

Climate Change Committee

Heat risk and adaptation in the urban built environment

An analysis of impacts on health and productivity in the UK's towns and cities.

May 2026



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Glossary

Active cooling	Mechanical cooling systems such as air-conditioning.	Dry bulb temperature (DBT)	The true ambient air temperature, measured without accounting for humidity, wind, or solar radiation. In this document it is referred to as "air temperature".
Adaptation measure	Physical or operational action to reduce heat risk.	Dynamic thermal modelling (DTM)	Indoor climate/building simulations.
Adaptation package	Grouped set of adaptation measures modelled together (A–F).	ERA5	A global climate reanalysis dataset providing historical temperature conditions used to define baseline heat hazard.
Baseline	No pro-active heat adaptation scenarios for 2022 (present day), 2030s and 2050s.	Exposure	The presence of people or workers who are subjected to hazardous heat conditions in a given location.
Benefit–cost ratio (BCR)	An economic measure comparing expected benefits of adaptation to total implementation cost.	Extreme year	A year with intense heat events.
Blue infrastructure	Water-based cooling features such as ponds or fountains that lower local temperatures through evaporation.	Green infrastructure	Green infrastructure refers to networks of natural or planted features that deliver cooling.
Building archetype	Representative buildings used in modelling: terrace, semi-detached, flat, office.	Gross value added	An economic measure of productivity used to quantify financial losses from heat-related disruption.
Capex / opex / repex	Capital, operating and replacement costs.	HadUK Grid	A high-resolution UK climate dataset produced by the Met Office, used in this study to model present day temperature patterns and heat exposure.
Capital expenditure (capex)	Investment in physical assets or infrastructure to implement heat adaptation measures.	Hazard	The potential occurrence of a natural physical event or trend that may cause harm.
CIBSE weather files	TMY (Typical Meteorological Year) and DSY2 (Design Summer Year) weather files for baseline present and future modelling.	Heat-related mortality	Excess deaths statistically attributable to high temperatures. These are the number of deaths from heat during a specific period that exceed the expected, "normal" number of deaths based on historical data.
Climate scenario	A projected trajectory of future temperature conditions used to model future heat risk.	International Territorial Level 3 (ITL3)	A regional classification system used for productivity analysis.
Co-benefits	Wider benefits from implementing adaptation measures, such as carbon sequestration, recreation, biodiversity, stormwater mitigation.	Local Climate Zones (LCZ)	International scheme classifying urban form/land cover; basis for UK typologies.
Design summer year	These are warmer than typical summers, used as weather files from CIBSE to assess overheating risk. There are three variations: DSY1: A moderately warm summer (approx. 1-in-7 year return period). DSY2: A summer containing a short, intense warm spell. DSY3: A summer containing a long, less intense warm spell.		

Lower layer super output area (LSOA)	A statistical geographic unit used for high-resolution analysis of heat impacts across the UK.
Multi-criteria analysis (MCA)	A structured decision-making tool used to shortlist and prioritise adaptation measures across impact, cost and feasibility.
Nature-based solutions (NBS)	Green/blue infrastructure delivering cooling and co-benefits.
Operating expenditure (opex)	Ongoing running costs of heat adaptation measures.
Passive measures	Non mechanical building/urban cooling actions.
Present value (PV)	Discounted value of future costs/benefits.
Productivity loss	A reduction in work capacity or hours worked due to heat stress, measured in lost hours and associated GVA loss.
Replacement expenditure (repex)	Investment in replacing expired or ageing heat adaptation assets.
Risk	The potential for adverse consequences. In this context, from high temperatures.
Surface Urban Energy & Water Balance Scheme (SUEWS)	Urban climate model for outdoor heat and adaptation effects.
Typical year / typical meteorological year	A representative climatic year used to assess average heat conditions.
UKCP09 / UKCP18	UK climate projections produced by the Met Office; UKCP09 files used in modelling.
Urban heat island (UHI)	Towns and cities being warmer than surrounding rural areas due to dense buildings, paved surfaces and low vegetation trapping heat.
Urban typology	Classification of UK urban areas used to run urban climate modelling consistently nationwide.

Value of a life year	An economic valuation metric used to monetise avoided mortality attributable to heat adaptation.
Vulnerability	The sensitivity of people or sectors to heat impacts, influenced by age, health or job type.
Wet-bulb temperature (WBT)	Wet-bulb temperature (WBT) is the lowest temperature that air can reach through the process of evaporation. It represents the combined effect of air temperature and humidity.
Wet bulb globe temperature (WBGT)	A heat-stress index combining air temperature, humidity and solar radiation, used to estimate impacts of heat on productivity.
Years of life lost	A metric estimating premature mortality by calculating years lost relative to expected remaining life expectancy.

Table 1: Glossary of terms

Acronym	Full wording
ABDE sectors	Agriculture, forestry & fishing; Mining, quarrying & utilities
BCR	Benefit–Cost Ratio
Capex / Opex / Repex	Capital / Operating / Replacement costs
CCC	Climate Change Committee
CCRA4 - IA	4th Climate Change Risk Assessment – Independent Assessment
CIBSE	Chartered Institution of Building Services Engineers
DBT	Dry-Bulb Temperature
DSY2	Design Summer Year 2
DTM	Dynamic Thermal Modelling
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA5	ECMWF Reanalysis 5
GLA	Greater London Authority
GVA	Gross Value Added
HadUK Grid	Hadley UK Grid
ITL3	International Territorial Level 3
LCZ	Local Climate Zones
LSOA	Lower Layer Super Output Area
MCA	Multi-criteria analysis
NBS	Nature-Based Solutions
NCRAT	Natural Capital Register and Account Tool
OBR	Office for Budget Responsibility
ONS	Office for National Statistics

Acronym	Full wording
ORVal	Outdoor Recreation Valuation tool
PV	Present Value
SUEWS	Surface Urban Energy & Water Balance Scheme
TMY	Typical Meteorological Year
UHI	Urban Heat Island
UKCP09 / UKCP18	UK Climate Projections 2009 / 2018
UKHSA	UK Health Security Agency
VOLY	Value of a Life Year
WBGT	Wet-Bulb Globe Temperature
YLL	Years of Life Lost

Table 2: Acronyms



Overview: Key messages and outcomes of this study

Why heat matters in the UK

Extreme heat is one of the fastest-growing climate risks facing people living and working in UK towns and cities. Recent summers have repeatedly broken national temperature records, with 2022 marking the first time the UK exceeded 40°C, causing over 3,300 excess deaths from heat in England and Wales [1]¹. Hot conditions are no longer unusual – climate change is making them more frequent, more intense and more harmful.

The impacts are already visible. Hot weather worsens underlying health conditions, drives excess deaths and affects the most vulnerable people first – older adults, children, those with chronic illnesses, and people experiencing deprivation or disadvantage. Heat also reduces productivity, disrupts transport networks, places strain on essential services, and intensifies other environmental conditions, such as air pollution, water scarcity and biodiversity decline.

The impact of heat is felt more intensely in urban areas. High building density, paved surfaces and limited green space - combined with heat generation from human activities - can make towns and cities several degrees warmer than surrounding areas.

As the UK continues to urbanise and the climate warms, understanding heat risks – and the options for adaptation - has become essential.

Objectives of this study

This study was commissioned by the Climate Change Committee (CCC) to determine how the UK's urban built environment can be adapted to escalating heat risks. The analysis was designed to identify the most cost-effective strategies for reducing heat-related mortality and economic productivity losses in UK towns and cities. The evidence generated has informed the UK's 4th Climate Change Risk Assessment (CCRA4-IA), supporting robust, evidence-based policy and investment decisions.

The study answered four core questions:

What is the present and projected future risk from urban heat in the UK, in terms of health (mortality) and economic productivity? The study examined heat-related mortality and productivity losses, capturing how these vary between regions, sectors and age groups.

How do adaptation needs vary between regions, urban typologies, and climate scenarios? The study developed five adaptation packages comprising building and urban-scale heat adaptation measures that reflect different levels of ambition, cost and complexity.

Which adaptation actions and packages deliver the greatest benefits, and how should they be sequenced over time? The study evaluated a wide range of building-scale and urban-scale measures – from shading and insulation to green spaces and active cooling.

Which adaptation package provides the greatest value for money for the UK to reduce heat-related mortality and productivity losses? A cost-benefit analysis identified a proposed cost-effective strategy and explored how rollout could be staged across the UK.

This analysis focused intentionally on heat-related mortality and productivity impacts. These metrics enable a consistent national-scale assessment, while also allowing sufficient spatial resolution for locally-specific conclusions to be drawn. The proposed adaptation measures have focused on physical interventions for buildings and the urban realm. It is acknowledged, however, that heat has wider impacts and can be addressed through a broader suite of measures beyond those considered here, including public health interventions such as heat-health warning systems, community outreach, behavioural guidance and healthcare preparedness, which were outside the scope of this study.

As with all modelling of complex urban and environmental systems, results are subject to uncertainty and should be interpreted as indicative rather than definitive. The analysis is intended to support informed decision-making by illustrating relative risks and the potential scale of benefits from adaptation, rather than to predict precise outcomes.

Headline findings

Heat risk in the UK is rising rapidly, affecting nearly all urban areas.

This analysis shows that the impacts of extreme heat on mortality and economic productivity are already significant and will intensify sharply under central projected climate scenarios corresponding to global mean temperature increases of 1.5°C warming in the 2030s and 2°C in the 2050s, in the absence of adaptation.

In 2022, the UK experienced the highest number of heat-related deaths on record, with older adults identified as particularly vulnerable. The analysis estimates around 4,000 heat-related deaths occurred in 2022, a figure that exceeds twice the number of road traffic deaths recorded in the same year [2]. Even in a typical UK summer, heat can still cause significant loss of life, causing an estimated 1,900 deaths per year across the UK according to this analysis ². Under present-day conditions, 80% of heat-related deaths occur in people aged ‘over 75’.

As the climate warms, if no action is taken annual heat-related deaths could triple by the 2050s, with an even sharper increase in extreme heat years (Figure 1). This study shows that the impact of extreme heat is projected to accelerate at a more-than-linear pace. Excess deaths in typical years may grow by 60% in the 2030s (3,000 per year) and 200% in the 2050s (5,700 per year). Extreme heat years may see heat-related deaths increasing to 6,100 and 13,000 per year over the same periods. The proportion of deaths occurring in the ‘over 75’ age group could rise to 90%, reflecting an ageing society combined with age-related vulnerability.

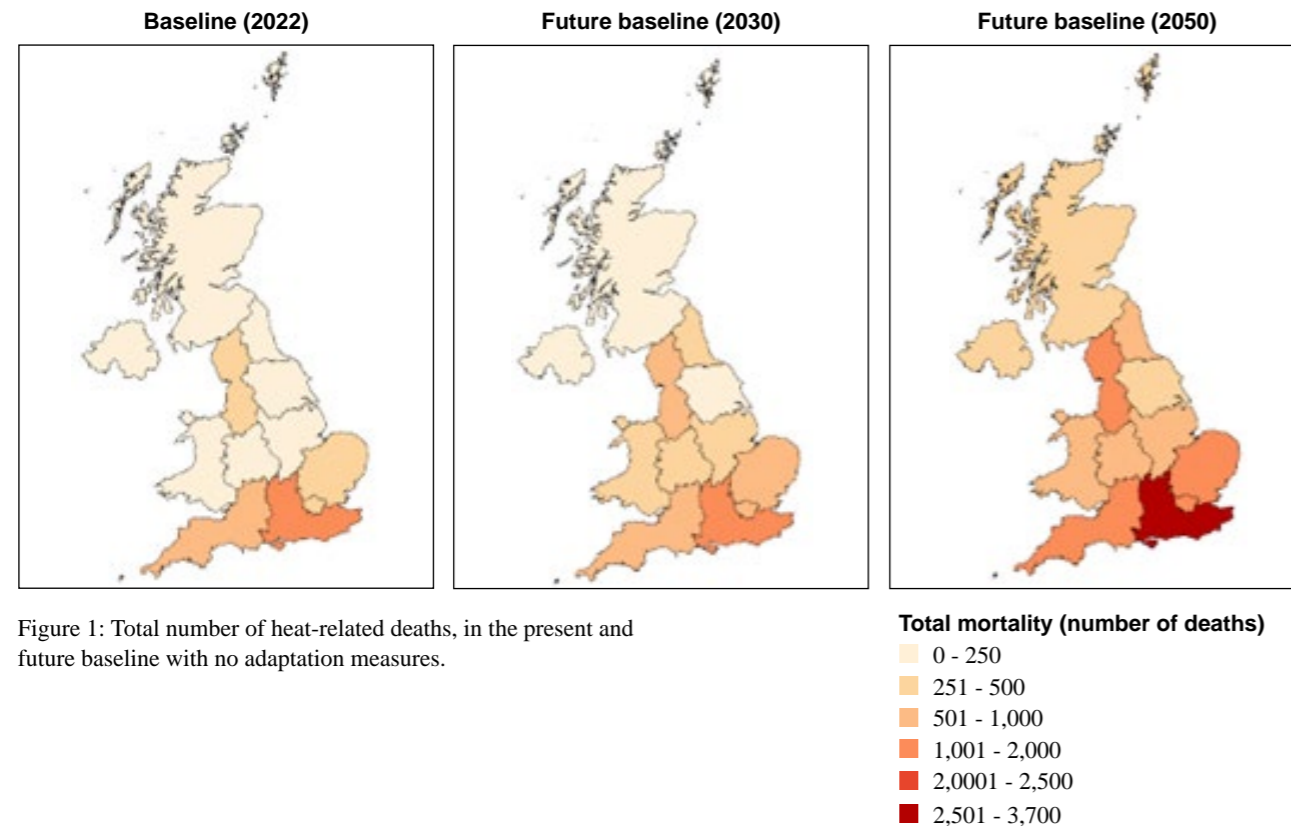


Figure 1: Total number of heat-related deaths, in the present and future baseline with no adaptation measures.

Increasing temperatures will have a growing impact on economic productivity. This analysis shows approximately 0.93 million working days were lost in 2022 due to extreme heat, costing the UK approximately £450 million in Gross Value Added (GVA). By 2030, heat-related losses are projected to increase to around 1.8 million working days in an extreme year, with associated GVA impacts of approximately £720 million. Looking ahead to the 2050s, heat-related lost working time is projected to increase substantially—around 3.6 times higher than in the 2030s, reaching up to 6.3 million lost working days—with GVA impacts rising by almost five-fold (4.6 times) over the same period to around £3.3 billion per annum in GVA. Even in typical years, heat can impact the UK economy, with impacts increasing from an estimated £200 million per annum today, to around £540 million per annum by the 2030s, and over £1.8 billion in the 2050s.

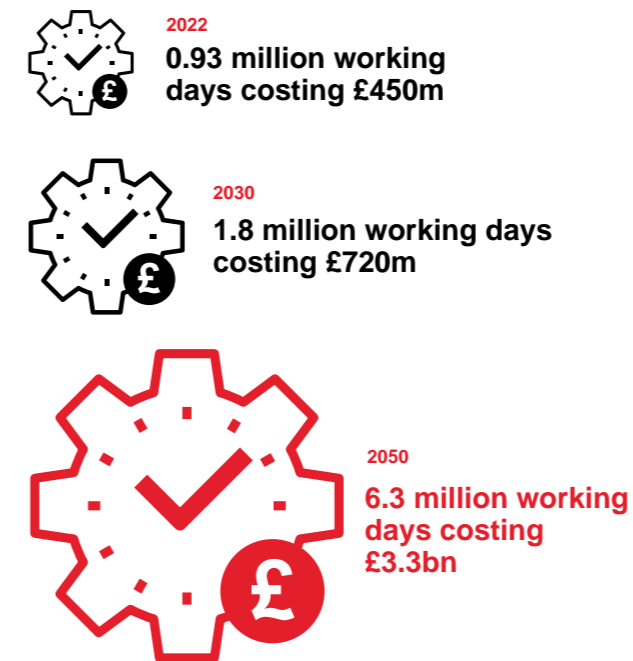


Figure 2 : Heat-related productivity loss from present day to the future.

As temperatures rise, higher productivity sectors will be significantly affected, bringing impacts for the UK economy. In the present day (2022), extreme urban heat primarily impacts the productivity of outdoor-based sectors, such as construction. However, without adaptation heat will increasingly exceed thresholds for indoor comfort, affecting higher productivity sectors such as professional services. This translates into an accelerated impact on the country’s economy.

Heat impacts are disproportionately felt across the UK.

The South East currently experiences the most heat-related deaths in the UK, and this trend is expected to continue into the future. By the 2050s, forecasts suggest that almost one-quarter of all heat-related fatalities in the country will occur in the South East (see Figure 1). The South East experiences higher baseline excess heat-related deaths per capita than other regions, driven by higher temperatures and an older population.

Heat will disproportionately impact the South of England’s economy, with Greater London accounting for up to 40% of the national heat-related productivity loss across all time periods. This is due to the high exposure to extreme temperatures, exacerbated by the urban heat island effect, and the density of high productivity jobs in the region. However, other urban areas in the country show significant impacts such as Bristol and Bournemouth.

Overall, the study reveals that 60% of monetised heat impacts on mortality and productivity in the UK are concentrated in only 30% of the country ³. Impacts are predominantly focused on the South East, South West, and London. Nevertheless, heat vulnerabilities exist across the UK, with communities nationwide expected to experience heat-related impacts—calling for country-wide action.

3x increase by the 2050s

Annual heat-related deaths could triple without adaptation.

Reducing heat risk through adaptation packages

A wide range of adaptation options exists to mitigate these risks: physical measures such as reflective roofs, insulation improvements, and large scale greening, and operational measures such as adjusting work hours, implementing cooling protocols, and providing public guidance during heatwaves. This study focused on physical adaptation measures, recognising their potential to provide lasting benefits. We modelled urban-scale and building-scale measures to determine the impact of adaptation on mortality, productivity, and associated monetised impacts.

A long list of measures was assessed through a multi-criteria analysis which defined different levels of impact (in terms of heat risk-reduction and co-benefits), cost, and implementation potential. These were then combined in five different packages reflecting different combinations of active and passive measures and different intensities of intervention (Table 3). Packages A-C focused on increasingly more comprehensive deployment of passive measures, including nature-based solutions at an urban scale. Package D and E focused on active cooling in residential buildings, with package E augmented by the selective use of

passive building-scale measures. All of the packages included air-conditioning in offices to mitigate indoor productivity losses, as well as construction shading to reduce productivity losses during outdoor work.

The analysis shows the effect of adaptation on mortality, productivity and associated monetised impact if these packages were rolled out in urban areas across the whole of the UK.

Adaptation measures can significantly reduce heat-related impacts on mortality and productivity across all future scenarios. Even the least intensive packages (A, B) can deliver measurable benefits, while the highest-impact packages (D, E) facilitate major reductions in both deaths and productivity losses.

Package	Details	Residential		Workplace		Urban scale
		Passive retrofit	Active cooling	Shading for outdoor workers	Active cooling	
A – Foundational	A lightweight package composed of quick win adaptation measures (low cost, low impact)	Light green circle	Grey bar	Light green circle	Light green circle	Grey bar
B – Enhanced	A medium package with quick wins and complementary measures	Dark green circle	Grey bar	Light green circle	Light green circle	Light green circle
C – Enhanced Nature	A more comprehensive package of actions combining nature-based solutions with urban and building cooling measures	Dark green circle	Grey bar	Light green circle	Light green circle	Dark green circle
D - Active Cooling	Focused on active cooling	Grey bar	Dark green circle	Light green circle	Light green circle	Grey bar
E – Integrated Cooling	Building-scale active cooling complemented by low-cost passive measures	Light green circle	Dark green circle	Light green circle	Light green circle	Grey bar

Table 3: Adaptation Packages defined for the study, and their associated measures. Dark green indicates a higher presence within the package; light green indicates a lower presence, and grey indicates no presence in the package.

The largest reductions in heat-related mortality are available through implementation of integrated adaptation packages (Figure 3). Passive measures (Foundational - Package A) reduce heat-related deaths by almost 180 per typical year in the 2030s (6% of the future baseline) when deployed across the UK, rising to almost 290 per year by the 2050s. By comparison, incorporating nature-based measures across the UK (Enhanced Nature – Package C) reduces deaths by a third on the baseline, avoiding over 1,000 deaths per year in a typical year in the 2030s and more than 2,000 deaths per year by the 2050s, reflecting the combined impact of indoor cooling and moderated outdoor temperatures.

Combining passive measures with targeted active cooling (Integrated Package E) delivers the greatest overall benefits when broader energy efficiency impacts are also considered. Package E provided active cooling for homes and indoor workplaces and external shading for outdoor workers, as well as passive measures including insulation and internal thermal blinds. If implemented across the UK, it can reduce heat-related mortality by almost 3,000 deaths per year in the 2030s when implemented across the UK,

rising to around 5,700 deaths avoided per year by the 2050s under typical conditions. The pace of grid decarbonisation in the UK will help ensure that future increases in cooling demand are met by a low carbon energy supply [2].

