimation and parameters

#1.0 – Local heat-health action plans:

Local heat-health action plans are costed using estimates from public announcements of similar procurements:

- *Cost estimate of local plan:* Using three different estimates[209] of local authority procurements of local action plans from the gov.uk contracts finder, an average cost of approximately £75,000 per plan is established.
- *Number of counties by region:* A list of 79 counties, mapped to the UK's 12 regions, was obtained from ONS.

Roll-out of local heat-health action plans entails only capex to set up the plan – no repex or opex is included.

#1.2 – Heat advice and information services:

The establishment of a website, app and annual media burst was costed in the following way:

- *Cost estimate for one-off development:* Using cost estimates to build a website[210], develop a heat alert enabled app[211], make creative content[212], set up a media burst[213], and evaluate[214], a national upfront cost of £1.4m is established
- *Cost estimate for running costs:* Using cost estimates to host and secure a website[215], maintain the app[216], run a digital-only annual media burst[217], and maintain a team of two

[209] West Midlands Combined Authority, City of York Council, Warwickshire County Council
[210] https://gcs.civilservice.gov.uk/news/new-wordpress-platform-for-campaigns-revealed/
[211] https://www.bryj.ai/the-real-cost-of-app-development-and-the-key-advantage-you-need-to-know-about/
[212] Brown et al (2014) "How effective and cost-effective was the national mass media smoking cessation campaign 'Stoptober'?", Link
[213] https://hansard.parliament.uk/%E2%80%8CCommons/2002-11-05/debates/57e19248-16eb-4578-b4ed-932c534589ef/WrittenAnswers
[214] Assumption
[215] https://assets.applytosupply.digitalmarketplace.service.gov.uk/g-cloud-14/documents/721421/274386226674801-pricing-document-2024-05-03-1220.pdf
[216] https://ahex.co/app-maintenance-cost/#:~:text=On%20average%2C%20the%20yearly%20app,to%20keep%20it%20running%20smoothly
[217] Assumption based on TV-ad burst https://www.theguardian.com/media/2012/dec/28/new-year-anti-smoking-campaign-cancer-risks

staff members for contents and communications[218], an annual running cost of £529,000 is estimated.

Roll-out of information services plans would entail a small amount of capex to set up systems, and annual costs of overseeing and continually updating and disseminating information.

#1.1 – preventative outreach:

Costing of preventative outreach is estimated based on number of people reached and staff costs to carry out home visits. There may be more cost-effective alternatives, such as virtual appointments / wards, and a move to more localised, domiciliary-based care system in future. To provide a reasonable estimate for this assignment, the costs are estimated on the basis of:

- *Cost per hour:* £47 per hour[219] of time for a Band 5 health care professional. This includes both wages and additional employment costs to the NHS, such as pension contributions, national insurance, holiday and sick leave, and other overheads. This estimate represents either the opportunity cost of diverting existing staff towards this activity, or additional hours, but does not include any extra costs associated with hiring substantially more staff (i.e. it is costed on the basis of scaling up hours spent)
- *Number of visits per year:* 4 health visits per year, each with an hour allocated, for at-risk populations.
- *Population targeted:* The people receiving these targeted health visits during heat events would be based on an at-risk register maintained by local health authorities. The estimated number of visits need is based on visits reaching:
    - 5% of people aged 5-64, with underlying health conditions
    - 30% of people aged 65-74, with underlying health conditions
    - 50% of people aged 75+, with underlying health conditions

Implementing this in high- and medium-risk regions by 2050 would imply a UK-wide at-risk register comprising around 4 million people. Carrying out health visits would then entail no capex or repex, and opex for the time allocated by health care professionals as described above.

#1.3 - Public cooling

Public cooling spaces are assumed to be established predominantly in buildings with existing cooling solutions, such as libraries; therefore, costing was estimated based on operational expenses only:

[218] https://uk.indeed.com/cmp/Uk-Civil-Service/salaries/Communications-Officer
[219]University of Kent (2024) "Unit Costs of Health and Social Care 2024", Link

- *Estimate number of people reached:* Based on population projections by age and region, and the assumptions on reach of public cooling stations established in Table 47, the number of people reached per hot day are estimated.
- *Estimate number of cooling stations:* Based on number of people reached, usage as share of capacity (40%)[220], average visit duration (1 hr)[221], average capacity of cooling stations (124 people)[222] and an assumed number of hot hours per hot day (8 hrs), the total number of required cooling stations per region is estimated.
- *Estimate costs per person and cooling station:* We compute three cost components using literature estimates:
    - *Staffing:* 23% of cooling stations incur costs for additional staffing members[223]. This finding is combined with an estimated cost of £350 (including overheads) per staff member per hot day.
    - *Water:* Cooling stations provides on average 58 bottles of water per hot day[224], at a cost of £0.19 per bottle[225].
    - *Outreach:* One-third of cooling stations incur costs for printed outreach materials[226], with an assumed yearly cost of £300 per station (for example, using flyers).