The benefits of adaptation are even more pronounced during an extreme heat year, when risks rise sharply. An integrated approach to adaptation (Integrated - Package E) eliminates almost all indoor heat-related deaths even in an extreme year, preventing 6,100 deaths in the 2030s and over 13,000 deaths by the 2050s under a national-scale rollout scenario. Productivity impacts are also significantly reduced under Package E, preventing the loss of almost 1.9 million working days in an extreme year in the 2030s and almost 6.2 million days by the 2050s. Adaptation is essential for protecting people and the economy during the most severe and consequential heat events.

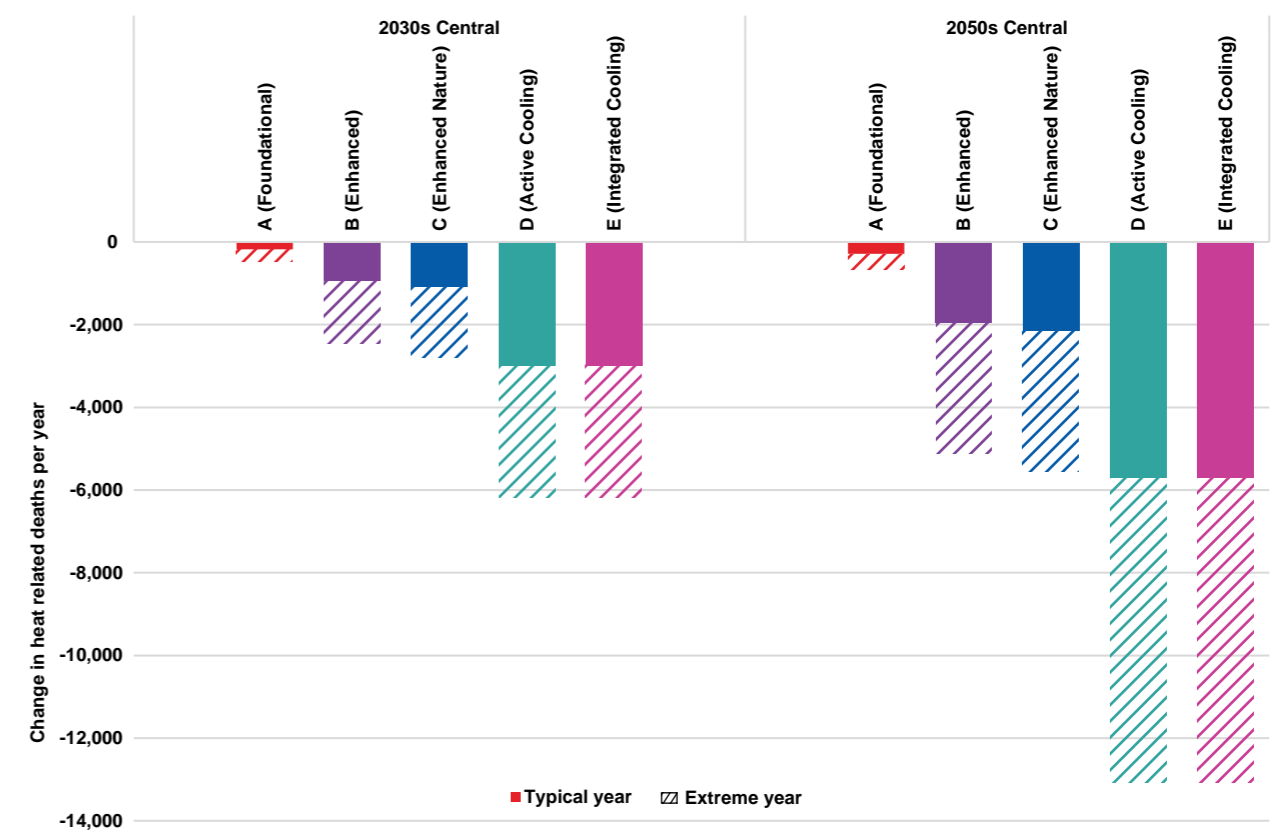


Figure 3: Change in deaths per year from adaptation packages for heat-related mortality for a UK-wide rollout scenario.

Adaptation offers value for money, but it must be targeted to the most at-risk places first

While adaptation delivers benefits across the country, the degree of risk reduction depends on local climate, built environment, economic conditions, and population vulnerability. In assessing value for money, including benefit–cost ratios (BCRs), the analysis is based on typical year conditions under a central climate scenario.

UK-wide physical adaptation to heat risk requires significant investment, with cumulative present-value costs over the 2025–2059 period ranging from around £18 billion for Package E (Integrated Cooling) to approximately £2.2 trillion for Package C (Enhanced Nature). The analysis explored rollout scenarios across different spatial extents and found that, while benefit–cost ratios remain above one even at full national implementation, the marginal benefits decline as coverage extends beyond higher-risk locations. In particular, rolling out measures across the highest-risk 30% of LSOAs captured a large proportion of the total risk reduction, beyond which additional investment delivered positive but diminishing returns.

Active and integrated cooling packages provide the greatest value for money in mitigating heat risk in the urban built environment. In particular, the economic case for adaptation becomes compelling when targeted active cooling is introduced, such as cooling a single high-use room within a dwelling. Packages D and E achieve attractive BCRs (greater than 3) when rolled out to the highest-risk areas, reflecting the substantial reductions in mortality and productivity impacts that integrated cooling delivers.

Package E offers the best value for money overall, achieving the highest risk reduction and the strongest economic return. In addition to a strong BCR, Package E delivers energy efficiency improvements and reduces operational costs, with passive measures that also enhance winter thermal performance and reduce heating demand. These

passive measures further help to moderate the externally vented heat associated with active cooling, supporting a more balanced approach to managing urban heat. The package remains cost-effective even under different rollout extents. Benefits outweigh costs under all tested rollout scenarios, including a full UK-wide rollout.

Earlier uptake in the highest-risk locations helps to manage residual risk. The modelling explored the potential effects of risk-informed patterns of uptake and indicates that higher-risk areas adopting measures earlier delivers the greatest benefit per pound spent. For instance, in a central climate scenario uptake of Package E in the top 45% of at-risk LSOAs maintains heat-related deaths in the 2050s below today’s levels, while still delivering an attractive benefit–cost ratio of almost 3.

Under a high climate change scenario, the economic case for adaptation is considerably stronger. The analysis shows that adaptation packages continue to perform well under a high-warming pathway, assuming 2°C warming by the 2030s and 2.5°C by the 2050s. Under this scenario, the BCR increases to above 4 when Package E is rolled out UK-wide and rises to almost 7 when targeted to the top 10% of highest-risk areas. A 70% rollout is sufficient to maintain heat-related deaths at or below present-day levels, while still achieving a BCR above 5.

70% rollout maintains current risk

A national rollout of Package E at around 70% is sufficient to keep heat-related deaths at or below present-day levels, while achieving a BCR above 5.

Package	Cumulative benefits (£billion, 2025-59, discounted)	Cumulative costs (£billion, 2025-59, discounted)	BCR
A – Foundational	17	120	0.1
B – Enhanced	39	2,000	0.02
C – Enhanced Nature	58	2,200	0.03
D - Active Cooling	54	17	3.2
E – Integrated Cooling	54	18	3

Table 4: Summary of benefit-cost ratio for each adaptation package (central climate change scenario, 30% rollout).

The study highlights wider benefits from passive and nature-based solutions

While integrated adaptation packages provide the strongest economic case for reducing heat-related mortality and productivity impacts, the wider suite of passive and nature-based adaptation options still plays an important role in delivering multi-benefit outcomes and contributing to the UK’s broader environmental and social objectives. Although the scale of the avoided mortality and productivity loss is not sufficient on its own to offset their implementation costs, passive and nature-based measures provide substantial wider benefits that are not fully captured in the BCR for this study.

Co-benefits materially improve the case for adaptation, with the Enhanced Nature package (Package C) delivering the greatest overall benefits. When co-benefits are included, Package C generates around £58 billion in cumulative discounted benefits between 2025 and 2059, exceeding the £54 billion delivered by Packages D (Active Cooling) and E (Integrated Cooling), even though D and E provide the greatest direct heat risk reduction. This uplift is driven by the additional benefits of nature-based solutions, with around 47% of total monetised benefits arising from co-benefits such as air quality improvements, carbon sequestration, urban cooling, stormwater management and recreational value.

This makes the case for a more holistic approach: designing, evaluating and delivering nature-based solutions that intentionally serve multiple objectives. This will be essential to enable the uptake of solutions that support long-term resilience across a range of climate hazards, while also addressing wider social and environmental priorities.

47% from co-benefits

For the nature-enhanced package, almost half of total benefits come from wider co-benefits, not heat risk reduction alone.

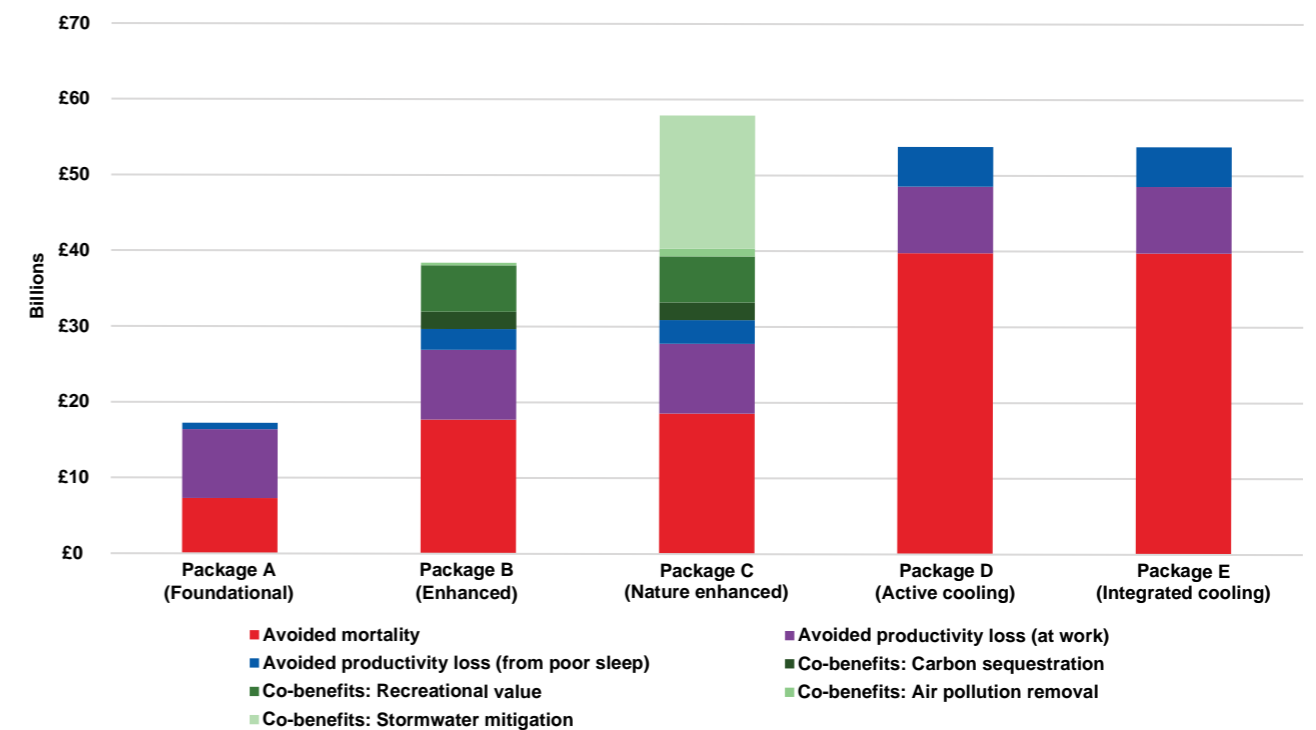


Figure 4: Total monetised risk reduction and co-benefits of adaptation packages. Central climate change scenario, discounted, 2025-29, 30% rollout.

Next steps for further understanding urban heat resilience

This analysis demonstrates that heat adaptation materially reduces projected impacts on health and economic productivity. In the absence of adaptation, heat-related mortality and productivity losses could increase rapidly by the 2030s.

The study provides a robust national-scale evidence base on heat risks and the relative performance of different adaptation measures. The results offer consistent insights into the scale, distribution and drivers of heat impacts across the UK, and into the comparative effectiveness of alternative adaptation approaches. The study provides a foundation for further analysis and decision-making to address heat risk in the urban built environment.

The results highlight the importance of understanding who and where heat risks are most concentrated, and how these risks evolve under future climate conditions. Improving awareness of heat exposure and vulnerability—particularly in a country with limited historical experience of extreme heat—remains an important factor in enabling effective resilience-building across sectors and geographies.



1. Why heat matters in the UK's towns and cities

1.1 Background

Extreme heat is one of the fastest-growing climate hazards facing the people living and working in UK towns and cities. Recent summers have repeatedly broken national temperature records, with 2022 marking the first time the UK exceeded 40°C. These conditions are no longer rare events – climate change is making them more frequent, more intense and more harmful.

1.1.1 How temperatures are changing in the UK
Heat is a growing concern for the UK, exacerbated by climate change. The UK's future climate is expected to bring hotter summers, more frequent and intense heatwaves, and warmer nights. 2025 was the warmest year in UK records, placing it alongside 2022 and 2023 as the warmest years observed since 1884 [3]. In 2022, the UK recorded its highest temperatures on record, exceeding 40°C at weather stations in Lincolnshire, Nottinghamshire and Greater London. Met Office climate models show that temperatures of 40°C are now more than 20 times more likely than they were in the 1960s, due to climate change [4]. Extreme heat is an escalating risk and growing adaptation challenge for the UK.

The impacts of high temperatures are intensified in towns and cities due to the Urban Heat Island (UHI) effect. An UHI develops when a city becomes warmer than its rural surroundings due to a combination of increased heat-absorbing materials like concrete and asphalt, reduced vegetation, and additional heat from human activities such as transport, industry, and energy use. Urban expansion is a driver of increased heat risk.

20x

Met Office climate models show that temperatures of 40°C are now more than 20 times more likely than they were in the 1960s, due to climate change [4]

1.1.2 What hotter weather means for our communities

The impacts of a warmer climate are already visible, affecting people, communities, physical infrastructure, the natural environment and critical services. Higher temperatures exacerbate physical and mental health conditions and contribute to heat-related mortality.

During 2022, when the UK experienced unprecedented heat, deaths linked to high temperatures far exceeded those from road traffic accidents. Heat-health risks are higher for vulnerable groups, including older adults, young children, people with pre-existing health conditions, and those living in deprivation.

Heat also affects economic productivity due to impacts such as heat stress, sleep deprivation, school closures, and extended commute times due to infrastructure failures, among other things. Reduced productivity affects individual businesses, local economies and national output. Previous UK heatwaves have resulted in millions of lost working days and caused monetised impacts of hundreds of millions of pounds [5].

Importantly, heat is also intertwined with other environmental hazards, including water scarcity, wildfire, and ground subsidence. When a heatwave is closely followed by intense rainfall – such as occurred in August 2022 – severe flash flooding may arise.

1.2 Objectives of this study

This study was commissioned by the Climate Change Committee (CCC) to determine how the UK's urban built environment can be adapted to escalating extreme heat risks. The analysis was designed to identify the most effective strategies for reducing heat-related mortality and economic productivity losses in UK cities – issues that are becoming increasingly urgent as climate change intensifies. The evidence generated from the study is part of the Well-Adapted UK Report and has been used to inform the UK's 4th Climate Change Risk Assessment (CCRA4-IA). It can support robust, evidence-based policy and investment decisions.

Understanding how adaptation can reduce not only the heat risk to people but also the consequent impact on the economy is central to this work. Existing evidence shows that extreme heat is already harming UK communities, yet we still lack a clear, national picture of how those risks are changing, who is most affected, and what the most effective adaptation measures look like in practice. This study responds to that gap. It brings together the best available research on heat, mortality and productivity, and applies new nationwide modelling to build a stronger, more joined-up evidence base for CCRA4-IA.

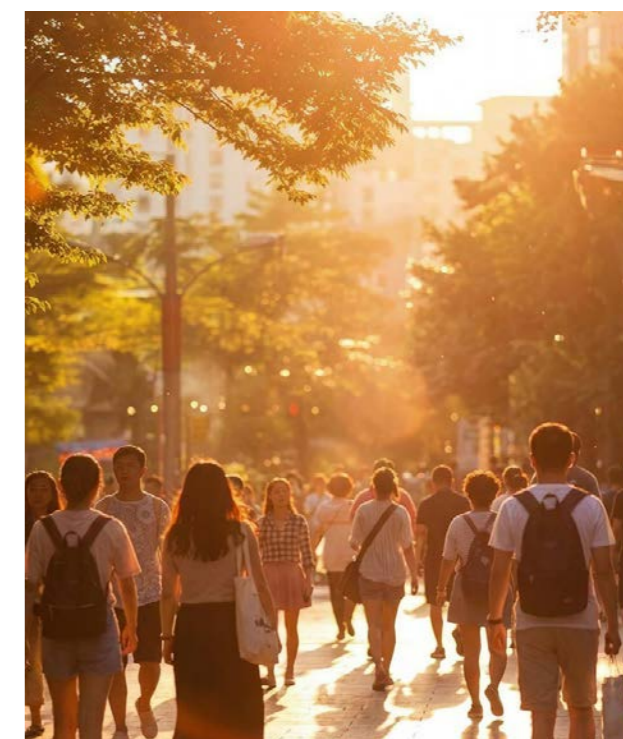
Key questions explored in this study are:

What is the current and projected future risk from urban heat in the UK, both in terms of health (mortality) and economic productivity?

How do risks and adaptation needs vary across different regions, urban typologies, and climate scenarios?

Which adaptation actions and packages deliver the greatest benefits, and how should actions be sequenced over time?

Which adaptation package provides the greatest value for money for the UK to reduce heat-related mortality and productivity losses?



1.2.1 Using this analysis to guide action

This analysis provides a national evidence base that can be used to guide heat-risk planning and investment across government, regions and local areas. It should be used alongside the other CCRA4-IA supporting research projects, to build a picture of climate risks and adaptation needs across the UK.

This work can be used by stakeholders across all levels:

For national-level decision-makers, the results highlight broad patterns of heat risk, the effectiveness of different adaptation pathways and the relative costs and benefits of alternative strategies.

For local authorities and city-regions, the analysis helps to pinpoint where risks are greatest, where interventions should be prioritised, and opportunities to integrate adaptation into local plans, regeneration programmes, climate strategies and infrastructure upgrades. It also provides a shared evidence base to support conversations across internal departments and with external partners, helping to align responsibilities and coordinate delivery.

For communities, this work can help build awareness of local heat risks, support informed participation in neighbourhood-scale action, and empower residents to engage with local plans for creating cooler, healthier and more resilient places.

1.3 Report structure

The key stages of the project are presented in Figure 5, and have been used to structure this report:

Section 1

Why heat matters in the UK's towns and cities – Research context, objectives and an overview of this report.

Section 2

Method overview – Summarising the analytical approach used to identify a cost-effective adaptation approach.

Section 3

Existing evidence of heat impacts on mortality and productivity – Existing evidence on how heat affects mortality and productivity, and the metrics used in this study.

Section 4

Establishing the baseline: present day and future heat risk across the UK in a 'no adaptation' scenario – Establishing baseline temperatures across the UK in current and future scenarios, including baseline estimates of heat-related mortality and productivity impacts.

Section 5

How towns and cities can be adapted to a hotter climate – Identifying adaptation measures and proposed adaptation packages.

Section 6

The effectiveness of adaptation packages to address urban heat risk – Modelling the effects of adaptation packages on mortality and productivity.

Section 7

Testing the influence of assumptions about the future – Sensitivity analysis for alternative climate change and socioeconomic scenarios.

Section 8

Reaching a cost-effective adaptation approach for the UK's towns and cities – Cost-benefit analysis, co-benefits and identification of a cost-effective package and rollout scenario.

Section 9

Key findings and conclusions – Main findings and implications.

Appendices

Detailed methodology, data sources, results tables, sensitivity studies and further discussion.

Section 3	Section 4	Section 5	Section 6 and 7	Section 8
Existing evidence of heat impacts	Establishing the baseline	How towns and cities can be adapted	The effectiveness of adaptation packages	Reaching a cost-effective adaptation approach
Review of existing work and methods.	Estimate baseline present day and future heat impacts	Identify adaptation options	Estimate future heat risk reduction	Identify cost effective package
Establishing metrics to quantify heat impacts on health and productivity.		Shortlist adaptation options using a multi-criteria assessment	Conduct sensitivity analysis.	Establish cost effective approach to rollout
Identifying adaptation solutions at building and urban scale.		Develop packages of adaptation measures.		

Figure 5: Project stages and associated report sections.



2. Method overview

This study used a structured analytical approach to understand how heat affects health and productivity across UK towns and cities, and to assess how different physical adaptation measures can reduce these impacts. In line with Annex 2 of the Well-Adapted UK Report, the approach integrates climate analysis, urban and building modelling, demographic data, and economic valuation:

- Quantification of baseline heat impacts, estimating the effects of heat on mortality and labour productivity under current and future climate scenarios, assuming no additional adaptation.
- Appraisal and selection of adaptation measures, using a structured multi-criteria analysis to prioritise feasible and effective building-scale and urban-scale interventions.
- Modelling and economic evaluation of adaptation packages, assessing their ability to reduce heat related impacts under both central and high-impact sensitivity scenarios.
- Development of a scenario of cost-effective adaptation deployed by 2030s and by 2050s.

This section provides an overview of the climate analysis and urban building modelling, with the complete technical methodology detailed in Appendix A.1. Information regarding the identification of adaptation measures, selection of adaptation packages, economic cost-benefit analysis, and determination of a cost-effective package can also be found in Appendix A.1.

2.1 Technical approach

The project’s methods were refined through an initial literature review (see Section 3), validated by a steering group of technical and strategic experts and are grounded in the latest available data and modelling tools.

Figure 6 presents an overview of the parameters of the technical analysis which include:

Climate

High spatial resolution, hourly climate datasets were developed for the UK by combining several established climate data sources.

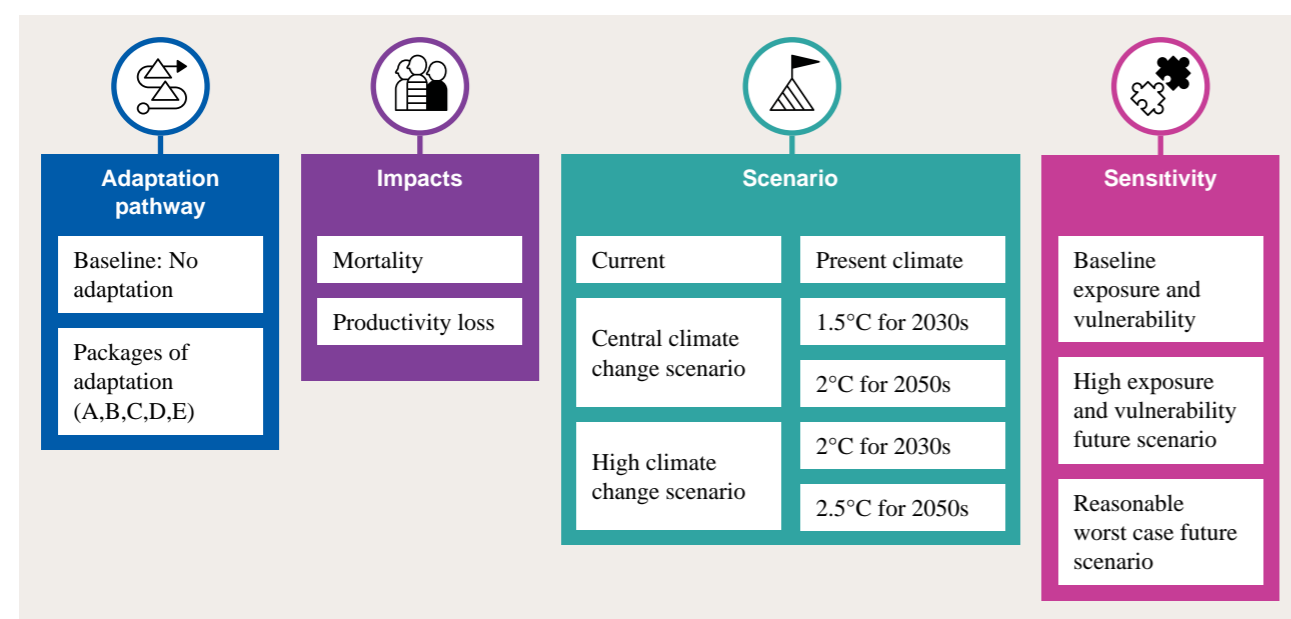


Figure 6: Overview of project variations setting out key stages.

The analysis was carried out on an hour-by-hour basis using a full year representing the climate in both present-day conditions (2022) and future conditions in the 2030s and 2050s. To ensure that the most severe heat impacts were captured, the modelling focused on extreme heat years—defined here as years with particularly high temperatures.

For the present day, 2022 was selected as a representative recent extreme heat year. Equivalent extreme climate datasets were developed for the 2030s and 2050s to represent future conditions. Results from these extreme year analyses were then converted to represent a typical year, allowing impacts to be expressed on an average annual basis for use in the economic appraisal.

Future climate was assessed under two scenarios:

- a central scenario, representing moderate levels of global warming (global mean temperature increases of 1.5°C above preindustrial levels in the 2030s and 2°C in the 2050s), and
- a high scenario, representing more severe global warming (global mean temperature increases of 2°C above preindustrial levels in the 2030s and 2.5°C in the 2050s).

The climate variables required for the analysis include air temperature, relative humidity and solar radiation. These datasets underpin all modelling of heat related mortality and productivity impacts.

Heat-impact metrics

Two primary heat-impact indicators were assessed:

- Heat-related mortality, estimated using established UK temperature–mortality relationships that vary by age group and region.
- Heat-related productivity loss, estimated using heat-stress thresholds (wet-bulb globe temperature, WBGT) and sector-specific productivity relationships.

Impacts were monetised using:

- Value of Life Year (VOLY) for mortality impacts.
- Gross Value Added (GVA) for productivity losses.

These metrics allow comparison of heat risks between locations, time periods and adaptation scenarios.

Socioeconomic sensitivity.

The analysis embedded age structure in the mortality assessment, and job sector and work exertion in the productivity assessment, reflecting two socioeconomic drivers of heat impacts with significant existing evidence.

Results were presented for a central socioeconomic scenario, with sensitivity testing undertaken to explore the implications of alternative assumptions. For future time periods, a high socioeconomic sensitivity for mortality used an ONS “old age structure” scenario to uplift baseline all-cause deaths, reflecting a higher proportion of older people and therefore greater vulnerability to heat.

For productivity, a higher productivity workforce was tested, increasing the economic value of each hour worked and resulting in larger GVA losses for the same heat related reduction in working hours.

A high impact sensitivity combined the high climate change scenario and high socioeconomic sensitivities to represent a reasonable worst case outcome.

Adaptation

Analysis was carried out for a no-adaptation (or baseline) scenario and for several packages of adaptation measures. Although referred to as “no adaptation”, the baseline scenario assumes no proactive heat adaptation was implemented, but some level of business-as-usual adaptation is implicitly captured, such as expected uptake of air-conditioning in office buildings.

Spatial framework and typology-based approach.

All analysis was carried out nationwide enabling a detailed assessment across UK towns and cities⁴.

The analysis was undertaken using the smallest available urban statistical units in each nation:

- England at a Lower Layer Super Output Area (LSOA) level for 25,000 areas
- Wales at a Lower Layer Super Output Area (LSOA) level for 1,000 areas
- Scotland at Data Zone level covering 5,800 areas
- Northern Ireland at Super Data Zone level covering 630 areas.

To enable a consistent UK-wide assessment at neighbourhood scale, the analysis adopts a typology-based approach (Figure 7):

- The UK is divided into four representative climate regions, capturing major north–south and east–west climatic differences.
- Urban areas are classified into 12 representative urban typologies, derived from the Local Climate Zone framework and adapted to UK conditions.
- Heat exposure within buildings is represented using typical residential and office building archetypes, selected to capture common and high-risk building forms.

This framework allows national coverage while accounting for variations in climate, urban form and building characteristics.

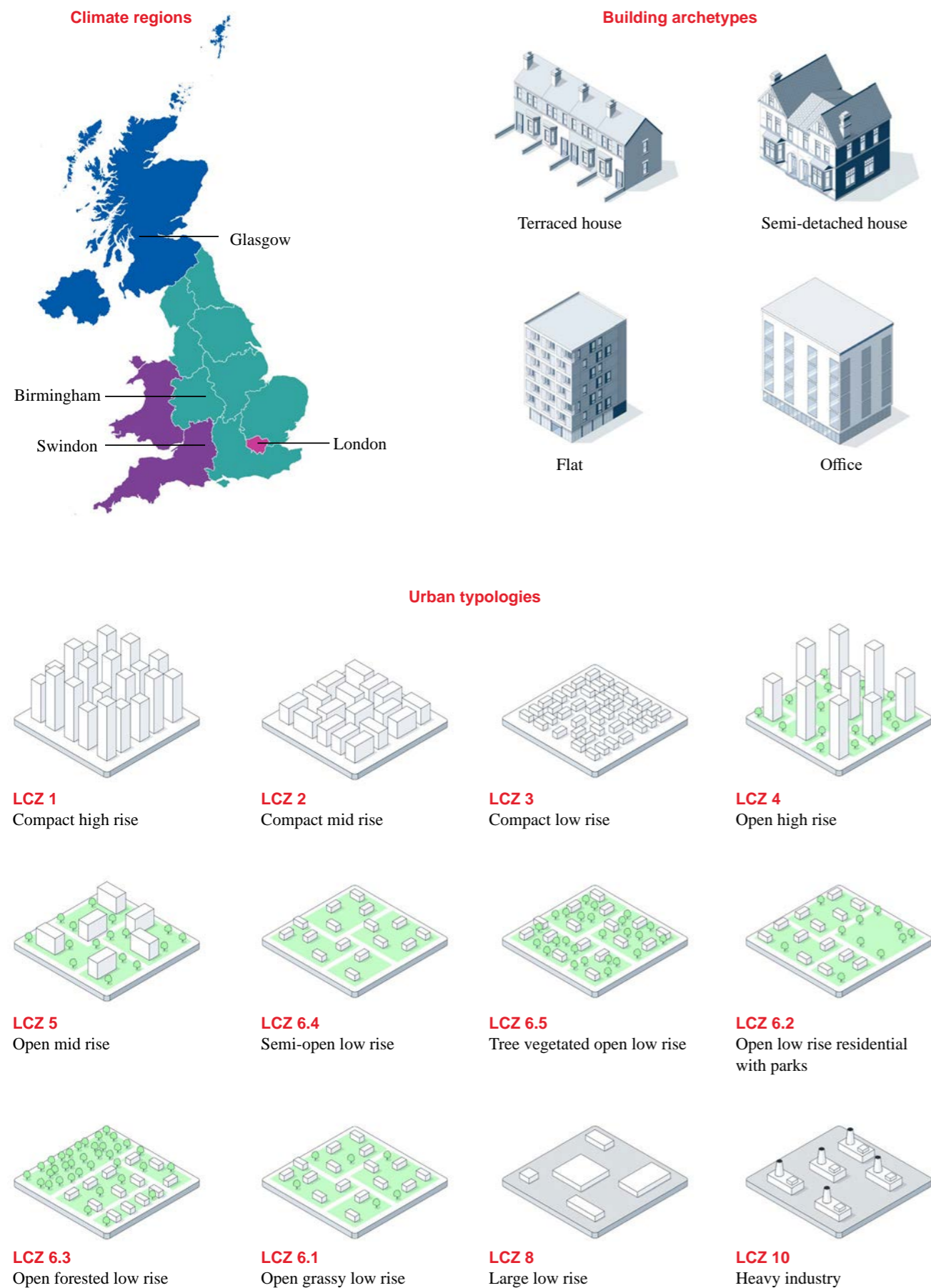


Figure 7: Typologies used in the analysis

2.2 Analysis tools

The analysis used several data analytics and modelling approaches. The key tools used included:

Climate analysis and data morphing – several climate datasets such as ERA5, HadUK and CIBSE weather files were collated and processed to produce present day (2022) and future (2030s, 2050s) climate datasets at LSOA level across the UK. UK-wide climate data at the appropriate resolution was fundamental to this project.

Urban climate analysis. To quantify the risk reduction from urban-scale adaptation measures, the Surface Urban Energy and Water Balance Scheme (SUEWS) climate model was utilised.

Dynamic thermal modelling. DesignBuilder software allows building models and weather files to be used to run dynamic thermal models. It was used to determine the relationship between external climate conditions and internal conditions and quantify the impact of a range of building-scale adaptation options. A parametric modelling approach was utilised with DesignBuilder which accounted for the large variability of different parameters needed for this project.

The key analysis steps are summarised below with a detailed methodology presented in Appendix A.1.

2.3 Measuring current and future heat impacts

The baseline analysis combined the prepared climate datasets with the impact metrics (mortality and productivity loss) to quantify how many heat-related deaths and working hours lost are expected with no proactive heat adaptation.

Risk is derived by combining:

- Heat hazard (outdoor temperatures and heat stress conditions)
- Exposure (population and workers)
- Vulnerability (age structure, job intensity, sector).

The detailed baseline assessment methodology is presented in Appendix A.1; results are presented in Section 4.

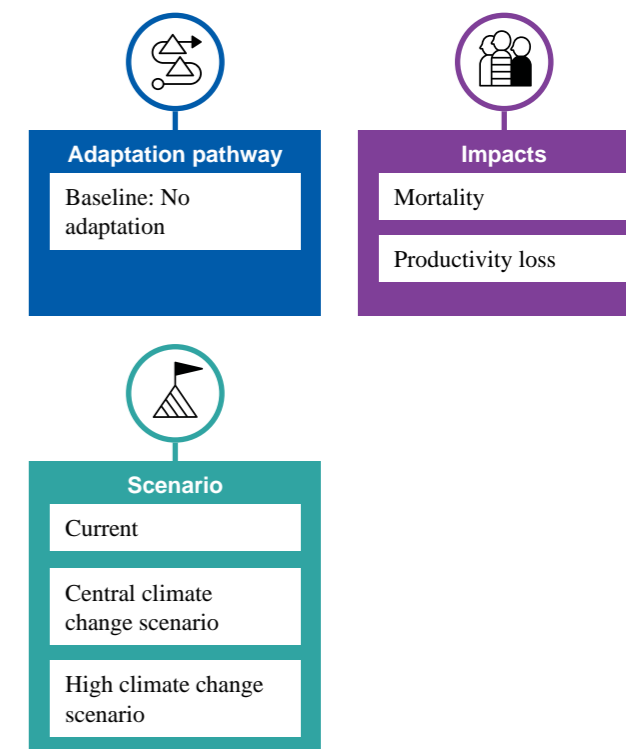


Figure 8: Parameters for measuring baseline heat impacts.



2.4 Selecting adaptation packages

A multi-criteria analysis (MCA) was used to systematically assess and prioritise potential heat adaptation measures for the UK context. The MCA was applied as follows:

- A longlist of building-scale and urban-scale adaptation measures was identified through literature review, case studies and expert input.
- Each measure was assessed against three core dimensions:
 - Heat risk reduction (for mortality and productivity),
 - Deliverability and scalability (including feasibility and flexibility), and
 - Cost (capital, operational and replacement costs).
- Measures were qualitatively scored using a Red–Amber–Green (RAG) framework, informed by available evidence, high level modelling and expert judgement.

– The highest scoring measures were shortlisted and grouped into adaptation packages, representing different levels of ambition and investment, for subsequent modelling and cost–benefit analysis.

The detailed selection methodology is presented in Appendix A.1; the adaptation packages are presented in Section 5.

2.5 Assessing the effectiveness of adaptation

To determine the heat risk reduction from adaptation packages, the modelling combined two levels of analysis: urban-scale modelling and building-scale modelling.

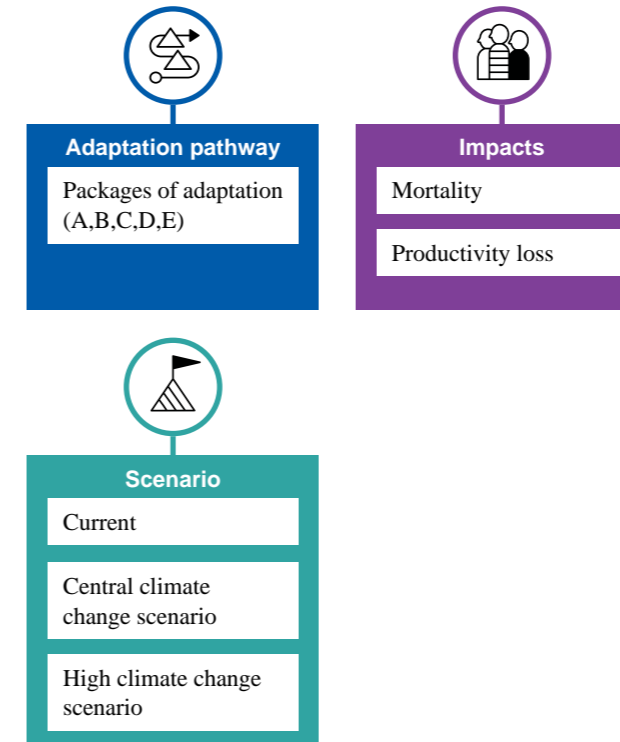


Figure 9: Parameters for assessing adaptation measures.

Urban-scale modelling. The Surface Urban Energy and Water Balance Scheme (SUEWS) model was used to estimate how urban measures (e.g. greening, reflective surfaces, water features) change local outdoor temperatures.

Building-scale modelling. Indoor conditions were modelled using DesignBuilder (based on the EnergyPlus engine). Over 4000 simulations were carried out to obtain the data.⁵

The outputs from both models were combined and mapped across UK urban areas at LSOA or equivalent level to generate adapted climate conditions and establish the impact of adaptation packages on health and productivity metrics and related monetised impact.

The detailed adaptation assessment methodology is presented in Appendix A.1; results are presented in Section 6: Reducing heat risk through adaptation – Modelling the effects of adaptation packages on mortality and productivity.



Figure 10: Simulations carried out to assess the impact of urban-scale adaptation measures.



Figure 11: Simulations carried out to assess the impact of building-scale adaptation measures.

2.6 Cost-benefit analysis and cost-effective deployment

A cost-benefit analysis (CBA) was undertaken to assess the economic performance of alternative heat adaptation packages and to identify cost-effective deployment pathways at national scale.

The CBA includes:

- Costs, comprising:
 - Capital costs for adaptation measures (e.g. building fabric retrofits, shading, green infrastructure),
 - Associated operation, maintenance and replacement costs where relevant,
 - Costs expressed in constant prices and applied on a per unit basis consistent with assumed roll out rates.
- Benefits, comprising:
 - Avoided heat-related mortality, monetised using established UK Value of Life Year (VOLY) estimates,
 - Avoided productivity losses due to heat stress, monetised using sectoral Gross Value Added (GVA),
 - Selected co-benefits where robust evidence is available (e.g. improvements in outdoor thermal comfort), while non-monetised benefits are captured qualitatively.

All costs and benefits are assessed over a 30 year appraisal period and discounted using standard Green Book discount rates.


To reflect real-world investment constraints, adaptation was not assumed to be deployed uniformly across all locations. Instead, an optimal deployment approach is adopted, whereby adaptation packages are:

- Implemented first in areas with the highest baseline heat risk, defined by a combination of extreme temperature exposure, population vulnerability and economic exposure.
- Progressively extended to lower-risk areas as overall adaptation ambition increases.

This approach allows the analysis to identify thresholds at which additional investment delivers diminishing marginal returns, helping to distinguish high-value early action from less efficient later deployment. A 30% rollout was selected as the initial rollout scenario to compare the different adaptation packages before a cost-effective package was chosen.

The detailed assessment methodology is presented in Appendix A.1; results are presented in Section 8.





3. Existing evidence of heat impacts on mortality and productivity

Research from recent UK heatwaves demonstrates clear increases in mortality, especially among older adults and those with underlying health conditions [6]. Global and UK studies also show measurable reductions in work capacity on hotter days, particularly in outdoor and physically demanding sectors [7] [5]. These insights guide the metrics, assumptions and methods used in this study.

3.1 Influences on urban heat patterns

Urban heat is a complex phenomenon driven by the interaction between climate, land use, human activity, and the materials that make up the built environment. Understanding this requires robust data and models, which are essential for analysing how heat affects urban areas, projecting future heat risks, and designing effective adaptation strategies.

High-resolution climate data (historic observed data combined with future projections) provide the baseline for understanding temperature patterns across the UK. This can be combined with information on land cover such as vegetation, building density, and surface cover, along with datasets that represent heat produced by human activities. Together, these inputs allow an understanding of heat in urban areas.