Based on the established roll-out schedule, these operating costs are incurred in the more than 1,600 required cooling stations across the UK, with no capex or repex as utilising existing facilities.

#1.9 - Cooling in care settings

A range of passive and active cooling measures could be deployed, from turning off hot water circulation during heat events, window opening protocols, curtain drawing protocols, natural

[220] Berisha et al (2017) "Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona", Link

[221] Berisha et al (2017) "Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona", Link

[222] Berisha et al (2017) "Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona", Link

[223] Berisha et al (2017) "Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona", Link

[224] Berisha et al (2017) "Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona", Link

[225] Tesco (2025). Link

[226] Berisha et al (2017) "Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona", Link

ventilation: such as trickle vents, replacement windows etc. through active cooling such as fans, air conditioning, air-to-air heat pumps etc. through to building design and retrofit.

To estimate a reasonable range of costs to implement adaptation in care home settings a cost per-resident based on deploying active cooling technologies is used. The costing is based on a mix of (1) domestic cooling technologies and (2) institutional cooling technologies (as described for active cooling in hospitals below), each with a 50% weight.[227] It is further assumed that 50% of rooms in care homes would be air conditioned, in line with uptake of air conditioning when offered to residents of care homes in Canada.[228]

- **Active cooling – domestic buildings (50% weight):** Air-to-air heat pumps at a cost of approximately £4,000 for device and installation, and an annual maintenance cost of 5%.
- **Active cooling – institutional buildings (50% weight):** see below on costing active cooling for hospitals.

This may over-estimate (or under-estimate), if there are more cost-effective combinations of passive or active cooling measures, or building design retrofit. For example, previous studies in the UK have shown that natural ventilation and passive cooling (e.g. opening secured windows at night and closing external shutters during hotter daytime hours) could be relatively effective at lowering temperatures.[229] However, natural ventilation would need to be implemented carefully, as it may expose residents to increased health risks associated with air pollution.[230]

In the absence of better information however, a cost per-resident targeted provides a reasonable estimate of a plausible region-wide and nation-wide spending need.

Furthermore, this costing is used to deliver a reasonable UK-wide estimate of the spending needed to adapt care homes – in practice there will be a mix of passive and active cooling needed at different sites. Practical considerations will also need to be considered. For example, health and safety protocols may limit the ability to implement some measures, with e.g. regulations limiting how wide windows can be opened and institutions routinely keeping windows closed at night for safety reasons.[231] The right type of adaptation will also depend on building types, with older (pre-1930) buildings in general overheating less than more modern buildings, although with some significant outliers with some older buildings getting much

[227] The 50% weight assumption is based on two sources. First, that 49% of care home residents are in facilities with more than 50 beds, which are large enough to be better represented by larger scale (and more cost effective) air conditioning solutions. This is based on the breakdown of bed capacity of care homes in the Care Quality Commission "CQC Care Directory" database, Link, last accessed on 28th October 2025 . Second, that 49% of elderly care home residents are in facilities with nursing, based on ONS data on "Older people living in care homes in 2021 and changes since 2011", Link
[228] TVA Nouvelles (29 July 2024)" Amélioration notable: tous les résidents de CHSLD peuvent désormais réclamer un climatiseur", Link
[229] Isaacs et al (2022) Passive Strategies to Improve Thermal Conditions in a Care Home in London, UK, Link
[230] Tsoulou et al (2023), Indoor environmental quality trade-offs due to summertime natural ventilation in London care homes, Link
[231] Gupta, et al (2021), Examining the magnitude and perception of summertime overheating in London care homes, Link

hotter, and significant variation in temperatures depending on the direction (e.g. West and East facing) or the floor on which rooms are located.[232]

H.2 Demand Side – Well-being

These affect well-being and health during heat events but are (1) not expected to have significant impacts on either mortality or attendance rates, or (2) are not primarily a heat-health related issue.

H.2.1 Included in this bundle

#	Measure	Costs and benefits estimated
1.6	Invest in improving health on key co-morbidity factors	Not estimated – included as one of the co-drivers of health outcomes, but not costed how to improve underlying population health
1.7	Monitor and review heat stress protocol for at-risk professions	Not estimated – benefits are primarily well-being and productivity
1.8a	Develop heat action plans for prisons and schools, and invest in recommended infrastructure	No – welfare gains but no evidence of significant impact on health care
1.8b	Improve housing stock in key deprived / heat exposed regions	No – beyond the scope of this study, and has been covered in detail in previous studies (see below)

H.2.2 Benefit estimation and parameters

These measures are discussed qualitatively in the main report, but not costed, as their main benefits do not relate to the three health outcomes of interest to this study, and there is very limited information to allow a unit costing assumption.

H.2.3 Cost estimation and parameters

No cost estimation for these measures.

H.3 Supply Side – NHS Staffing and Operations

The main benefit is an increase in healthcare supply (quantity and quality) to meet higher-than-usual demand during heat events, and to compensate for heat-related staff absences. On hot days, excess demand for healthcare services and staff absences due to heat put a strain on effective healthcare provision. Staffing solutions will be needed to increase staff availability on

[232] Gupta et al (2024) Monitoring the prevalence and intensity of overheating in English care homes during summer 2022, Link

hot days, while targeted training and refreshment policies support the welfare and productivity of staff. Co-benefits include improvements to quantity and quality of healthcare services all year round, including increased capacity during winter flu spikes.

Costs of this bundle include additional hiring of staff and introductions of novel policies and trainings. Costing of selected staffing measures are expressed in wage and overtime payments, as well as expenses to recruit, roll out new guidance and training. However, cost savings are made concurrently as fewer bank and agency staff are needed.

When considering policies affecting the delivery of healthcare, it should be noted that healthcare is devolved across the four nations of the UK. As a result, the precise mechanisms for implementation will deliver in line with local structures.

H.3.1 Included in this bundle

#	Measure	Costs and benefits estimated
3.4	Adapt working patterns and staffing	Yes – set out below
2.5	Targeted staff training / responsibilities on heat events	No – insufficient evidence to quantify impact on staff performance
2.6	Introduce healthcare staff refreshment policies and guidance nationwide	No – insufficient evidence to quantify impact on staff performance

#3.4 Adapt working patterns and staffing

Description: Introduce protocols to adapt working patterns and staffing structures in periods of extreme heat. For example, making use of national systems to integrate heat alerts into healthcare staffing protocols to allocation workforce resources across hospitals, emergency services, and primary care, and link to dynamic staffing rosters that can flex staffing levels in response to heat event forecasts. This would allow real-time adjustments across clinical and non-clinical teams to manage demand surges without compromising care quality.

UK approach: In England, the NHS uses the Operational Pressures Escalation Levels (OPEL) system to manage service pressures, particularly during winter. It defines four levels of operational strain, each with escalating staffing responses. The Integrated OPEL Framework (2024–2026) covers a broad range of NHS services; however, it does not explicitly cover heat scenarios. Staffing during extreme heat remains locally discretionary and reactive, which may lead to uneven preparedness and lack of coordinated resource planning.

The NHS in England also uses electronic rostering tools like HealthRoster, mainly for winter pressures and routine scheduling. These systems do not systematically include heat-specific triggers or predictive data into workforce planning. During peak times, the NHS often relies on

bank and agency staff to temporarily increase their workforce, amounting to an annual bill of approximately £10.4 billion[233] (£5.8 billion for bank staff, £4.6 billion for agency).

International examples and evidence: In the United States,[234] a large emergency department implemented a two-stage prediction-driven nurse staffing framework. This system utilizes real-time data, including weather forecasts and historical patient volumes, to forecast staffing needs. Adjustments are made 24 hours in advance, enabling proactive staffing decisions that optimise costs while maintaining patient care quality. In Italy,[235] national and regional health services have incorporated heat-health alerts into hospital response protocols, linked to improved emergency department performance. In Australia,[236] health systems use flexible workforce deployment strategies informed by heat-health forecasting.

#2.5 Targeted staff training / responsibilities on heat events

Description: Develop and deliver specialised training modules for healthcare staff on identifying, managing, and preventing heat-related illness. This includes clinical knowledge and guidance on self-care and occupational health during high-heat conditions.

UK approach: The Adverse Weather Health Plan provides guidance on roles for frontline clinical, community, or support staff during heat events.[237]

International examples and evidence: In South Korea,[238] the national heat event response policy includes targeted staff training across emergency departments and primary care. Training modules are mandatory during onboarding and refreshed seasonally. They cover clinical management of heatstroke and dehydration, communication protocols for vulnerable patients, and occupational self-care. In high-risk zones, simulation drills are conducted in partnership with local emergency services.

#2.6 Introduce healthcare staff refreshment policies and guidance nationwide

Description: Establish national standards requiring healthcare employers to ensure staff access to hydration, rest areas, shade, and appropriate attire during periods of extreme heat. This could be included as part of Duty of Care commitments from employers. These measures aim to protect workforce health and maintain service continuity.

UK approach: In England, some NHS trusts ensure hydration via 24/7 access, electronic tracking, staff support, and training. Strategies include protected mealtimes, personalized care plans, food

[233] The Guardian (16 January 2024) "NHS across UK spends a 'staggering' £10bn on temporary staff" Link
[234] Hu et al (2025) "Implementing a prediction driven framework for emergency department nurse staffing to optimize real time decisions", Link
[235] Alfano et al (2024) "Addressing heatwave impacts on hospital admissions in an Italian region", Link
[236] ACEM (2023) "Heatwave preparedness for emergency departments and emergency medicine systems", Link
[237] UK HSA (2025) "Adverse Weather and Health Plan Protecting health from weather related harm", Link
[238] Lee et al (2024) "Timely accessibility to healthcare resources and heatwave-related mortality in 7 major cities of South Korea: a two-stage approach with principal component analysis", Link

as fluid, and risk screening. However, most nutrition and hydration strategies focus on patients rather than staff (see, for example, King's,[239] Guy's and St Thomas'.[240]).