3.2 Heat impacts on health

Heat affects health in many ways, from causing new physical and mental strain to exacerbating other environmental stressors and aggravating underlying health conditions. Mortality remains the most well-researched and widely documented health outcome in literature. Evidence from UK heatwaves shows sharp increases in excess deaths during sustained high temperatures [8] [6]. Older adults and people with pre-existing conditions such as cardiovascular or respiratory illness are most at risk [9].

Most studies link mortality to outdoor air temperatures, and this remains the standard evidence base for national-scale modelling. However, indoor conditions also significantly affect heat-related health risks. Hot indoor environments – especially at night – sustain or amplify heat stress, particularly for vulnerable groups [10]. This study therefore considers both outdoor and indoor temperatures to more fully understand the potential health impacts.

Higher humidity can worsen heat impacts, but UK health alert systems primarily rely on temperature [11] so this study follows that practice. International research often uses heat-stress indices that combine temperature and humidity, but these relationships are far less developed in UK evidence, where temperature-mortality risk assessments are derived almost exclusively from outdoor air temperature.

Since the relationship between morbidity and heat is less well evidenced, and since morbidity cannot yet be converted into consistent economic metrics conducive to determining cost-effective adaptations, morbidity was excluded from the modelling [12] [13].

This study focuses on mortality as the key health indicator, using the methodology and risk relationships set out by Murage et al [14]. The outputs for heat related deaths were converted into monetised impacts using economic calculations based on Years of Life Lost (YLL) and the Value of a Life Year (VOLY).

3.3 Heat impacts on productivity

Productivity loss occurs when heat reduces people's capacity to work safely and effectively. Workers may need to reduce pace, work fewer hours, take more breaks, or stop working altogether during hot periods [15]. Evidence from UK and global studies shows measurable reductions in work capacity on hotter days, especially in outdoor and physically demanding sectors [7] [5] [16]. Indices such as wet-bulb globe temperature (WBGT) underpin most productivity research, as heat stress is an outcome of air temperature, solar radiation and humidity.

This study uses WBGT-linked productivity curves developed by Vivid Economics (2017) [17], which vary by job intensity. The economic impact on Gross Value Added (GVA) was calculated from annual hours of productivity loss due to heat stress.

Indirect impacts on productivity, such as disrupted sleep, fatigue or commuting delays, are recognised in the literature [18] but lack sufficient evidence for national-scale quantification and were therefore excluded from modelling.

4. Establishing the baseline: present-day and future heat risk across the UK in a ‘no adaptation’ scenario

To model the effectiveness of potential adaptation measures, it is crucial first to understand the present-day level of heat risk and how it may change over time in the absence of adaptation. Although this baseline is referred to as “no adaptation”, business-as-usual adaptation is implicitly captured, such as expected air-conditioning uptake in office buildings.

This begins with modelling the intensity and spatial distribution of the heat hazard across the UK under present day and two future time periods (2030s and 2050s). Risk is then assessed by combining hazard data with data describing the exposure and vulnerability of people and workers in each time period. By integrating hazard, exposure, and vulnerability, we determined risk. Baseline risk is measured by the number of heat-related deaths and lost productivity hours under each heat scenario, and the monetised consequences in a “no adaptation” scenario. The analysis was carried out at LSOA level, including only “urban” LSOAs, which were identified through a typology-based approach.

The analysis shows how significantly heat already affects people and the economy, with the greatest impacts concentrated in the South and East of England. Impacts on mortality and productivity increase sharply under future climate conditions. This forms the baseline against which the benefits of adaptation are assessed later.

+5°C

In extreme summers, peak temperatures in cities like London can exceed typical summer conditions by more than 5°C.

4.1 Present-day and future baseline heat intensity

The study focuses on typical years and extreme years in present and future climate conditions. The future climate follows a central scenario, consistent with global warming of 2°C above pre-industrial levels by the 2050s. A typical year describes average, or “normal” climate conditions without unusually hot weather or extreme events. An extreme year corresponds to those containing intense heat events. Typical and extreme summers vary across the UK.

Heat hazard is captured using air temperature (allowing measurement of mortality impacts) and wet-bulb globe temperatures (WBGT, allowing measurement of productivity impacts). These were mapped for the extreme present-day climate, and extreme future climate in the 2030s and 2050s using climate projections (see Section 2.2).

Heat varies across the UK, with the greatest heat intensity typically concentrated in the South East, South West and London, while cooler conditions are experienced in Scotland, Northern Ireland and the North of England. The South of England also records higher wet-bulb globe temperatures due to the combination of warmer air and higher humidity. Both air temperature and wet-bulb globe temperature – which accounts for the moisture in the air - metrics show clear upward trends under future climate scenarios, with all regions of the UK projected to experience increases from present-day conditions.

Across the specific locations we analysed, extreme summers show substantially higher temperature peaks than typical years. In London, maximum temperatures in an extreme summer can exceed those in a typical summer by more than 5°C; in Glasgow the difference is around 4°C; and in Swindon and Birmingham the uplift is typically around 2–3°C.

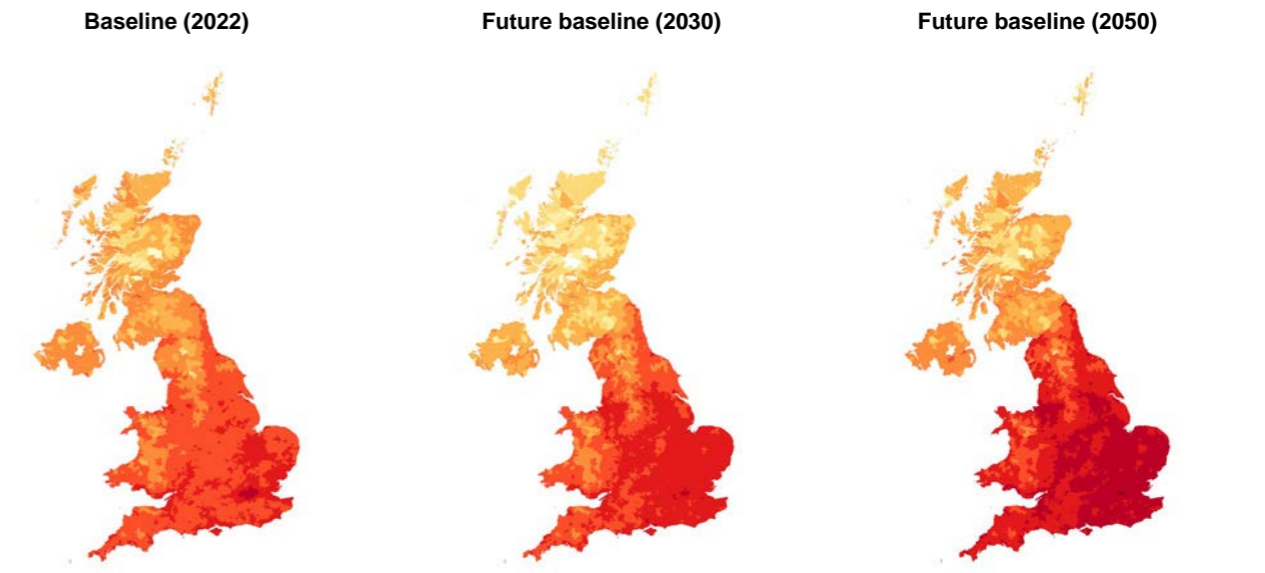


Figure 12: Mean air temperatures across the UK for an extreme year.

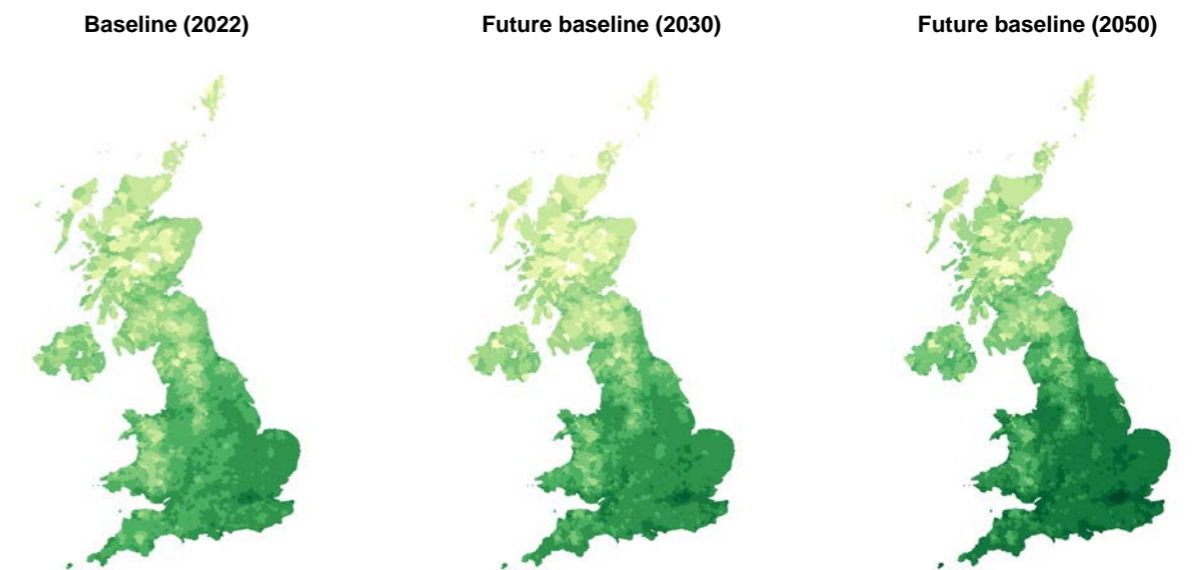
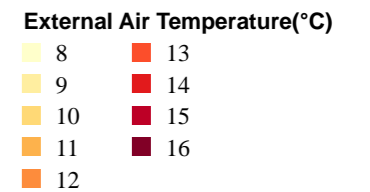
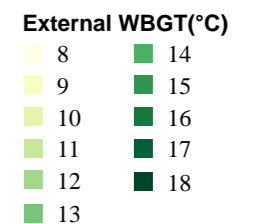


Figure 13: Mean WBGT across the UK for an extreme year.



4.2 Present-day and future baseline heat impacts

4.2.1 The impact of heat on mortality

Health impacts are presented at a regional scale due to the level of granularity in the available input data.

The 2022 data is used as the baseline for heat-related mortality. The baseline analysis estimated around 4,000 heat-related deaths across the UK in an extreme year in the present day. These results broadly align with published 2022 data; the Office of National Statistics (ONS) reported approximately 3,300 heat-related deaths in England and Wales across five defined heat periods in 2022 [1] ⁶.

As the climate warms through the century, heat intensity and associated mortality are projected to increase under extreme years. In the 2030s, heat-related deaths could increase by 50%, and by the 2050s 230%, compared with an extreme year in the present day. This aligns with academic studies such as Hajat et al., who estimate a 257% increase in heat-related deaths for the 2050s [19]. Some discrepancies would be expected due to differences in methods, including input data and the spatial resolution of the analysis.

For an extreme summer, the analysis estimates over 6,000 heat-related deaths per year in the 2030s, rising to over 13,000 per year in the 2050s.

Typical summers also showed a marked increase in heat-related mortality, rising from around 1,900 deaths per year in the present-day baseline to 3,000 in the 2030s and 5,700 in the 2050s, with corresponding monetised impacts increasing from £1.5 billion to £4.7 billion (2025 prices).

The distribution of heat-related mortality and monetised impact across the UK remains broadly consistent over time. The South East consistently experiences the highest levels of both mortality and monetised impact, with around a quarter of all UK heat-related deaths occurring in this region. The same pattern persists in future projections, reflecting the relative severity of heat in the South East, the region's population density, and the large underlying baseline of all-cause deaths from which heat-related mortality is derived.

Heat consistently affects older age groups more significantly, and this pattern continues into the future. In the extreme present-day baseline, 80% of heat-related deaths occur in the 'over 75' age group. By the 2050s, this proportion increases to 90% due to demographic changes of an older population. The projected mortality outcomes for each age category under future baseline conditions are provided in Appendix A.2.

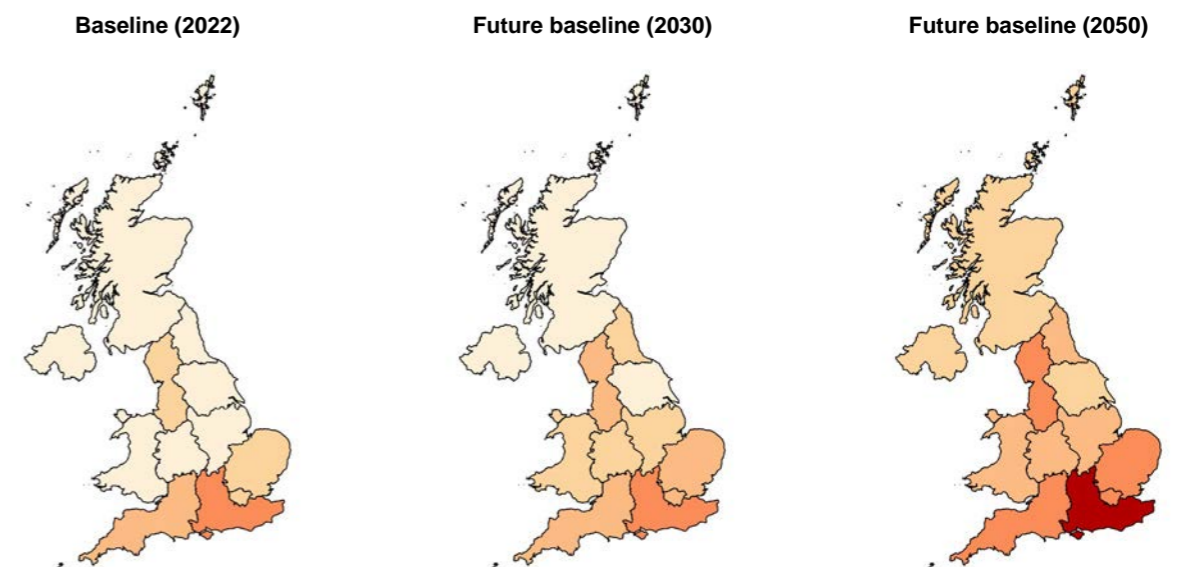


Figure 14: Total number of heat-related deaths in an extreme year.

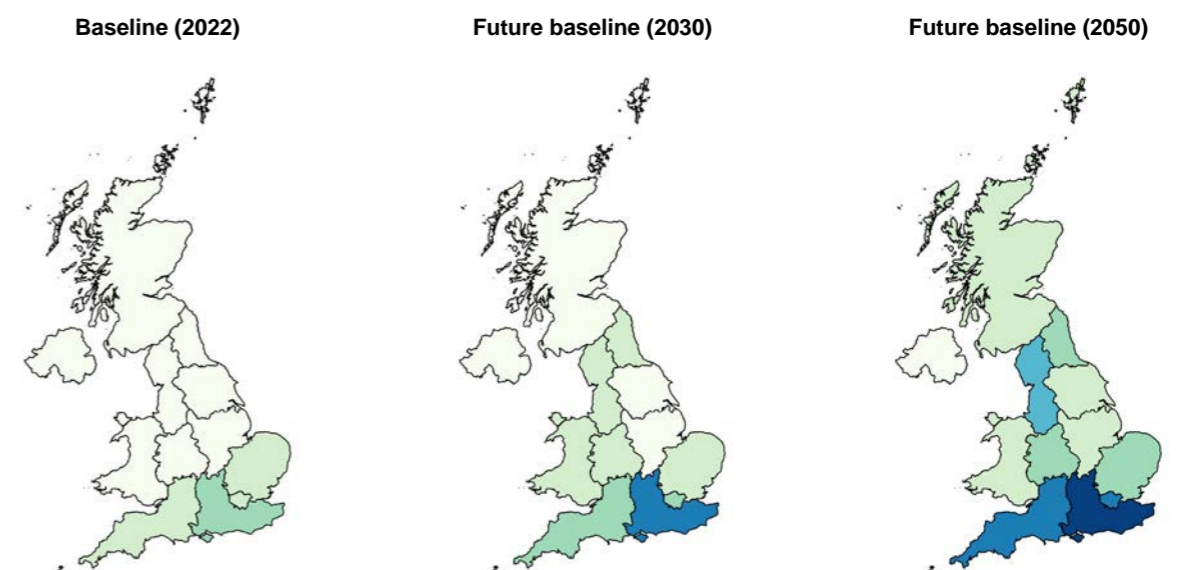
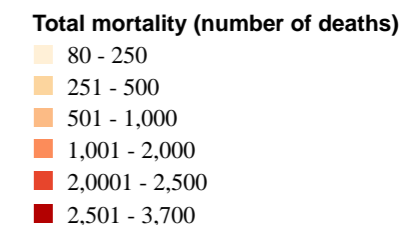
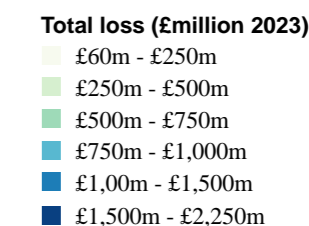


Figure 15: Total monetised impact from heat-related death in an extreme year.



13,000 deaths per annum

Heat-related deaths could exceed 13,000 annually in extreme years by the 2050s.

4.2.2 The impact of heat on productivity

Productivity impacts are shown at the ITL3 (International Territorial Level) scale to illustrate differences within towns and cities, linked to variability of predominant industrial sectors.

Heat stress was responsible for 7.5 million lost hours (0.93 million lost working days) across the UK in 2022 (an extreme year), generating a £450 million loss of GVA. Greater London experienced the most significant impacts, accounting for 38% of the overall loss - reflecting the relative severity of heat in the South East, high average productivity levels and dense concentration of employment in Greater London. Construction is a particularly significant sector in Greater London, with construction workers more vulnerable to heat stress. England generally shows higher heat-related productivity impacts than Scotland, Northern Ireland and Wales, also owing to higher average productivity levels and employment density.

Productivity impacts in urban areas are projected to rise to 14 million lost hours (1.8 million lost working days) for an extreme year in the 2030s, equivalent to £720 million in lost GVA – an increase of 61% compared with an extreme present-day year.

The spatial occurrence of productivity impacts becomes wider in future time periods, with more regions experiencing moderate to high impacts. Despite this wider spread, impacts remain concentrated in major urban areas, most notably in London, Bristol and Bournemouth, where higher economic activity and temperatures mean greater heat-related disruptions and larger total GVA losses.

Productivity impacts from heat are projected to increase substantially in an extreme year in the 2050s. Lost hours due to heat are projected to reach 51 million per year (6.3 million lost working days), generating a £3.3 billion per year GVA loss.

From the 2030s to 2050s, lost working hours due to heat are projected to increase by around 3.6 times, while the associated GVA loss rises nearly five-fold (4.6 times). This change reflects heat exposure increasingly affecting higher productivity sectors, for example engineers and lawyers, where each lost hour carries greater economic value (see Appendix A.1 for productivity methodology). Although these sectors are assumed to be less sensitive to heat, when disruptions do occur the monetised impact per hour is greater.

By the 2050s, an extreme heat year could generate £3.3 billion in lost economic output across the UK, roughly equivalent to half of Hull's annual economic output. [20].

Even in typical years, productivity losses can cost the UK economy. This could be £540 million in the 2030s and £1.8 billion per annum in the 2050s.

6.3 million working days

By the 2050s, extreme heat could drive up to 6.3 million lost working days across the UK.

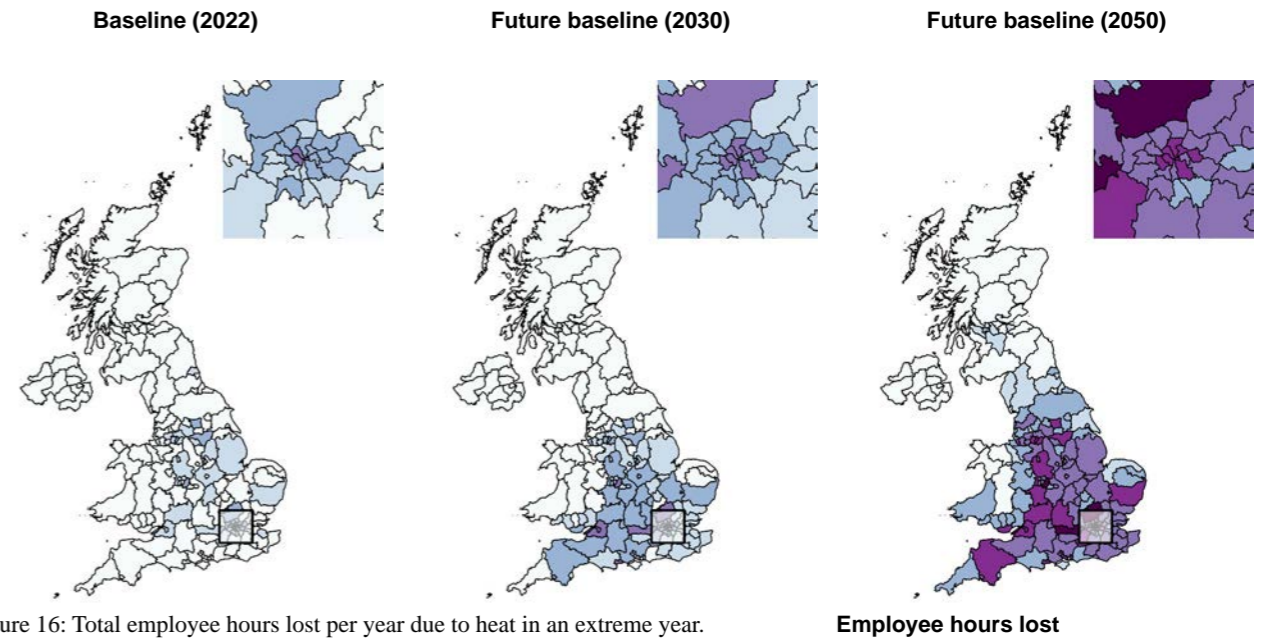


Figure 16: Total employee hours lost per year due to heat in an extreme year.