International examples and evidence: In the US, OSHA mandates employer actions to protect against heat stress, including water, rest, and shade. Australia and Canada have WHS laws and occupational health standards with similar provisions. However, many of these policies are generalised across professions and not tailored to healthcare staff.

H.3.2 Cost and benefit estimations and parameters

The costs of increasing staff availability during heat events can be quantified as additional labour expenses (opex), plus upfront recruitment expenses and a fixed administrative cost. Expanding staff availability to a) meet excess demand, and b) compensate for heat-related staff absences and productivity losses during hot days, involves increasing hours of existing nurses and doctors or hiring additional staff. Taking heat into account in and adapting working patterns and staffing and design will have an upfront cost, namely a one-off expense associated with the policy change and initial hiring effort, and per-head recruiting costs. No repex is envisioned. Moreover, operational expenses in the form of increased wage payments for healthcare staff are incurred. The cost calculation is explained below:

- 1: Estimate **additional annual labour costs (opex)** with adapting working patterns and staffing
    - 1.1: Quantify *additional healthcare staff hours required* to meet excess demand, and compensate heat-related staff absences (2.2% on hot days)[241] and productivity loss (non-linear function of temperature)[242] using the microsimulation model
    - 1.2: Quantify *hourly cost of healthcare staff* when increased supply is met predominantly with full-time staff. The average hourly wage of NHS staff is £17.19, calculated from NHS pay scales,[243] and workforce composition statistics for England,[244] Wales,[245] Scotland,[246] and Northern Ireland.[247] Additionally, the NHS must pay employer pension contributions, NICs, overheads for staff and sickness pay, jointly making up approximately 50% of pay.

[239] Kings College Hospital (2025), "Nutrition and Hydration Strategy 2025-2030", Link
[240] Guys and St Thomas, "Nutrition and Hydration Strategy 2023 2026", Link
[241] Davey et al (2024) "Prevalence of occupational heat stress across the seasons and its management amongst healthcare professionals in the UK", Link
[242] Seppänen et al (2006) "Room Temperature and Productivity in Office Work", Link
[243] NHS Employers (20 August 2024) "Pay scales for 2024/25", Link
[244] NHS England (27 Mar 2025) "NHS Staff Earnings Estimates, December 2024", Link
[245] Government of Wales (19 March 2025) "Staff directly employed by the NHS: as at 30 September 2024", Link
[246] NHS Scotland (04 March 2025) "NHS Scotland Workforce 31 December 2024", Link
[247] NISRI (19 February 2025) "Northern Ireland Health and Social Care - Quarterly Workforce Statistics - 31 December 2024", Link

    - 1.3: To get *total additional labour costs*, multiply additional required staff hours with average hourly cost of NHS staff
- 2: Estimate **additional recruitment costs (upfront cost)**
    - 2.1: Compute the *number of FTE positions that need to be filled* to meet the additional healthcare staff hours.
    - 2.2: Quantify *per-employee recruitment cost.* This is estimated to be in the region of £3,500.[248]
    - 2.3: Estimate *one-off administrative cost* for adapting working patterns and staffing. This upfront expense captures any costs associated with including heat as a consideration in the NHS staffing rosters and working hours, similar to how this has been done with cold/flu season. This fee has been approximated as £10 million.
    - 2.4: Get *total recruitment cost* by multiplying the number of FTE positions with per-employee recruitment expense and adding the one-off admin fee.

For increasing staff availability during heat events, the benefits can be quantified as opex savings compared to calling on temporary agency and bank staff. This includes policy level and facility level implementation so covers both #2.2 and #3.4. The benefit mechanism is based on the cost savings when meeting additional staffing requirements during heat events with employed NHS staff rather than temporary workforce. The underlying assumption is that the excess demand for healthcare is met – either through changing (permanent) staffing systems, or through increased use of temporary (agency and bank) staffing. The alternative – to not increase staffing to meet excess demand, in which case health care outcomes would deteriorate – is not modelled.

- A: Estimate **annual labour cost savings (opex savings)** compared to not adapt working patterns and staffing
    - A.1: Quantify the *additional healthcare staff hours required* (same estimate as in 1.1)
    - A.2: Quantify *hourly cost of healthcare staff* when increased supply is met predominantly with agency and bank staff (i.e. in the absence of adapted working patterns and staffing).

[248] https://www.oleeo.com/blog/recruitment-costs-in-nhs/

        - Pay premium for bank staff,[249] compared to full-time staff[250] (incl. employer contributions): 27%
        - Pay premium for agency staff compared to full-time staff (incl. employer contributions): 55%[251]
        - Proportions of agency compared to bank staff are fixed at current levels, namely 61% bank vs 39% agency staff hours (calculated based on relative expenditure shares[252] and pay premia above)
        - This gives an estimated average hourly cost of £34.75 for temporary staffing.
    - A.3: To get *total labour cost savings* of adapt working patterns and staffing compared to relying on bank and agency workers, multiply additional required staff hours with average hourly cost of temporary staff. These are the "benefits" of adapting working patterns and staffing, as expenses on bank and agency staff would be saved.

Finally, costs and benefits of increasing staff availability are augmented to reflect more realistic estimates. Both options (adapting working patterns and staffing and do nothing) are likely to draw on a mix of full-time vs temporary staff. In a future without adaptation, 10% of additional healthcare hours are met with full-time staff compared to bank and agency staff in line with staffing responses of current capacity constraints. By contrast, the adaptation bundle includes staffing improvements which means that 75% of additionally required healthcare hours can now be met in-house. Cost and benefit estimates are then calculated as a weighted average of steps 1. and A. in the calculations described above.

Co-benefits and co-costs of adapting working patterns and staffing are not quantified as part of this piece of work. The cost of increasing NHS healthcare supply during heat events with full-time staff is measured, but quantifying the costs and benefits of keeping them employed all year is beyond the scope of this project. An increase in full-time employees is likely to be beneficial year-round, supporting the healthcare system during winter flu spikes and to decrease its waiting-list backlog; however, it offers less flexibility than relying on bank and agency temporary staffing during peak season.

[249] Frimley Health NHS Foundation Trust (2024) "Agenda for Change Bank Rates (effective 1 April 2023)", Link
[250] NHS Employers (20 August 2024) "Pay scales for 2024/25", Link
[251] https://www.england.nhs.uk/long-read/agency-rules/
[252] Guardian (16 January 2024) " NHS across UK spends a 'staggering' £10bn on temporary staff", Link

H.4 Supply Side – NHS Building Stock

A major challenge for defining and quantifying building stock adaptation measures is the absence of a baseline on the condition of the existing building stock. There is no detailed baseline study of the availability and performance of active or passive cooling, or current temperatures within hospitals on heat event days. As with care home related measures, an 'Immediate Action' should therefore be to review existing evidence from the Estate Returns Information Collection (ERIC) database (in England, and similar analysis should be carried out in the other UK nations),[253] and carry out a more detailed review of building stock of NHS trusts related to cooling and heat-readiness, for regions expected to be high and medium risk by 2030.

The other unknown is how many new build hospitals should be expected between now and 2050. Uncertainty around the plans of successive governments makes it challenging to predict the number and locations of future hospitals. However, there is information on planned major capital spends in the New Hospital Programme,[254] which gives a good indication of how much major retrofits and capacity additions to the NHS Estate are expected to cost. Given that new hospital facilities will need to include heating by design, the marginal impact of adding in cooling measures are likely minimal, particularly if air source heat pumps are used.

The NHS 10-year plan sets out some guidance related to retrofitting for heat, alongside the drive to reduce carbon emissions. Integrated Care Systems (ICSs), while developing a ten-year infrastructure strategy, are required to identify sites with a risk of overheating. This ensures investment in new buildings or retrofitting to tackle heat-related pressures, including both active and passive cooling measures.[255] Moreover, new buildings and major refurbishment projects must align with the NHS Net Zero Building Standard, meaning that any retrofitting must be a part of the broader decarbonisation strategy. However, the source of funding for this, or the timelines for implementation, are not addressed.

The NHS has developed a climate change risk assessment tool which can support ICSs, individual hospitals, and other stakeholders to assess and react to their specific risks. This tool works to help organisations identify and evaluate their specific climate risks, relating to the sites and services they offer. The tool enables an assessment of impacts of climate risks, including heat, on factors such as health service demand, essential supplies, equipment, infrastructure, and staff and patients. The tool helps organisations to identify and evaluate local climate risks specific to NHS sites and services, facilitating collaboration among various workforces and teams involved in climate change adaptation and resilience planning.

[253] NHS England "Estate Returns Information Collection", Link
[254] UK Department of Health and Social Care (20 January 2025) "Policy Paper - New Hospital Programme: plan for implementation", Link
[255] NHS Guidance on developing a 10-year infrastructure strategy, https://www.england.nhs.uk/long-read/guidance-on-developing-a-10-year-infrastructure-strategy/

Unit cost multipliers are developed based on known characteristics of healthcare facilities. Data at regional level on the number of NHS Trusts, square metres of building, age of buildings and projected population growth will be used to estimate unit cost multipliers. This represents a combination of increasing capacity (new hospitals, or new capacity added to existing sites) and retrofitting existing facilities.