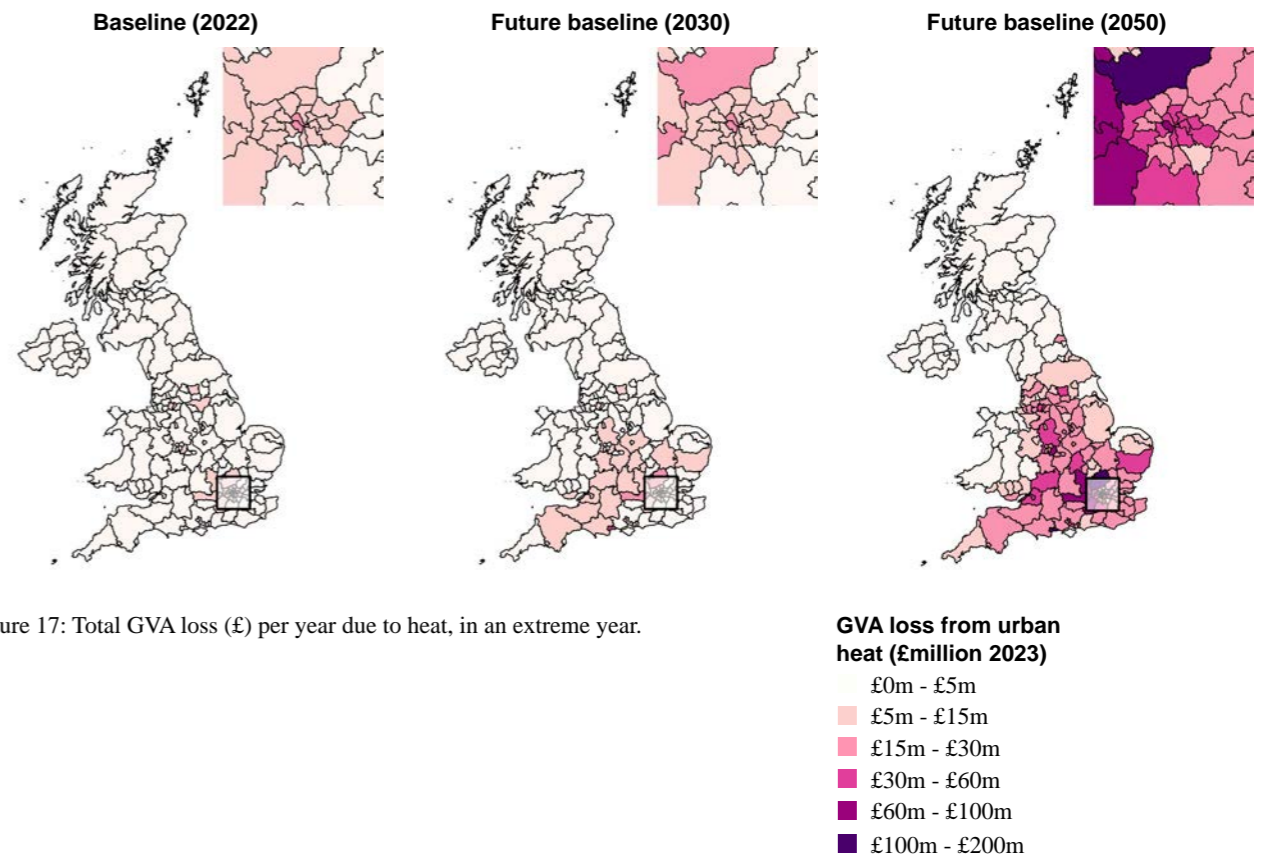


Figure 17: Total GVA loss (£) per year due to heat, in an extreme year.

4.2.3 Summary

The total monetised impact from heat on mortality and productivity is forecast to increase from £3.7 billion per year in an extreme present-day year, to £12 billion in an extreme year in the 2050s; an increase of over three-fold. This combines to provide a total monetised impact across the UK for the three time periods.

Heat is a growing issue for health, productivity, and total cost to the UK economy. The total monetised impact from heat on mortality and productivity is presented in Table 5

£3.7bn

2022

£5.4bn

2030s

£12.2bn

2050s

Total monetised annual impact from heat on mortality and productivity.

Year	Mortality				Productivity			
	Typical year		Extreme year		Typical year		Extreme year	
	Total Deaths (number)	Monetised impact of mortality (£million)	Total lost hours (1000 Hours)	Total GVA loss (£m)	Total lost hours (1000 Hours)	Total GVA loss (£m)	Total lost hours (1000 Hours)	Total GVA loss (£m)
2022	1,900	1,500	4,000	3,200	3,700	200	7,500	450
2030s	3,000	2,400	6,100	4,700	8,200	540	14,000	720
2050s	5,700	4,700	13,000	8,900	21,000	1,800	51,000	3,300

Table 5: Heat impacts on mortality and productivity (per year) for the present and future baseline scenarios.



5. How towns and cities can be adapted to a hotter climate

The baseline assessment illustrates the urgent need for the UK to adapt and build resilience to heat risks. It demonstrates that we are already experiencing the effects of heat on health and productivity today, and that impacts are likely to worsen under all future climate scenarios.

There is a wide range of adaptation solutions that address heat, including both physical and operational measures. Physical measures involve modifications to buildings, infrastructure and the public realm – such as installing reflective roofs, improving insulation, or implementing large-scale greening or shading in outdoor areas. Operational measures focus on management practices and behavioural changes, such as adjusting work hours to avoid peak heat periods, implementing cooling protocols in workplaces, or providing guidance to the public during heatwaves. This study primarily focuses on physical adaptation measures, recognising their potential to provide systematic and lasting benefits.

This section summarises the available solutions and presents five adaptation packages whose effectiveness has been modelled.

5.1 Identification of physical adaptation solutions

A long list of heat adaptation measures was identified through a literature review. The review sought to understand where different measures have been applied and how effective they have been, using case study examples.

The scale of measures varies considerably, from individual building-level interventions to city-wide strategies applied across urban areas. For example, large-scale nature-based solutions — such as urban greening and shading of public spaces — have proven to be effective in cities with frequent heatwaves. Green corridors in Medellín, Colombia have been implemented and shown to create more comfortable conditions, reducing temperatures by 2°C across the city [21]. At the building level, retrofitting measures like improved ventilation and window shades help to reduce overheating, as detailed in Arup’s previous study for the CCC “Addressing overheating risk in existing UK homes” [22].

Measures were categorised into building-scale measures, which can be applied to residential and commercial properties to reduce internal overheating, or urban-scale measures which reduce outdoor temperatures and may provide some cooling effects to surrounding buildings (e.g. through shading).








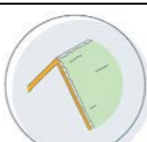


Building adaptation measure	Icon	Specific measure	How the measure reduces overheating in buildings
Windows		Internal blinds or curtains	Reduces solar gain
		External shading on south, east and west orientated windows	Reduces solar gain
		External and internal shutters	Reduces solar gain
		Low g-value window film (Plastic film which can be applied to windows to reduce the solar transmittance) or replacement of windows with low g-value glazing to reduce solar transmittance	Reduces solar gain
		Replacement of windows with an increased openable area	Increases natural ventilation of home
Building skin		Solar reflective coating to walls/ roofs, or solar reflective tiling	Reduces heat gains through conduction via the building envelope
		Roof insulation	Reduces heat gains through conduction via the building envelope
		Green roofs/walls	Reduces temperature of the roof surface and surrounding air by providing shade and evapotranspiration
Active cooling		Ceiling fans	Increases air movement to provide cooling
		Active conditioning (air-conditioning)	Provides cool air supply

Table 6: Long list of building-scale adaptation measures for analysis.

Building adaptation measure	Icon	Specific measure	How the measure reduces overheating in buildings
Green infrastructure		Green infrastructure – establishing parks and green spaces, increasing tree cover or undertaking strategic planting around buildings	Increases evapotranspiration, shade and albedo of the urban surface
Water management		Blue infrastructure – establishing ponds and rivers and water features	Increases heat absorption and evaporation.
		Irrigation	Cooling through evaporation
Pavements and surfaces		Pervious or porous surfaces	Increases heat absorption and evaporation (when there is moisture)
		Cool roofs/pavements	Increases albedo of the urban surface
Urban design		Pedestrianisation of streets	Reduces heat generating vehicle traffic
		Street shading	Reduces absorption of solar radiation
Building massing and heights		Building massing and heights* and optimal building or street orientation*	Minimises solar gain, increases airflow

Notes: *These measures are not assessed further, as they cannot be implemented in existing building fabric.

Table 7: Long list of urban-scale adaptation measures for analysis.

5.2 Multi-criteria analysis of adaptation solutions

To shortlist solutions, it was essential to identify those that could be both effective and appropriate for the UK context. The UK's distinctive climate, combined with the characteristics of its building stock and urban environments, needs careful consideration of measures that can genuinely deliver results.

The longlist of solutions was evaluated using a multi-criteria analysis (MCA) to create a prioritised shortlist of measures considered most suitable for the UK. The solutions were qualitatively scored against a range of sub-criteria (Figure 18) under three key dimensions:

Impact

The ability of the solution to reduce heat-related risks and generate co-benefits. The core risk reduction was assessed through three sub-criteria: indoor heat reduction, outdoor heat reduction, and benefit realisation (the time required for the solution to achieve its full heat adaptation potential following completion). Co-benefits related to biodiversity, carbon reduction, flood resilience, air quality, amenity, and recreation. Equity was considered in terms of whether a measure has disproportionate impacts on different groups, and whether benefits can be accessed by wider groups or only homeowners.

Implementation

This looks at scalability, flexibility, and feasibility. Scalability checks whether the measure suits different building and area types and considers delivery times. Flexibility means how easily and cheaply it can be adapted or removed later. Feasibility considers technical challenges, supply chain capacity, required expertise, and how likely people are to adopt the measure, especially if it affects building appearance.

Cost

This covers the up-front (capital), ongoing (operating and maintenance), and replacement costs. Costs were estimated using standard unit cost rates and applied to typical building and urban examples to allow fair comparison.

Further details on the MCA and scoring approach are provided in Appendix A.1.

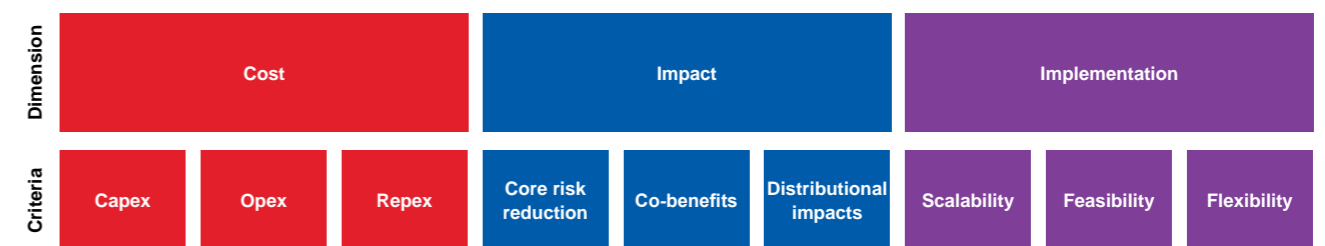


Figure 18: MCA criteria and sub criteria.

5.3 Proposed adaptation packages

Building- and urban-scale measures were assessed separately due to their distinct contribution to heat risk reduction and unique implementation considerations.

While individual adaptation measures - when deployed at scale - can contribute to reducing heat risk, it can be more cost-effective to package multiple measures together. Layering measures can also help to achieve meaningful reductions in heat risk. Packaging involves combining the shortlisted building-scale and urban-scale solutions for maximum impact. The final adaptation packages comprise a combination of building- and urban-scale measures, reflecting a holistic approach to mitigating heat-related risks.

Within each package, adaptation measures targeting heat-related mortality were separated from those aimed at reducing productivity impacts. This was necessary because the location and application of adaptation measures for productivity impacts differ from those for mortality. For the purposes of this study, mortality impacts were assumed to occur primarily within homes. Mortality-related adaptation measures focused on building-scale measures for homes, and urban-scale measures that help lower internal temperatures. In contrast, adaptation measures for productivity impacts were selected for their applicability to office buildings (representing indoor workplaces) and outdoor urban areas where workers are present.

The five adaptation packages were selected based on their role in passive or active cooling, their MCA scores, relevance at building or urban-scale, and the combination of measures to address mortality and productivity impacts due to heat. The packages are presented in Table 8.

The five packages developed represent a structured range of options, from low regret, quick win measures through to more transformative nature-focused and active cooling approaches. This provides choices for different levels of ambition and investment. The next stage of the study assesses the effectiveness of these packages in reducing heat risk across UK urban areas, under the baseline present-day and future climate scenarios (2030s and 2050s) presented in Section 4.

Package	Details	Adaptation measures	
		Mortality (applied to residential areas)	Productivity loss (applied to workplaces)
A – Foundational	A lightweight package composed of quick win low impact adaptation	Building-scale Internal blinds Low g-value window film Solar reflective coating to external walls Urban-scale None	Building-scale Active cooling Urban-scale Construction site shading
B – Enhanced	A medium package with quick wins and complementary measures	Building-scale Internal blinds Low g-value window film Solar reflective coating to external walls Solar reflective coating to roofs Roof/loft insulation Urban-scale Cool pavements Parks and green spaces Irrigation Blue infrastructure	Building-scale Active cooling Urban-scale Construction site shading Cool pavements Parks and green spaces Irrigation Blue infrastructure
C – Enhanced Nature	A more comprehensive package of actions combining nature-based solutions with urban and building cooling measures	Building-scale External shutters Solar reflective coating to external walls Solar reflective coating to roofs Roof/loft insulation Urban-scale Cool pavements Parks and green spaces Irrigation Blue infrastructure Increasing pervious surfaces Increasing tree cover	Building-scale Active cooling Urban-scale Construction site shading Parks and green spaces Irrigation Blue infrastructure Increasing pervious surfaces Increasing tree cover
D - Active Cooling	Focused on building-scale active cooling.	Building-scale Active cooling – room unit Urban-scale None	Building-scale Active cooling Urban scale Construction site shading
E – Integrated Cooling	Building-scale active cooling complemented by some passive measures	Building-scale Active cooling – room unit Internal blinds Roof/loft insulation Urban-scale None	Building-scale Active conditioning Urban-scale Construction site shading

Table 8: Proposed adaptation packages.

6. The effectiveness of adaptation packages to address urban heat risk

The next stage of the study quantifies how each adaptation package could reduce heat risk when applied across the UK's urban areas and buildings. A modelling approach was designed to mirror the structure of the baseline data: combining urban-scale heat modelling with building-scale dynamic simulations and applying them consistently across present-day and future climate scenarios (2030s and 2050s). High climate change sensitivity tests were also applied (see Section 6). The analysis captured the interaction between external urban heat and building performance.

This allowed us to estimate the potential reduction in heat-related impacts on mortality and productivity compared with a "no adaptation" pathway. The modelling presents a UK-wide picture of the benefits that different levels of adaptation ambition could achieve, forming the quantitative backbone for the cost-benefit analysis and determining the cost-effective approach that follows.

6.1 Adaptation package modelling results

This section presents the modelled results of applying the adaptation packages across the UK. The five packages are presented against the future baselines for the 2030s and 2050s. The maps show extreme year comparisons, with data provided for both typical and extreme future periods.

6.1.1 Reduction in mortality risk

All of the proposed adaptation packages reduce heat-related mortality. Compared with the future baseline (no adaptation), Packages D (Active Cooling) and E (Integrated Cooling) deliver the largest reductions in heat-related mortality, by eliminating heat-related deaths. The other packages, without residential active cooling, also deliver measurable reductions in heat-related mortality, with Package C (Enhanced Nature) achieving the greatest impact among them.

The 2050s show a greater reduction in heat-related deaths per year than the 2030s. As heat events intensify over time, the effectiveness of adaptation packages increases, highlighting the value of early action to minimise future impacts.

The adaptation packages achieve clear reductions in mortality and the associated monetised impacts in both typical and extreme heat years. Packages D and E effectively reduce mortality risk to near zero for an extreme year in the 2030s and 2050s, lowering monetised losses by £4.7 billion and £8.9 billion respectively if deployed across the UK.

In typical heat years, these packages also produce measurable benefits, reducing deaths by around 3,000 in the 2030s and 5,700 in the 2050s, and decreasing monetised losses by £2.4 billion and £4.7 billion respectively under a nationwide rollout scenario. Package C, with nature-based measures, averts over 1,000 deaths per year in a typical year in the 2030s and more than 2,000 deaths per year by the 2050s, a reduction of over a third on the baseline if implemented nationally.

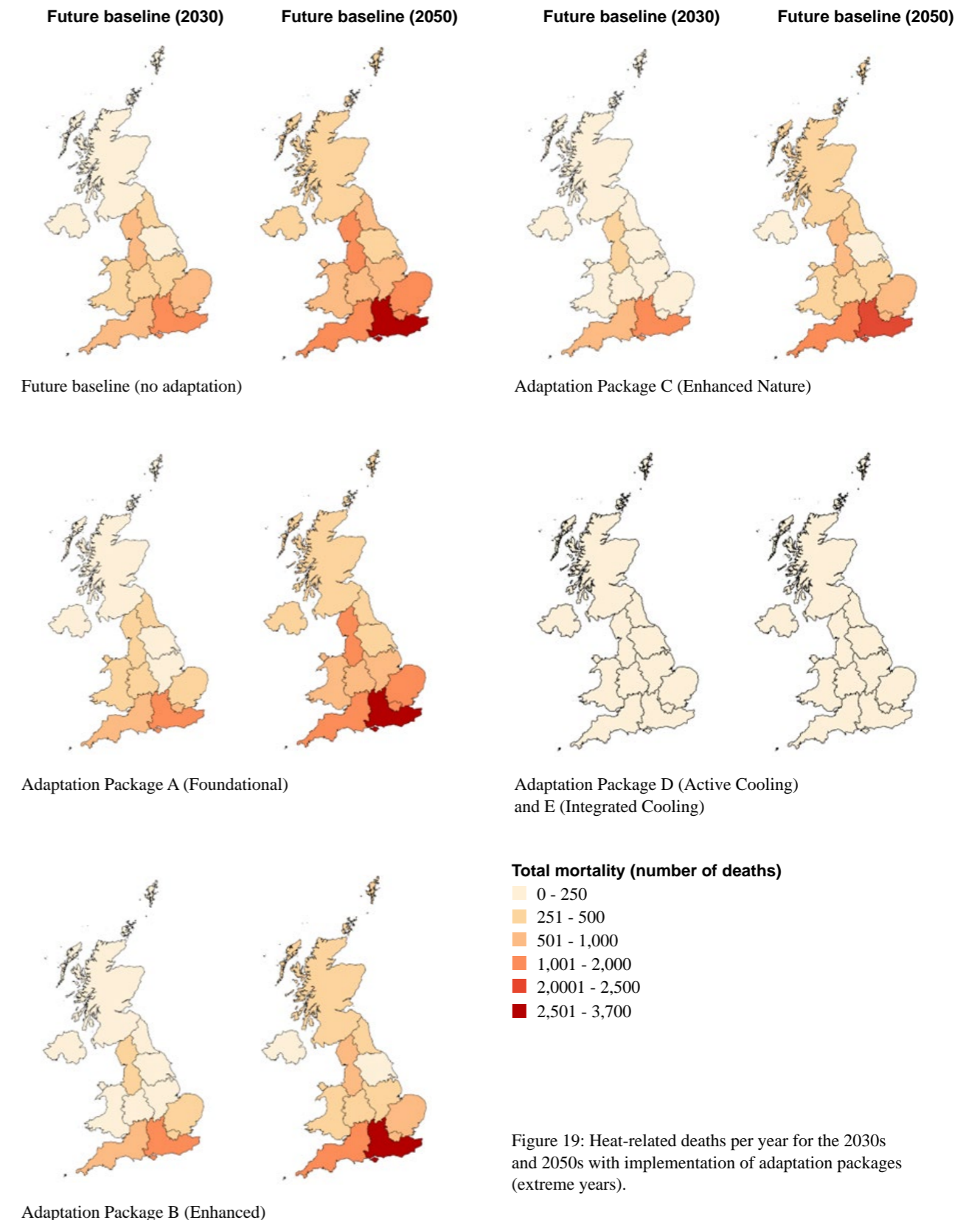


Figure 19: Heat-related deaths per year for the 2030s and 2050s with implementation of adaptation packages (extreme years).