Heat within health settings has a wide range of impacts, including on patient mortality and morbidity, length of stay and occupancy, and staff productivity and well-being. To mitigate these effects, procedures can be put in place to better monitor, control or reduce the indoor temperatures of hospital buildings. These policies can range from establishing heatwave plans within the hospital, through to complete retrofits or rebuilds of hospital buildings. Current recommendations for healthcare facilities suggest general wards be between 18ºC and 28ºC, and more sensitive areas between 18ºC and 25ºC. In England, between 2023-2024, there were 4,551 instances of overheating above 26ºC reported in NHS buildings, 26% higher than in 2019-2020.[256] Beyond this point, a risk assessment is triggered for vulnerable patients and staff.

H.4.1 Included in this bundle

#	Measure	Costs and benefits estimated
2.3	Building code / design for all new build facilities	No – costs are marginal on newbuild buildings
2.4	Retrofit policy	Yes – set out below
3.1a	Low intensity cooling (e.g. low-cost passive cooling)	Yes – set out below
3.1b	High intensity cooling (e.g. full climate control with A2A heat pumps)	Yes – set out below
3.2	Medium intensity cooling (e.g. dedicated cooling stations)	Yes – set out below
3.5	Heat and humidity monitoring	No – costs are marginal, baseline monitoring is unknown, and benefits are felt only through adapted behaviour
3.8	Increase maintenance & facilities management during heat alerts	Yes – set out below

H.4.2 Benefits estimation and parameters

Three main benefits to reducing heat within hospital settings are considered:

[256] NHS England Estates Returns Information Collection, https://digital.nhs.uk/data-and-information/publications/statistical/estates-returns-information-collection/summary-page-and-dataset-for-eric-2023-24

1. *Reduction in mortality within a hospital setting.* For patients already in hospitals, mortality increases during heat events.[257] Using the number of heat-related annual excess deaths estimated in the microsimulation model, together with the share of deaths occurring in hospitals (43%)[258], the reduction in mortality risk from being fully cooled (60%)[259], and an assumption on the effectiveness of passive cooling (60%).
2. *Decreased duration of stay of patients, and reduced hospital congestion.* Evidence is limited and mostly from outside the UK. For example, evidence from Hong Kong shows that for older adults with respiratory conditions in hospitals, extreme heat beyond 29.4ºC (30.4ºC) adds an extra 4 (5) days in hospital annually.[260] Using the insights from this paper, together with modelled findings regarding the number of hot days beyond the mentioned thresholds and the standard hospital bed cost per day of £345, [261] we estimate the reduced cost of patient stays to the NHS.
3. *Reduction in heat-related staff absences and productivity losses.* Occupational heat stress impairs healthcare professionals' performance and leads to heat-related absenteeism in the UK. On hot days, NHS staff absences are approximated to be 2.2% higher than usual[262]. Moreover, an estimate of the non-linear relationship between indoor temperature and performance has been established in the literature,[263] which, together with a translation mechanism between indoor and outdoor temperature,[264] can be used to estimate staff productivity losses. For example, a 40ºC outdoor temperature implies an average indoor temperature of 30.6ºC in NHS buildings, leading to a 26% reduction in staff productivity.

These benefits occur according to the degree of heat reduction within hospitals. The measures below set out the potential means to achieve this, and the scale of likely impact.

H.4.3 Cost estimation and parameters

Retrofit policy

The regional cost for each hospital site to develop a retrofit policy is based on an assumed cost of £100,000 per hospital, therefore varying according to the number of hospitals within the

[257] Stafoggia et al (2008) "Factors affecting in-hospital heat-related mortality: a multi-city case-crossover analysis", Link
[258] ONS Dataset, accessed May 2025 "Deaths registered in England and Wales", Link
[259] Bedi et al (2022) "The Role of Cooling Centers in Protecting Vulnerable Individuals from Extreme Heat", Link (source states 66%, but this analysis uses 60% to account for potential cooling solution malfunctioning or power outages)
[260] Long et al (2024) "Association between ambient temperature and increased total length of hospital stay of patients with cardiopulmonary disease in Hong Kong", Link
[261] UK Parliament (14 March 2024) "Written questions, answers and statements", Link
[262] Davey et al (2024) "Prevalence of occupational heat stress across the seasons and its management amongst healthcare professionals in the UK", Link
[263] Seppänen et al (2006) "Room Temperature and Productivity in Office Work", Link
[264] Nguyen et al (2014) "The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity", Link

region. The estimate is loose, based on the staffing cost for someone to deliver the policy, any external work to estimate the costs of alternate approaches, and the cost of meetings over a 12-month period to ensure hospital wide consultation and consideration. As this is a policy and not implemented actions, there is no direct impact on heat within facilities. However, the policy should be seen as an enabler for subsequent actions.

#3.1a Low intensity cooling (e.g. low cost passive cooling measures)

Low intensity cooling measures would mean implementing the best available low cost and feasible cooling measures at each site. This could be a combination of passive (e.g. shades and internal blinds) and active cooling (e.g. small portable air conditioning units), targeted to rooms and wards with the highest need in terms of high temperatures and vulnerable patients. This would need to be done carefully and in a package alongside decarbonisation objectives.

To provide a reasonable illustrative costing of this low-intensity cooling retrofit, two specific passive cooling measures are combined. This does not mean that these are the only, or right, measures that would be deployed at each site, nor that only passive cooling measures should be deployed in this first sequence of low-intensity cooling measures.

- *External insulation:* This reduces unwanted heat transfers. Expenses are estimated per m^2 of external wall, using technical estimates of cost (£75 per m^2),[265] and an assumed ratio of wall-to-internal floor area (40%).
- *External shading, specifically, shutters*: These are estimated using technical estimates of costs per m^2 of window (£260)[266], and an assumed ratio of window-to-floor area (10%)[267]. The internal floor area of buildings is available from the ERIC database and currently stands at approximately 35.8 million m^2.

The precise costs of delivering on these will depend on the hospital structure, and so these are broad estimates. Other passive and active cooling measures may be better suited to particular structure, and the hospital retrofit policy should be able to determine these. However, these two measures are widely recognised in the literature as being important for hospital cooling retrofits.

The impact of low-intensity cooling is likely to be quite variable from one site to another. External shading has been shown to reduce heat by 2°C on hot days,[268] rising to 4°C on peak heat days.[269] Estimates from Europe suggest that the impact can be greater still. To capture this variation, a mean of 3°C degrees is assumed. External insulation estimates are harder to come

[265] UK BEIS (2017) "WHAT DOES IT COST TO RETROFIT HOMES? Updating the Cost Assumptions for BEIS's Energy Efficiency Modelling", Link
[266] https://www.checkatrade.com/blog/cost-guides/window-shutter-installation-cost/
[267] Isaacs (2024) "'The window area shall be at least one-tenth of the area of the room': The origins of a daylight (and ventilation) requirement in modern building codes", Link
[268] https://enviroblinds.co.uk/external-shading-helps-staff-and-saves-energy-at-eastbourne-district-general-hospital/
[269] Alawadhi (2012) "Using phase change materials in window shutter to reduce the solar heat gain", Link

by, but it is known to have a smaller impact than shutters,[270] although the difference is not substantial; a 2°C degree reduction is assumed. Together with a translation mechanism for outdoor to indoor temperature and an assumed ideal temperature of 21°C,[271] and data on temperature distributions from CMIP6, this leads to an approximate cooling effectiveness of 60%.

#3.1b High intensity cooling (e.g. full climate control with A2A heat pumps)

While low intensity cooling likely represents a no- or low-regrets adaptation measure, it will not go far enough in some sites in reducing the risks associated with extreme heat. For some hospitals, as heat risks increase, a higher intensity of cooling may be optimal, where it can deliver further benefits in reducing health risks to patients and in supporting health care workers to carry out their functions.[272] High intensity cooling would involve a more complete rollout of large active cooling to reduce temperatures, such as air-to-air heat pumps, and major passive cooling works (such as fitting external shutters to buildings). These may be costlier than the low intensity measures and so would not be recommended in all settings in the short- to medium-term. Given the need to decarbonise the NHS estate, heat pumps may be a preferrable solution and would be consistent with decarbonisation plans.

These estimates are approximate and are intended to provide a reasonable UK-wide costing of the cooling needs to respond to extreme heat. The actual cost of implementing high intensity cooling throughout a hospital building will be specific to each site.

The cost estimates below are based on installing fixed (permanent) air-to-air heat pumps. For regions that at are relatively lower risk of extreme heat, it may be more cost effective to (at least initially) deploy smaller mobile air conditioning units.

First, we estimated the capital costs of implementing high intensity cooling:

- Map the regional breakdown of hospitals by size (floor space) and age to the 12 regions of the UK which are assessed for their extreme heat vulnerability.[273]
- An average capital investment cost of £487.10 per kW.[274]

[270] Lalor and Gillich (2014) "Retrofitting a Fifth Generation District Heating and Cooling Network for Heating and Cooling in a UK Hospital Campus", Link
[271] Nguyen et al (2014) "The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity", Link
[272] ARCC Network "Maintaining thermal comfort in hospitals with ventilation & good design", Link
[273] For England, we use NHS England "Estate Returns Information Collection", Link
For Wales, we use the Welsh Health Board's "Estates Condition Final Internal Audit Report", Link
For Scotland, we use NHS Scotland "Annual State of NHS Scotland Assets and Facilities 2020 Performance Report", Link
[274] Eunomia (2023) "The Cost of Heating Appliances: A Comprehensive UK Database" (2023), Link