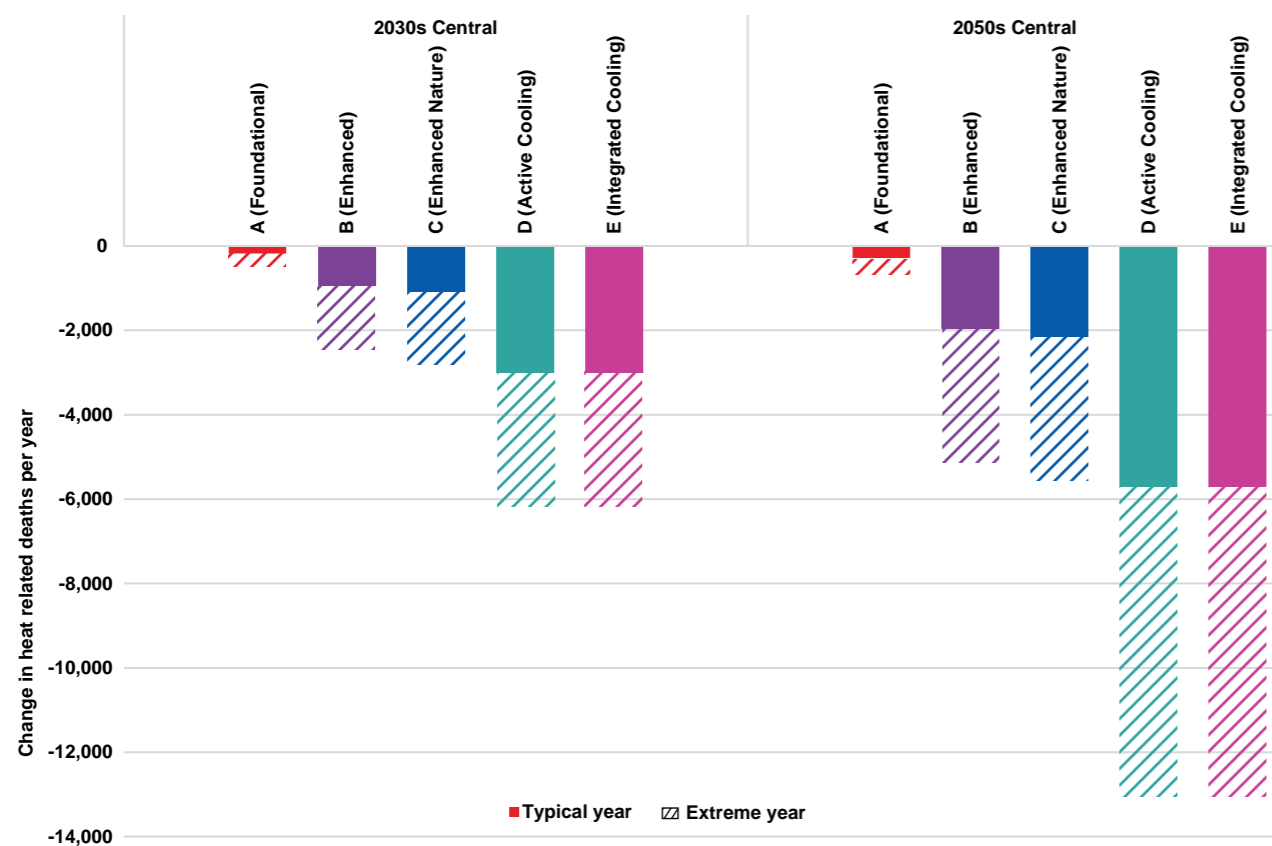


Figure 20: Impact of adaptation packages for the UK on heat-related deaths per year in the 2030s and 2050s.

6.1.2 Reduction in productivity risk

It was assumed that around 65% of indoor workplaces already have air-conditioning [23], meaning the remaining workplaces are vulnerable to overheating without further adaptation. Active cooling measures are highly effective at reducing heat-related productivity impacts. All adaptation packages assessed include workplace active cooling. The introduction of active cooling for indoor workplaces across the UK is expected to eliminate all remaining indoor productivity impacts, reflecting that indoor workers are protected from heat impacts when active cooling is available.

Outdoor workers remain the most exposed to heat stress. As the study only considers urban areas, construction workers are the only sector to be considered as ‘outdoor’ and are assumed to undertake the highest intensity work (see Appendix A.1 for full method to quantify productivity impacts). Construction site shading therefore helps reduce productivity losses among these workers, by reducing solar glare. Construction site shading is implemented in all packages.

The modelling results show that implementing these adaptation packages across the UK substantially reduces lost working hours compared with the baseline. Urban measures in Packages B and C can produce greater benefits to the baseline (no adaptation) due to influences on outdoor workers, in addition to shading. However, some productivity losses remain where outdoor exposure cannot be fully avoided. Adaptation has the potential to reduce heat-related GVA loss by up to 98% if implemented across the UK, with greater avoided GVA loss in later decades as climate change accelerates.

	2030s				2050s			
	Change in lost hours (1000 hours)		Change in total GVA loss (£million)		Change in lost hours (1000 hours)		Change in total GVA loss (£million)	
	Typical year	Extreme year	Typical year	Extreme year	Typical year	Extreme year	Typical year	Extreme year
A (Foundational)	5,300	14,900	270	710	17,800	49,400	1,200	3,200
B (Enhanced)	5,400	15,000	270	720	18,000	50,000	1,200	3,300
C (Enhanced Nature)	5,400	15,000	270	720	18,000	50,000	1,200	3,300
D (Active Cooling)	5,300	14,900	270	710	17,800	49,400	1,200	3,200
E (Integrated Cooling)	5,300	14,900	270	710	17,800	49,400	1,200	3,200

Table 9: Reduction in productivity hours lost compared with the baseline (no adaptation), due to adaptation packages implemented across the UK. Results show typical and extreme years in a central warming scenario.

	2030s		2050s	
	Total monetised risk reduction in a typical year (£billion)	Total monetised risk reduction in an extreme year (£billion)	Total monetised risk reduction in a typical year (£billion)	Total monetised risk reduction in an extreme year (£billion)
A (Foundational)	0.41	1.1	1.4	3.8
B (Enhanced)	1.0	2.6	2.5	6.9
C (Enhanced Nature)	1.1	2.9	2.7	7.2
D (Active Cooling)	2.6	5.4	5.9	12
E (Integrated Cooling)	2.6	5.4	5.9	12

Table 10: Aggregated risk reductions generated by adaptation packages, relative to baseline monetised impacts of heat if implemented across the UK.

6.2 Summary

The implementation of adaptation packages across the UK reduces the monetised risk of heat-related mortality and productivity loss. The aggregate impact across both monetised risk reductions is summarised in Table 10. These monetised risk reductions are relative to the baseline monetised impacts (with no adaptation packages applied) presented in Section 4. Monetised risk reductions are higher in extreme years compared with typical years and increase further from the 2030s to the 2050s. This demonstrates the greater impact and value of adaptation in a warming climate.

£12bn avoided

Adaptation can reduce heat-related mortality and productivity losses by up to £12 billion per year by the 2050s.

7. Testing the influence of assumptions about the future

Any modelled approach can be highly sensitive to the underlying assumptions; in this case, assumptions about what the future might be like. The influence of future assumptions was tested through a series of sensitivity studies to explore how uncertainty in climate change and socioeconomic conditions affected the results.

The sensitivity studies considered a faster rate of warming through a ‘high climate change’ sensitivity test, and different population age structure and productivity forecasts through a ‘socioeconomic’ sensitivity test. A reasonable worst case which considered both these sensitivities together was also considered as a ‘high impact’ scenario.

The risk reduction resulting from applying the sensitivities was recalculated for comparison. Evaluating these futures alongside the core scenarios gave greater confidence that the recommendations would remain robust, even if real-world conditions differ from assumptions.

Additional sensitivity testing was also carried out to understand how focusing the adaptation packages on building-scale measures for homes alone would influence the findings of the study.

Results for the high climate change sensitivity are used in the benefit-cost analysis in Section 8 and presented in detail in Section 6.1. The other sensitivity studies were not considered in producing a benefit-cost ratio but were used to test and validate assumptions and are presented in Appendix A.3.

Sensitivity studies

High climate change sensitivity: This considered the impact of a faster rate of global warming. The high climate change scenario included warming of 2°C in the 2030s and 2.5°C in the 2050s, in addition to the 1.5°C in 2030s and 2°C for 2050s analysed.

High socioeconomic sensitivity: The sensitivity study for mortality used an ONS “old age structure” [24] for uplifting the baseline all-cause deaths to the future scenarios. The highest vulnerability to mortality from heat is age, therefore this sensitivity assumes a greater proportion of older people than the baseline future results. For productivity, a higher productivity workforce was considered. This matters because higher assumed productivity increases the economic value of each hour worked, meaning that the same number of hours lost to heat results in a larger GVA loss.

High impact: The study combining the high climate change and high socioeconomic sensitivities to represent a reasonable worst case.

‘Building-only’ variants: For Packages B (Enhanced) and C (Enhanced Nature), the large-scale urban measures were removed to produce a set of ‘building-only’ variants. Urban-scale measures, which cover larger areas, are generally more expensive than building-scale measures. These sensitivity studies looked at more lightweight and targeted solutions to reduce capital costs.

7.1 Results of sensitivity studies

The studies showed that:

- A warmer climate leads to significantly higher baseline impacts in the absence of pro-active adaptation. Heat-related GVA losses increase by around 310% and heat-related deaths rise by up to 60% in a typical year in the 2050s in the high climate change scenario compared to the central scenario. As a result, the absolute monetised benefits of adaptation are greater, with combined productivity and mortality risk reductions around two to three times higher under the high warming scenario.
- An older future population leads to higher projected mortality rates in the 2030s and 2050s, however, by the 2050s this also results in lower monetised impact compared to the core study. This occurs because older populations have fewer Years of Life Lost, reflecting their shorter remaining life expectancy. Adaptation packages could have a greater impact on number of lives lost, but less so on the monetised risk reduction from reduced mortality.
- A higher productivity workforce results in the same number of lost hours as the core study, but each hour has a higher economic value. The adaptation packages would therefore result in higher monetised risk reduction from heat-related productivity loss.
- The high impact sensitivity considered both high climate change and high socioeconomic scenarios. The results were consistent with findings from individual studies, where an older population leads to higher heat-related mortality but lower monetised impacts, whilst a more productive workforce experiences similar lost working hours but greater GVA losses, even under more extreme heat conditions.

- Building-only variants of the adaptation packages result in equivalent reductions in heat-related productivity impacts. These packages still reduce mortality compared with the baseline (no adaptation), however to a lesser extent compared with the variants of Packages B (Enhanced) and C (Enhanced Nature) that include urban-scale measures. This shows the benefit of combining building- and urban-scale measures within a package.

The data sources and assumptions used in the sensitivity analyses are presented in Appendix A.1. The results for the sensitivity studies for extreme years are presented in Appendix A.3.

7.2 High climate change sensitivity study

In the core analysis in this study, a climate scenario for the 2030s and 2050s was modelled, which we will refer to as the ‘central scenario’ and which relates to global warming of 1.5°C in the 2030s and 2°C for the 2050s. A higher rate of warming was tested for the 2030s and 2050s, called the ‘high scenario’ and relating to global warming rates of 2°C in the 2030s and 2.5°C in the 2050s.

These results are for a typical year, where each adaptation package is assessed against its future baseline. The adaptation packages are applied UK-wide.

Up to +60% deaths

Heat-related deaths rise by up to 60% by the 2050s (typical year) under higher warming, compared with the central scenario.

+310% productivity losses

Under higher warming, heat-related GVA losses increase by around 310% by the 2050s (typical year), compared with the central scenario.

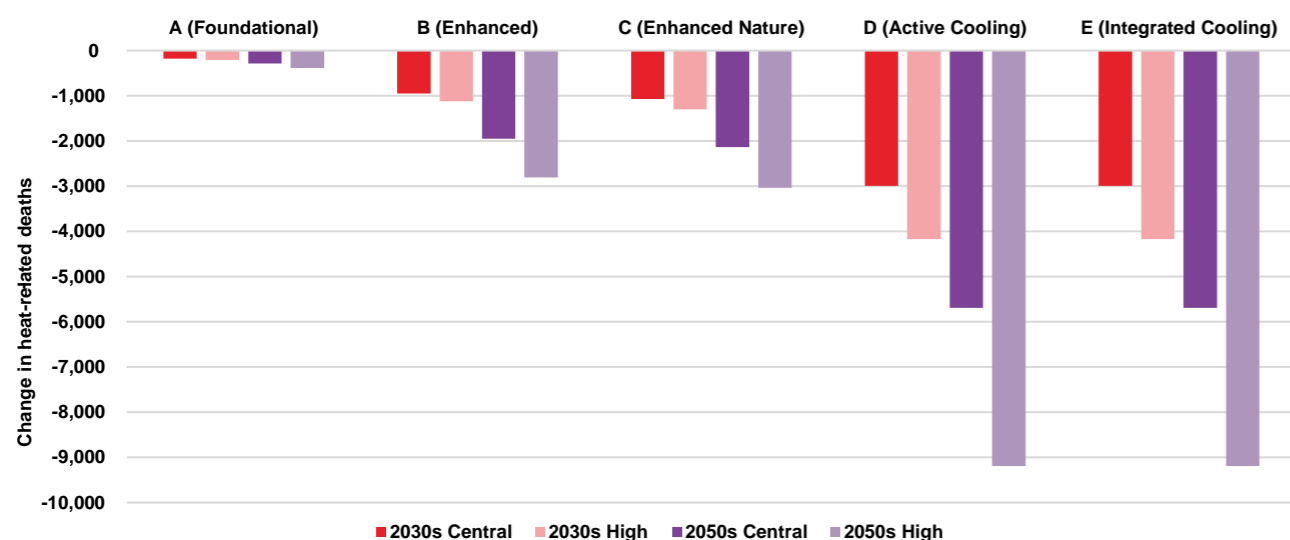


Figure 21: Change in heat-related deaths between the baseline (no adaptation) and adaptation packages for the four climate scenarios in typical years.

7.2.1 Mortality

Without pro-active adaptation, and under a higher warming scenario, heat-related mortality increases substantially, reaching around 4,200 deaths in a typical year by the 2030s and 9,200 by the 2050s (a 40-60% increase compared to the central scenario).

Under a warming climate, adaptation measures can still substantially reduce heat-related mortality. For example, under a national rollout scenario, Package C (Nature Enhanced) was projected to avert around 3,000 deaths in the 2050s. However, under higher warming scenarios the baseline rate of heat-related mortality rises sharply. With the rollout of adaptation measures, more deaths are prevented under higher warming scenarios in absolute terms, but the proportion of total deaths avoided compared with the baseline is lower. Package C was estimated to avert around 42% of heat-related deaths under the central scenario, compared with approximately 38% under higher warming.

In contrast, Packages D and E remain the most effective at reducing mortality under both scenarios, as they are assumed to eliminate all heat-related deaths through use of home air-conditioning. These packages deliver markedly greater reductions in heat-related mortality under a high warming scenario, avoiding around 4,200 deaths in the 2030s compared with 3,000 under the central scenario, an increase of 40% if deployed nationally. By the 2050s, avoided deaths rise from 5,700 to approximately 9,200, an increase of around 61%.

7.2.2 Productivity

Under a higher warming scenario, heat-related productivity impacts increase substantially in the absence of adaptation. Here, lost working hours across the UK are projected to rise to around 24 million in a typical year by the 2030s and 65 million by the 2050s, an increase of 190% and 220% compared to the central scenario. In monetary terms, this corresponds to around £2.1 billion in lost GVA in the 2030s and £7.4 billion by the 2050s in a typical year under a higher warming scenario, corresponding to a 280-310% increase compared to the central scenario if implemented across the UK.

The benefits of adaptation also increase under higher warming, with larger absolute reductions in both lost hours and GVA. In a typical year in the 2030s, all packages reduce lost working hours by around 14 million hours, generating approximately £730 to £740 million in avoided GVA losses under a national rollout scenario. This is a substantial increase compared to the central scenario, where reductions are around 5.3 to 5.4 million hours and £270 million per year, equivalent to an uplift of around 2.5 to 3 times (Table 11).

	2030s				2050s			
	Change in lost hours (1000 hours)		Change in total GVA loss (£million)		Change in lost hours (1000 hours)		Change in total GVA loss (£million)	
	Typical year	Extreme year	Typical year	Extreme year	Typical year	Extreme year	Typical year	Extreme year
A (Foundational)	13,900	39,000	730	2,000	54,200	157,000	3,400	9,900
B (Enhanced)	14,000	39,000	740	2,000	55,400	161,000	3,600	10,200
C (Enhanced Nature)	14,000	39,000	740	2,000	55,400	160,000	3,600	10,200
D (Active Cooling)	13,900	39,000	730	2,000	54,200	157,000	3,400	9,900
E (Integrated Cooling)	13,900	39,000	730	2,000	54,200	157,000	3,400	9,900

Table 11: Reduction in productivity hours lost compared with the baseline (no adaptation), due to adaptation packages implemented across the UK. Results show typical and extreme years in a high warming scenario.

	2030s		2050s	
	Total monetised risk reduction in a typical year (£billion)	Total monetised risk reduction in an extreme year (£billion)	Total monetised risk reduction in a typical year (£billion)	Total monetised risk reduction in an extreme year (£billion)
A (Foundational)	0.9	2.5	3.8	11
B (Enhanced)	1.6	4.4	5.5	15
C (Enhanced Nature)	1.8	4.8	5.7	16
D (Active Cooling)	3.5	8.1	12	24
E (Integrated Cooling)	3.5	8.1	12	24

Table 12: Monetised reductions in risk to mortality and productivity due to adaptation packages implemented across all UK, in a high warming scenario.

7.2.3 Total monetised impacts of adaptation

The total monetised risk reduction from a full UK rollout of the adaptation packages increases under the higher warming scenario. The magnitude of the risk reduction varies across packages, with the risk reduction of Package A (Foundational) almost three times greater in the high warming scenario, while the remaining risk reductions of packages are just over twice as high. This suggests that investing in adaptation offers even stronger value for money as temperatures rise.

8. Reaching a cost-effective adaptation approach for the UK's towns and cities

Adaptation packages can significantly reduce heat-related mortality and productivity impacts, but understanding which package represented the best national investment required looking beyond risk reduction alone. A cost-effective strategy depends on the balance between the benefits each package delivers – including wider co-benefits such as improved air quality, biodiversity and reduced flood risk – and the investment required to implement them across UK buildings and urban areas. This section outlines the combination of costs with benefits, to identify which packages offer the strongest return on investment and how different levels of rollout influence the overall cost-effectiveness of heat adaptation packages at a national scale. The analysis in this section was designed to appraise the overall value for money of each adaptation package.

The extent of implementation across the UK was an important consideration. Modelling was adjusted to test whether adaptation should be deployed everywhere or prioritised in the highest-risk locations. The baseline heat risk assessment was used to determine the most effective rollout scenario and establish an optimal scenario to allow comparison across packages.

The BCRs were subsequently estimated to compare the net present value (NPV) of monetised benefits of adaptation – including avoided deaths, reduced productivity impacts and wider co-benefits – with the full costs of implementation. A BCR greater than one indicates that the benefits outweigh the costs.

This approach surfaced a cost-effective package and assessed how its performance changed under different rollout scales. This section therefore shows not only which package offers the strongest return on investment, but also how and where adaptation should be rolled out to deliver the greatest national benefit.

The cost-benefit analysis follows HM Treasury Green Book guidance and applies best practice in cost estimation, discounting, sensitivity testing and uncertainty management. Further methodological detail is provided in Appendix A.1.

8.1 Determining a cost-effective adaptation package

8.1.1 Implementation rollout

The pace and spatial extent of implementation have a major influence on the benefits delivered and the overall cost of adaptation. It is essential to understand whether measures should be deployed universally across the UK or prioritised in the highest-risk locations, both to maximise the benefit-cost-ratio and support future analysis relating to the feasibility of implementing the measures at scale.

The baseline assessment illustrated that heat risk varies significantly across the UK. This variation reflects not only climatic differences, but also socioeconomic and physical factors such as age distribution, housing type and concentration, and the make-up of the local economy. These spatial differences mean that the same level of investment will deliver different levels of benefit across the UK, reinforcing the need for prioritised implementation.

To explore this, an initial rollout scenario was determined by ranking all LSOAs according to their present day monetised heat impacts on mortality and productivity, and then cumulatively summing these impacts from highest to lowest (Figure 22). This approach identifies the sequence in which areas contribute to total national impact and provides a consistent basis for comparing the cost-effectiveness of different adaptation packages. The cost of implementing the adaptation package increases in proportion to the scale of rollout, although it is not strictly linear due to geographic variation in construction costs and differences in local employment density.

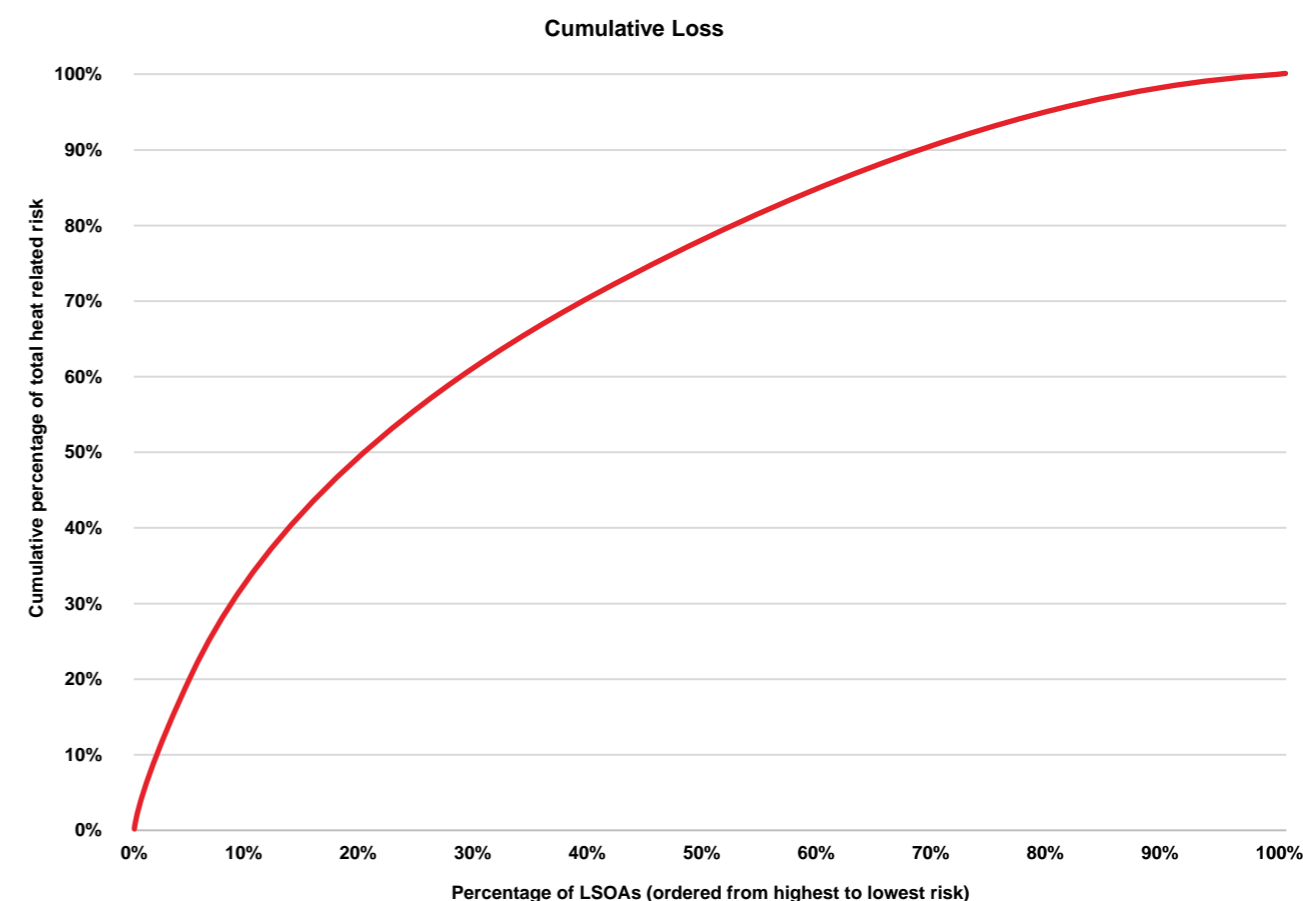


Figure 22: Cumulative monetised heat impact of LSOAs across the UK, ordered according to relative heat risk.

The resulting cumulative loss curve shows that the:

- Highest-risk 20% of LSOAs account for 50% of total monetised risk
- Highest 30% account for 61.5%
- Highest 40% account for 71%
- Highest 60% account for 85%

Beyond the highest-risk 30% of areas, additional rollout covers a growing share of the country but delivers progressively smaller reductions in overall heat risk, indicating diminishing returns. As a result, a 30% implementation rollout scenario was selected to test the value for money of the adaptation packages. Further details on the methodology are presented in Appendix A.1.

Implementation was assumed to begin in 2030, with rollout staged across three periods between 2030 and 2045 to reflect a more realistic delivery pathway. Each rollout stage was assumed to be implemented within five years. In practice, rollout would depend on multiple factors - including supply-chain capacity, construction sequencing and procurement timelines. For the purpose of this study, a reasonable and illustrative rollout scenario was adopted for the modelling assumptions. For the purposes of the cost-benefit analysis, all risk and risk reduction was transformed to represent a typical year following the methodology set out in Appendix A.1. A typical year describes average, or “normal” climate conditions without unusually hot weather or extreme events.

8.1.2 Risk reduction benefits of adaptation packages

Total monetised risk reduction was calculated for the 30% rollout scenario selected. The largest risk reductions are delivered by Active and Integrated Cooling packages, D and E (Figure 23). Between 2025 and 2059, the cumulative discounted benefits of these packages exceed £50 billion. This is around 1.7 times greater than the next most impactful package, which focuses on a mix of passive and nature-based adaptation measures and generates approximately £30 billion in benefits.

The monetised benefit of avoided mortality drives these risk reductions. This comprises the largest component of risk reduction across almost all of the packages, making up 75% of risk reduction in active cooling packages, more than four times the gains from reduced productivity losses at work during hot weather.

The only exception is Package A (Foundational), where avoided productivity losses represent the largest share of risk reduction (56%). This reflects the package's focus on passive cooling measures at the building scale, which are comparatively less effective at reducing heat-related mortality.

8.1.3 Heat-related sleep deprivation

As an additional risk reduction, the impacts of heat-related sleep deprivation on productivity were also considered alongside the detailed analysis of mortality and productivity impacts. This assessment examined the potential for adaptation packages to reduce sleep disruption during periods of high temperatures and the subsequent resulting effect on productivity. See Appendix A.1 for method.

Across all packages, the productivity benefits from improved sleep are relatively small but consistent, contributing around 5-10% of total risk reduction. These impacts are therefore secondary compared with the much larger gains from avoided mortality and reduced productivity losses at work.

47% from co-benefits

For the nature-enhanced package, almost half of total benefits come from wider co-benefits, not heat risk reduction alone

8.1.4 Considering co-benefits alongside risk reduction

The package centred on nature-enhanced solutions (Package C) delivers the highest overall monetised benefits when wider environmental co-benefits are included alongside direct heat risk reduction. Together, heat risk reduction and wider co-benefits generate benefits totalling £58 billion (present value terms, 2025-59) under a 30% implementation rollout scenario (Figure 23). In this package, co-benefits account for around 47% of total benefits, illustrating the broader societal value of nature-based solutions that reduce heat risk.

Four key co-benefits of green and nature-based solutions were considered in the analysis: carbon sequestration, stormwater mitigation, air pollution removal and recreational value. The method and source used to estimate these wider benefits is outlined in Appendix A.1. These estimates are indicative and intended to provide an estimated understanding of potential wider impacts, rather than a comprehensive or detailed valuation.

8.1.5 Costing of adaptation packages

For each adaptation package, capital (capex), operational (opex) and replacement (repex) costs were calculated for all building-scale and urban-scale measures. The total accumulated costs for the period 2030-2059 are presented in Table 13 and Table 14.

The cost calculations reveal significant variation in costs across the different adaptation packages and individual measures, ranging from £18 billion to £2.2 trillion cumulatively in present value terms over the 2025-2059 period, for a 30% rollout of Packages E (Integrated cooling) and C (Enhanced Nature) respectively. Urban-scale measures, which cover larger areas and typically involve more significant works, are generally more expensive than building-scale measures. At the building-scale, deeper passive retrofit measures accumulate greater costs than more lightweight solutions. Solutions that can be more targeted incur lower costs.

For instance, in active cooling retrofits, lightweight solutions were selected that focus only on cooling one living space in a property, helping to reduce overall costs. For external shading for workers, the extent of shading is linked to the number of workers in an area, providing a more targeted and lower-cost solution.

Further details on costs are provided in Appendix A.1.

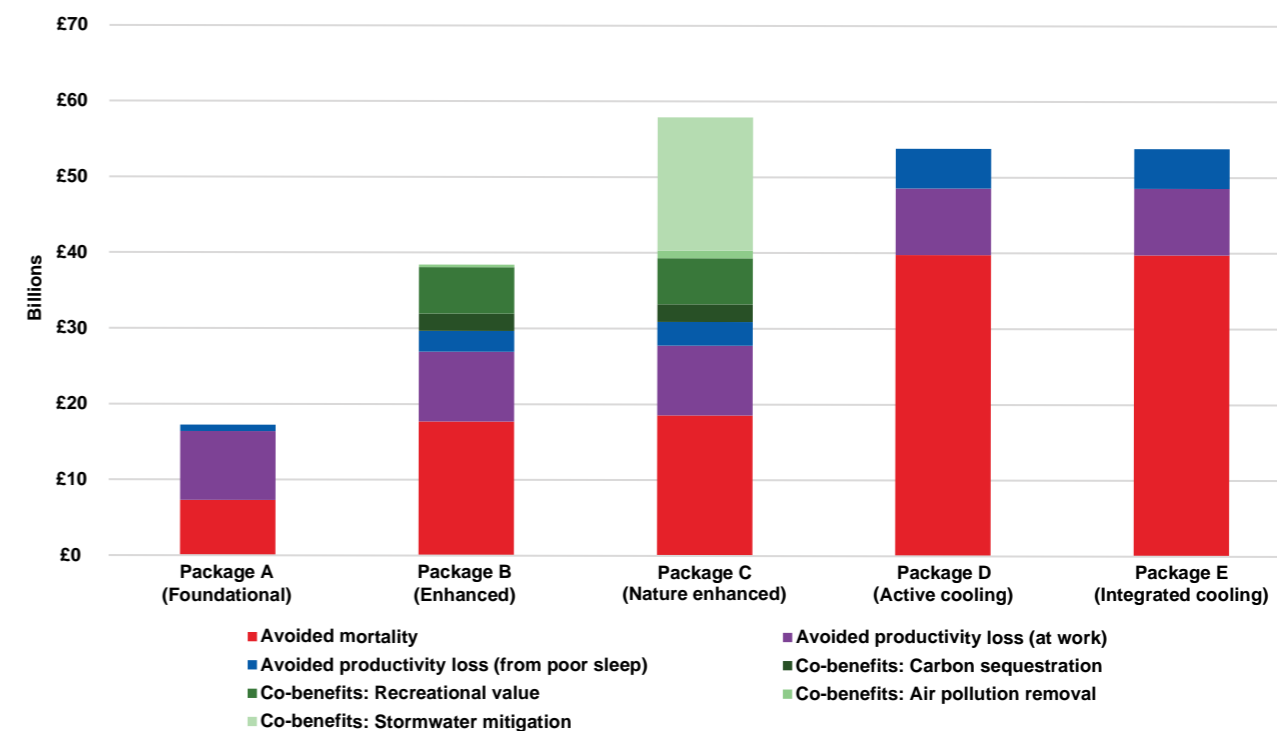


Figure 23: Total monetised risk reduction and co-benefits of adaptation packages discounted, 2025-59, 30% rollout scenario.

8.1.6 Selection of a cost-effective adaptation package

The appraisal of the selected packages reveals a large spread of benefit-cost ratios.

When comparing costs and benefits of a rollout across the top 30% of at-risk regions, packages that include active cooling measures (Packages D and E) show the greatest value for money, with BCRs of 3.2 and 3.0 respectively. Package E, which combines passive and active cooling, was selected as the preferred option. In addition to a strong BCR, Package E delivers energy efficiency improvements and reduces operational costs, with passive measures that can also improve winter thermal performance and reduce heating demand (not accounted for in our calculation). While active cooling systems may result in some heat being released to the external environment, incorporating passive measures alongside active cooling helps to reduce overall cooling demand and limit potential contributions to the urban heat island effect.

Package A, which includes foundational measures such as improved shading, ventilation and insulation, has a BCR of 0.1, around 30 times lower than Packages D and E. This highlights that the simplest or lowest cost approach is not necessarily optimal, as limited interventions may fail to deliver sufficient risk reduction to justify their costs.

Packages centred on large-scale urban and nature-based measures also do not achieve value for money within this appraisal. Packages B and C, which build on Package A by adding measures such as green and blue infrastructure and wider urban cooling strategies, involve very high implementation costs. As a result, costs far outweigh the monetised benefits, even when environmental co-benefits are included, leading to very low BCRs of 0.02 and 0.03 respectively.

For the purposes of this study, Package E was selected as the cost-effective package for further analysis to understand how it could be implemented strategically in the UK.

Under the high climate change scenario, Packages D and E deliver even stronger value for money, with BCRs of 6.3 and 6.0 respectively (Table 14). This indicates that targeted active cooling measures provide the highest value for money even under more severe climate conditions. While the absolute benefits of all packages increase as heat risks intensify, Packages A, B and C still do not achieve value for money, with BCRs remaining below 1.

Package	Cumulative benefits, (£billion, 2025-59, discounted)	Cumulative costs, (£billion, 2025-59, discounted)	BCR
A (Foundational)	17	120	0.1
B (Enhanced)	39	2,000	0.02
C (Enhanced Nature)	58	2,200	0.03
D (Active Cooling)	54	17	3.2
E (Integrated Cooling)	54	18	3.0

Table 13: Summary of benefit-cost ratio for each adaptation package (central climate scenario, 30% rollout scenario)

Package	Cumulative benefits, (£billion, 2025-59, discounted)	Cumulative costs, (£billion, 2025-59, discounted)	BCR
A (Foundational)	44	120	0.4
B (Enhanced)	77	2,000	0.04
C (Enhanced Nature)	97	2,200	0.04
D (Active Cooling)	120	19	6.3
E (Integrated Cooling)	120	20	6.0

Table 14: Summary of benefit-cost ratio for each adaptation package (high climate scenario, 30% rollout scenario).

8.2 Testing scenarios for adapting the UK's towns and cities

The BCR was calculated for the selected package (Package E) under the 30% rollout scenario and then repeated for a range of alternative rollout options to understand how value for money changes with scale and whether other rollout configurations present advantages.

Package E (Integrated cooling) delivers the strongest returns at lower rollout levels, with the BCR declining as the scale of rollout increases; reflecting the fact that the areas most vulnerable to heat are prioritised first (Figure 24). Rolling out Package E to the top 45% of most at-risk LSOAs maintains heat-related deaths in 2059 remain at just below today's levels, while delivering a BCR of 2.6 (central scenario).

However, all rollout options provide attractive BCRs in reducing heat-related risks to mortality and productivity, with the BCR in the high climate change scenario reaching up to 6.7 when considering only the top 10% of most at-risk LSOAs. Even delivering Package E across the UK (100% rollout) yields a BCR between 2 (central scenario) and 4.3 (high scenario) and is assumed to mitigate all heat-related deaths.

In a high climate scenario, a rollout of 70% or greater is sufficient to keep heat-related deaths at present day levels of approximately 2,000 per year (in a typical year), while still maintaining a BCR of 5.4.

A 30% rollout was selected as the preferred option as it provides the best balance between value for money and risk reduction, particularly in terms of avoided future heat-related deaths.

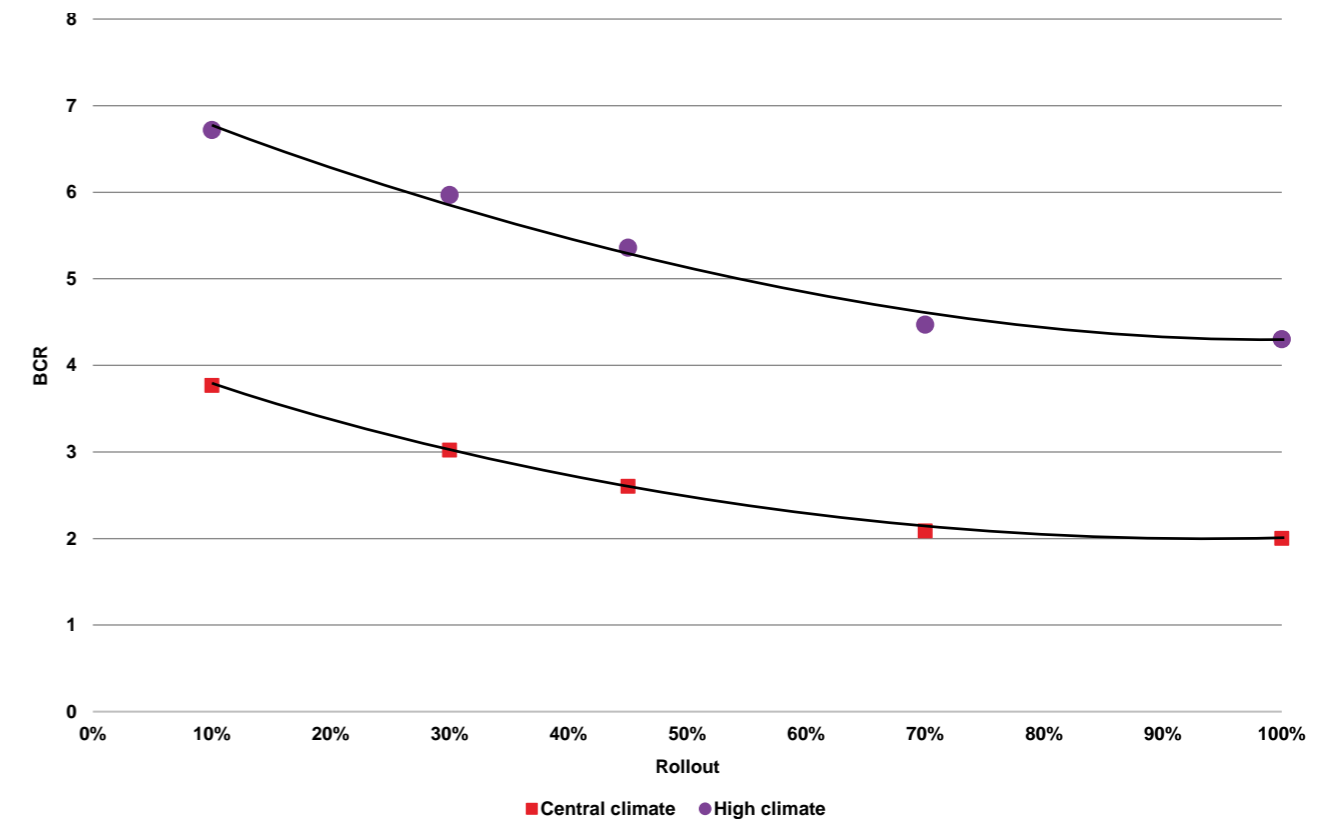


Figure 24: BCR of Package E (Integrated cooling) under tested rollout scenarios and climate scenarios.

Under a 30% rollout scenario, annual monetised benefits exceed costs in the early 2030s, generating a positive return on investment by 2035. Investment is largely front loaded, with most capital expenditure occurring during the initial delivery phase, while benefits persist and grow over time as adaptation measures are implemented and heat risks intensify. As a result, the overall profile shows that benefits continue to rise over time, whereas costs remain relatively stable following the initial investment period, leading to sustained net benefits.

The cost-benefit analysis shows that while all adaptation packages deliver meaningful reductions in heat-related mortality and productivity impacts, their overall value depends on the balance between benefits, co-benefits and implementation costs. Package E consistently delivers the strongest return on investment under a range of rollout scenarios and future climate conditions, reflecting the combined effectiveness of active cooling and building-scale passive measures.