- Base the efficiency of cooling units on heat loss coefficients, assumed for new NHS estate buildings to be 60 watts per square metre, rising to 120 watts per square metre for older buildings.[275,276]
- Adjustments to reflect inefficiencies:[277]
    - Assume 80% efficiency of units on extremely hot days
    - Assume 85% efficiency in terms of space cooled – i.e. there will need to be slightly more units than in a perfectly designed space
    - Capacity buffer of 20% to ensure there is headroom in the systems to respond to extreme heat.
- From these data-points we estimate the cost per square metre of:
    - £51.58 for new buildings (<20 years old), where heat loss is assumed to be 60 W/m^2.
    - £77.36 for buildings between 20 and 50 old, where heat loss is assumed to be 90 W/m^2.
    - £103.15 for old buildings (>50 years old), where the heat loss is assumed to be 120 W/m^2.
- Where a hospital implements active cooling, it does so for the whole hospital, and all the capital costs of installation are included here.

Secondly, we triangulate our estimates against examples of investment in active cooling technologies at a specific NHS site.

Charing Cross Hospital used a £26.9 million grant to install an air-to-water heat-pump to serve the facility. The site has a floor size of 118,508 m^2, of which 80% dates from more than 50 years ago. The £26.9m corresponds to £250 per square metre. While this is 2.5 times our estimated cost per square meter for, that is because air-to-water (i.e. providing heated water not only heated air) heat pumps are 2.7 times costlier in the costing database we have used, while we are costing air-to-air heat pumps.[278,279]

Finally, we estimate the recurrent expenditure associated with capital maintenance and running costs.

Additionally, high-intensity cooling incurs operating costs through electricity consumption of the units on hot days. These are estimated from the literature as follows:

[275] Based on the lower and upper limits for University buildings (no health centre data points were identified) from https://remars.co.uk/heating-cooling-loads/

[276] The reason we use the heat loss coefficients, rather than cooling load, is because the costing source we are using from Eunomia is based on investment need for heat pumps based on heating requirements, which we are then adapting to arrive at a capital investment requirement for the same units, but based on sizing needed for their cooling functionality.

[277] Assumptions, based on desk research to allow for inefficiencies inherent in these systems

[278] Eunomia (2023) "The Cost of Heating Appliances: A Comprehensive UK Database" (2023), Link

[279] The comparison is not direct, as the Eunomia data expresses capital costs per kW, whereas our calculations are per floor space

- Maintenance of 5% of the initial capital cost per unit per unit per year.[280]
- Hourly running cost: using electricity cost projections for the commercial sector,[281] EER (cooling kW / input kW) of 3.5, and room cooling capacity of 5kW
- An assumed 16 hours required cooling per hot day.

#3.2 Medium intensity cooling (e.g. dedicated cooling stations)

A more cost-efficient, intermediary approach between low intensity and high intensity cooling measures may be targeted active cooling within healthcare facilities, in particular areas of the hospital. That could be with regard to critical infrastructure – for example data hubs – or with regard to patients – in much the same way that intensive care units and operating theatres often might have a higher degree of temperature control then the rest of hospital buildings.

For this study, medium intensity cooling is costed on the (illustrative) basis of cooling an additional 5% of internal floor space in a hospital to provide rooms where particularly vulnerable patients can be transferred. This may of course not be feasible in all building contexts but could be explored as an alternative to having to cool entire facilities to the same extent.

The costing is otherwise estimated as per hospital-wide active (high intensity) cooling, with roll out dedicated cooling stations as per suggested schedule results in the following expenses. Dedicated cooling stations are assumed to be able to reduce temperatures from external highs through to the desired 21°C.

#3.8 Increase maintenance & facilities management during heat alerts

A simple estimation of the cost of maintaining facilities during heat alerts is calculated using typical costs for a day's contractor, scaled according to the size of the hospital. The following estimates are used to cost increased maintenance during heat alerts:

- Labour: Daily rate for additional maintenance staff (including overheads) of £350.
- Coverage: Each contractor is assumed to cover approximately 50,000 square metres of hospital floor area.
- Scale: Estimated number of days of extreme heat by region.

This estimate does not capture the intricacies of whether extra maintenance could be done in-house with staff diversion, however it does provide a view to the opportunity cost if that were the preferred approach. Increased maintenance can include temperature checks for particular infrastructure, or ensuring vents and windows are opened to maximise efficiency of any cooling potential within the buildings.

[280] Assumption, noting this works out as roughly equivalent to the Eunomia maintenance estimate of £300 per unit per year

[281] https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.theccc.org.uk%2Fwp-content%2Fuploads%2F2025%2F05%2FThe-Seventh-Carbon-Budget-methodology-accompanying-data-v2-2025.xlsx&wdOrigin=BROWSELINK