However, the analysis also highlights that strategic, staged rollout is essential: costs and benefits evolve over time, and the most efficient pathway is one that targets adaptation where risks are highest. Although uncertainties remain—particularly around future climate extremes, behavioural responses and long-term system capacity—the findings provide a clear evidence base for what cost-effective adaptation could look like.

BCR up to 6.7

Active and integrated cooling deliver the strongest value for money, with benefit-cost ratios exceeding 6 under higher warming.

9. Key findings and conclusions

This study has combined a range of analyses to explore baseline present-day and future heat risk in the UK's towns and cities, and to offer guidance about the most cost-effective package of adaptation measures to reduce impacts on mortality and economic productivity. The findings are instructive for policy, planning and implementation of adaptation solutions. This section summarises the key takeaways from the study.

Discussion on the limitations of the analysis, as well as details on technical limitations, are presented in Appendix A.4.

Key findings

Heat risk in the UK is rising rapidly, affecting nearly all urban areas.

This analysis shows that the impacts of extreme heat on mortality and economic productivity are already significant and will intensify sharply under central projected climate scenarios corresponding to global mean temperature increases of 1.5°C warming in the 2030s and 2°C in the 2050s, in the absence of adaptation.

In 2022, the UK experienced the highest number of heat-related deaths on record, with older adults identified as particularly vulnerable. The analysis estimates around 4,000 heat-related deaths occurred in 2022, a figure that exceeds twice the number of road traffic deaths recorded in the same year [2]. Even in a typical UK summer, heat can still cause significant loss of life, causing an estimated 1,900 deaths per year across the UK according to this analysis. Under present-day conditions, 80% of heat-related deaths occur in people aged 'over 75'.

As the climate warms, if no action is taken, annual heat-related deaths could triple by the 2050s, with an even sharper increase in extreme heat years. This study shows that the impact of extreme heat is projected to accelerate at a more-than-linear pace. Excess deaths in typical years may grow by 60% in the 2030s (3,000 per year) and 200% in the 2050s (5,700 per year). Extreme heat years may see heat-related deaths increasing to

6,100 and 13,000 per year over the same periods. The proportion of deaths occurring in the 'over 75' age group could rise to 90%, reflecting an ageing society combined with age-related vulnerability.

Increasing temperatures will have a growing impact on economic productivity. This analysis shows approximately 0.93 million working days were lost in 2022 due to extreme heat, costing the UK approximately £450 million in Gross Value Added (GVA). By 2030, heat-related losses are projected to increase to around 1.8 million working days in an extreme year, with associated GVA impacts of approximately £720 million. Looking ahead to the 2050s, heat-related lost working time is projected to increase substantially—around 3.6 times higher than in the 2030s, reaching up to 6.3 million lost working days—with GVA impacts rising by almost five-fold (4.6 times) over the same period to around £3.3 billion per annum in GVA. Even in typical years, heat can impact the UK economy, with impacts increasing from an estimated £200 million per annum today, to around £540 million per annum by the 2030s, and over £1.8 billion in the 2050s.

As temperatures rise, higher productivity sectors will be significantly affected, bringing impacts for the UK economy. In the present day (2022), extreme urban heat primarily impacts the productivity of outdoor-based sectors, such as construction. However, without adaptation heat will increasingly exceed thresholds for indoor comfort, affecting higher productivity sectors such as professional services. This translates into an accelerated impact on the country's economy.



Heat impacts are disproportionately felt across the UK.

The South East currently experiences the most heat-related deaths in the UK, and this trend is expected to continue into the future. By the 2050s, forecasts suggest that almost one-quarter of all heat-related fatalities in the country will occur in the South East. The South East experiences higher baseline excess heat-related deaths per capita than other regions, driven by higher temperatures and an older population.

Heat will disproportionately impact the South of England's economy, with Greater London accounting for up to 40% of the national heat-related productivity loss across all time periods. This is due to the high exposure to extreme temperatures, exacerbated by the urban heat island effect, and the density of high productivity jobs in the region. However, other urban areas in the country show significant impacts such as Bristol and Bournemouth.

Overall, the study reveals that 60% of monetised heat impacts on mortality and productivity in the UK are concentrated in only 30% of the country. Impacts are predominantly focused on the South East, South West, and London. Nevertheless, heat vulnerabilities exist across the UK, and communities nationwide are expected to experience heat-related impacts.

Reducing heat risk through adaptation packages

A wide range of adaptation options exists to mitigate these risks: physical measures such as reflective roofs, insulation improvements, and large scale greening, and operational measures such as adjusting work hours, implementing cooling protocols, and providing public guidance during heatwaves. This study focused on physical adaptation measures, recognising their potential to provide lasting benefits. We modelled urban-scale and building-scale measures to determine the impact of adaptation on mortality, productivity, and associated monetised impacts.

A long list of measures was assessed through a multi-criteria analysis which defined different levels of impact (in terms of heat risk-reduction and co-benefits), cost, and implementation potential. These were then combined in five different packages reflecting different combinations of active and passive measures and different intensities of intervention. Packages A-C focused on increasingly more comprehensive deployment of passive measures, including nature-based solutions at an urban scale. Package D and E focused on active cooling in residential buildings, with package E augmented by the selective use of passive building-scale measures. All of the packages included air-conditioning in offices to mitigate indoor productivity losses, as well as construction shading to reduce productivity losses during outdoor work.

The analysis shows the effect of adaptation on mortality, productivity and associated monetised impact if these packages were rolled out in urban areas across the whole of the UK.

Adaptation measures can significantly reduce heat-related impacts on mortality and productivity across all future scenarios. Even the least intensive packages (A, B) can deliver measurable benefits, while the highest-impact packages (D, E) facilitate major reductions in both deaths and productivity losses.

The largest reductions in heat-related mortality are available through implementation of integrated adaptation packages. Passive measures (Foundational - Package A) reduce heat-related deaths by almost 180 per typical year in the 2030s (6% of the future baseline) when deployed across the UK, rising to almost 290 per year by the 2050s. By comparison, incorporating nature-based measures across the UK (Enhanced Nature – Package C) reduces deaths by a third on the baseline, avoiding over 1,000 deaths per year in a typical year in the 2030s and more than 2,000 deaths per year by the 2050s, reflecting the combined impact of indoor cooling and moderated outdoor temperatures.

Combining passive measures with targeted active cooling (Integrated Package E) delivers the greatest overall benefits when broader energy efficiency impacts are also considered. Package E provided active cooling for homes and indoor workplaces and external shading for outdoor workers, as well as passive measures including insulation and internal thermal blinds. If implemented across the UK, it can reduce heat-related mortality by almost 3,000 deaths per year in the 2030s when implemented across the UK, rising to around 5,700 deaths avoided per year by the 2050s under typical conditions. The pace of grid decarbonisation in the UK will help ensure that future increases in cooling demand are met by a low carbon energy supply [2].

Productivity losses from heat can be mitigated with adaptation measures. Productivity impacts drop substantially under all packages, driven by active cooling for workplaces. The total number of working days lost reduces by almost 680,000 days per typical year in the 2030s and almost 2.3 million days per typical year in the 2050s if the packages are deployed across the UK.

The benefits of adaptation are even more pronounced during an extreme heat year, when risks rise sharply. An integrated approach to adaptation (Integrated - Package E) eliminates almost all indoor heat related deaths even in an extreme year, preventing 6,100 deaths in the 2030s and over 13,000 deaths by the 2050s under a national-scale rollout scenario. Productivity impacts are also significantly reduced under Package E, preventing the loss of almost 1.9 million working days in an extreme year in the 2030s and almost 6.2 million days by the 2050s. Adaptation is essential for protecting people and the economy during the most severe and consequential heat events.

Adaptation offers value for money, but it must be targeted to the most at-risk places first

While adaptation delivers benefits across the country, the degree of risk reduction depends on local climate, built environment, economic conditions, and population vulnerability. In assessing value for money, including benefit–cost ratios (BCRs), the analysis is based on typical year conditions under a central climate scenario.

UK-wide physical adaptation to heat risk requires significant investment, with cumulative present-value costs over the 2025–2059 period ranging from around £18 billion for Package E (Integrated Cooling) to approximately £2.2 trillion for Package C (Enhanced Nature). The analysis explored rollout scenarios across different spatial extents and found that, while benefit–cost ratios remain above one even at full national rollout, the marginal benefits decline as coverage extends beyond higher-risk locations. In particular, rolling out measures across the highest-risk 30% of LSOAs captured a large proportion of the total risk reduction, beyond which additional investment to delivered positive but diminishing returns.

Active and integrated cooling packages provide the greatest value for money in mitigating heat risk in the urban built environment.

In particular, the economic case for adaptation becomes compelling when targeted active cooling is introduced, such as cooling a single high-use room within a dwelling. Packages D and E achieve attractive BCRs (greater than 3) when rolled out to the highest-risk areas, reflecting the substantial reductions in mortality and productivity impacts that integrated cooling delivers.

Package E offers the best value for money overall, achieving the highest risk reduction and the strongest economic return. In addition to a strong BCR, Package E delivers energy efficiency improvements and reduces operational costs, with passive measures that also enhance winter thermal performance and reduce heating demand. These passive measures further help to moderate the externally vented heat associated with active cooling, supporting a more balanced approach to managing urban heat. The package remains cost-effective even under different rollout extents. Benefits outweigh costs under all tested rollout scenarios, including a full UK-wide rollout.

Earlier uptake in the highest-risk locations helps to manage residual risk. The modelling explored the potential effects of risk-informed patterns of uptake and indicates that higher-risk areas adopting measures earlier delivers the greatest benefit per pound spent. For instance, in a central climate scenario, uptake of Package E in the top 45% of at-risk LSOAs maintains heat-related deaths in the 2050s below today's levels, while still delivering an attractive benefit–cost ratio of almost 3.

Under a high climate change scenario, the economic case for adaptation is considerably stronger. The analysis shows that adaptation packages continue to perform well under a high-warming pathway, assuming 2°C warming by the 2030s and 2.5°C by the 2050s. Under this scenario, the BCR increases to above 4 when Package E is rolled out UK-wide and rises to almost 7 when targeted to the top 10% of highest-risk areas. A 70% rollout is sufficient to maintain heat-related deaths at or below present-day levels, while still achieving a BCR above 5.

The study highlights wider benefits from passive and nature-based solutions

While integrated adaptation packages provide the strongest economic case for reducing heat-related mortality and productivity impacts, the wider suite of passive and nature-based adaptation options still plays an important role in delivering multi-benefit outcomes and contributing to the UK's broader environmental and social objectives. Although the scale of the avoided mortality and productivity loss is not sufficient on its own to offset their implementation costs, passive and nature-based measures provide substantial wider benefits that are not fully captured in the BCR for this study.

Co-benefits materially improve the case for adaptation, with the Enhanced Nature package (Package C) delivering the greatest overall benefits. When co-benefits are included, Package C generates around £58 billion in cumulative discounted benefits between 2025 and 2059, exceeding the £54 billion delivered by Packages D (Active Cooling) and E (Integrated Cooling), even though D and E provide the greatest direct heat risk reduction. This uplift is driven by the additional benefits of nature-based solutions, with around 47% of total monetised benefits arising from co-benefits such as air quality improvements, carbon sequestration, urban cooling, stormwater management and recreational value. This makes the case for a more holistic approach: designing, evaluating and delivering nature-based solutions that intentionally serve multiple objectives. This will be essential to enable the uptake of solutions that support long-term resilience across a range of climate hazards, while also addressing wider social and environmental priorities.

Next steps for further understanding urban heat resilience

This analysis demonstrates that heat adaptation materially reduces projected impacts on health and economic productivity. In the absence of adaptation, heat-related mortality and productivity losses could increase rapidly by the 2030s.

The study provides a robust national-scale evidence base on heat risks and the relative performance of different adaptation measures. The results offer consistent insights into the scale, distribution and drivers of heat impacts across the UK, and into the comparative effectiveness of alternative adaptation approaches. The study provides a foundation for further analysis and decision-making to address heat risk in the urban built environment.

The results highlight the importance of understanding who and where heat risks are most concentrated, and how these risks evolve under future climate conditions. Improving awareness of heat exposure and vulnerability—particularly in a country with limited historical experience of extreme heat—remains an important factor in enabling effective resilience-building across sectors and geographies.



A.1 Methodology

This Appendix gives a detailed explanation of the project’s methodology, covering the approach taken, tools and datasets utilised, as well as any assumptions and limitations considered.

A.1.1 Methodology overview

The approach followed the methodology highlighted in Annex 2 of the Well-Adapted UK Report, which is structured around the following steps:

- Quantification of baseline heat impacts, estimating the effects of heat on mortality and labour productivity under current and future climate scenarios, assuming no additional adaptation.
- Appraisal and selection of adaptation measures, using a structured multi-criteria analysis to prioritise feasible and effective building-scale and urban-scale adaptation measures.
- Modelling and economic evaluation of adaptation packages, assessing their ability to reduce heat-related impacts under both central and high-impact sensitivity scenarios.
- Development of a scenario of cost-optimal adaptation deployed by the 2030s and by 2050s.

The analysis covered present day of 2022, as well as projections for the 2030s and 2050s, and considers both climate and non-climate drivers of risk (such as demographic and economic changes). The project’s methods were refined through an initial literature review, validated by a steering group of technical and strategic experts, and are grounded in the latest available data and modelling tools.

Figure A.1 presents an overview of the parameters of the technical analysis which include:

Climate

High spatial resolution, hourly climate datasets were developed for the UK by combining several established climate data sources.

The analysis was carried out on an hour-by-hour basis using a full year representing the climate in both present-day and the future. To ensure that the most severe heat impacts were captured, the modelling focused on extreme heat years—defined here as years with particularly high temperatures.

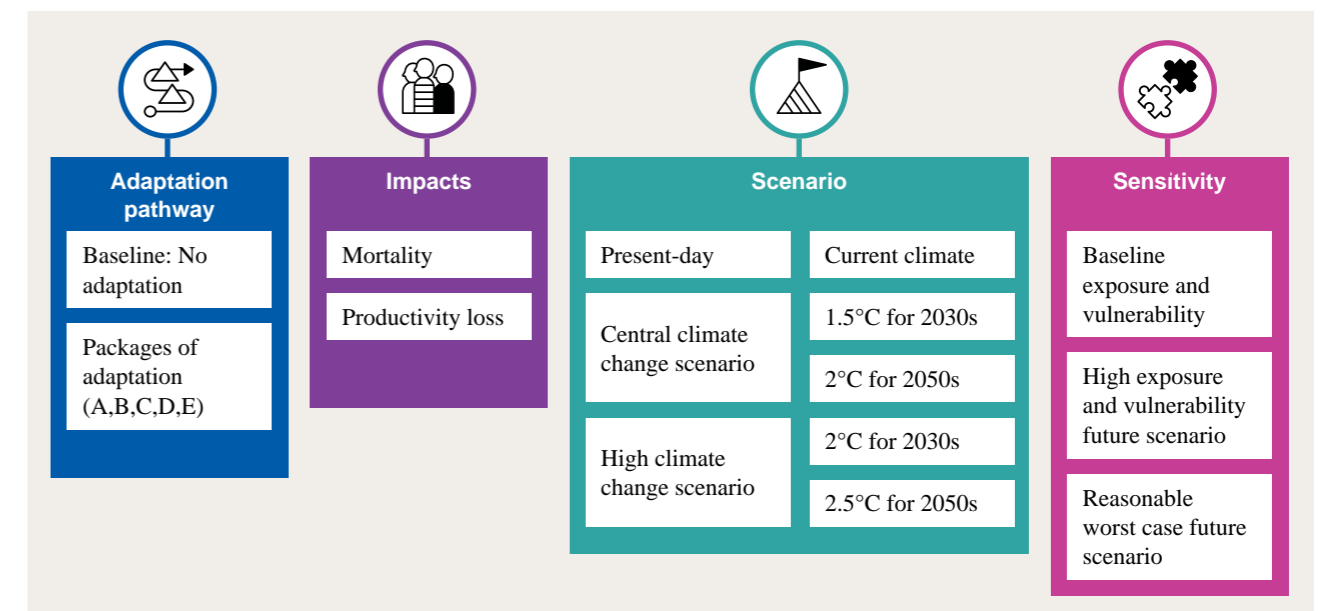


Figure A.1: Overview of project variations setting out key stages.

For the present-day, 2022 was selected as a representative recent extreme heat year. Equivalent extreme climate datasets were developed for the 2030s and 2050s to represent future conditions. Results from these extreme year analyses were then converted to represent a typical year, allowing impacts to be expressed on an average annual basis for use in the economic appraisal.

Future climate was assessed under two scenarios:

- a central scenario, representing moderate levels of warming (1.5°C to 2030s and 2°C to 2050s), and
- a high scenario, representing more severe climate change outcomes (2°C to 2030s and 2.5°C to 2050s).

The climate variables required for the analysis include air temperature, relative humidity and solar radiation. These datasets underpin all modelling of heat-related mortality and productivity impacts.

Heat-impact metrics

Two primary heat-impact indicators were assessed:

- Heat-related mortality, estimated using established UK temperature–mortality relationships that vary by age group and region.
- Heat-related productivity loss, estimated using heat-stress thresholds (wet-bulb globe temperature, WBGT) and sector-specific productivity relationships.

Impacts were monetised using:

- Value of Life Year (VOLY) for mortality impacts.
- Gross Value Added (GVA) for productivity losses.

These metrics allow comparison of heat risks across locations, time periods and adaptation scenarios.

Adaptation

Analysis was carried out for a “no adaptation” or baseline scenario and for several packages of adaptation measures. Although referred to as *no adaptation*, this scenario assumes no proactive heat adaptation is implemented, but some level of business-as-usual adaptation is implicitly captured.

Sensitivity

Sensitivity studies were conducted to test high exposure and socioeconomic future scenarios.

A.1.2 Overview of tools and methods used

A.1.2.1 Analysis tools

The analysis used several data analytics and modelling approaches. The key tools used included:

- Climate analysis and data morphing. Several climate datasets such as ERA5, HadUK and CIBSE weather files (see A.1.4) were collated and processed to produce current and future (2030s, 2050s) climate datasets at nationwide level across the UK. UK-wide climate data at the appropriate resolution was fundamental to this project.
- Urban climate analysis. To quantify the risk reduction from urban-scale adaptation measures, the [Surface Urban Energy and Water Balance Scheme \(SUEWS\)](#) climate model was utilised.
- Dynamic thermal modelling. [Design Builder](#) software allows building models and weather files to be used to run dynamic thermal models. It was used to determine the relationship between external climate conditions and internal conditions and quantify the impact of a range of building-scale adaptation options. A parametric modelling approach was utilised with Design Builder, which accounted for the large variability of different parameters needed for this project.

A.1.2.2 Spatial framework and typology-based approach

All analysis was carried out nationwide enabling a detailed assessment across UK towns and cities.¹

The analysis was undertaken using the smallest available urban statistical unit in each nation:

- England at a Lower Layer Super Output Area (LSOA) level for 25,000 areas
- Wales at a Lower Layer Super Output Area (LSOA) level for 1,000 areas
- Scotland at Data Zone level covering 5,800 areas
- Northern Ireland at Super Data Zone level covering 630 areas

Please note that in both the appendices and the main report, the term LSOA is used as a convenient shorthand for these statistical urban units, even though it is acknowledged that they are not identical in Scotland and Northern Ireland.

Since climate, urban form and building characteristics vary significantly across the country, it was not feasible to model every location and building type individually. Instead, a typology-based approach was used to represent this diversity in a structured and scalable way.

This involved sub-dividing the UK into four representative climate regions, classifying urban LSOAs into urban typologies based on their physical characteristics, and selecting a limited number of representative building archetypes for homes and offices. Together, these typologies provided a coherent framework that allowed modelling of heat risk consistently across the UK.

This section provides an overview of the typologies selected and the rationale behind them. Detailed descriptions of how they were applied within the modelling are set out in subsequent sections.

Climate regions

Although the UK falls within a temperate climate zone, there is still meaningful variation in temperature, humidity and other climate factors that influence the severity of heat hazard. Since it is not feasible to model all local climate differences directly, the UK was divided into four representative climate regions for the purposes of this analysis. These regions were defined using the Chartered Institution of Building Services Engineers (CIBSE) weather zones [1], ensuring that both north–south and east–west variations in UK climate are appropriately captured.

For each region, detailed climate data was extracted for a representative location and then adjusted to reflect variation within the wider area. This provided a robust set of climate inputs to underpin the modelling. The methodology for developing and applying these climate datasets is set out in the following section.

To cover the range of UK climatic conditions, the following locations were selected to represent the UK regions.

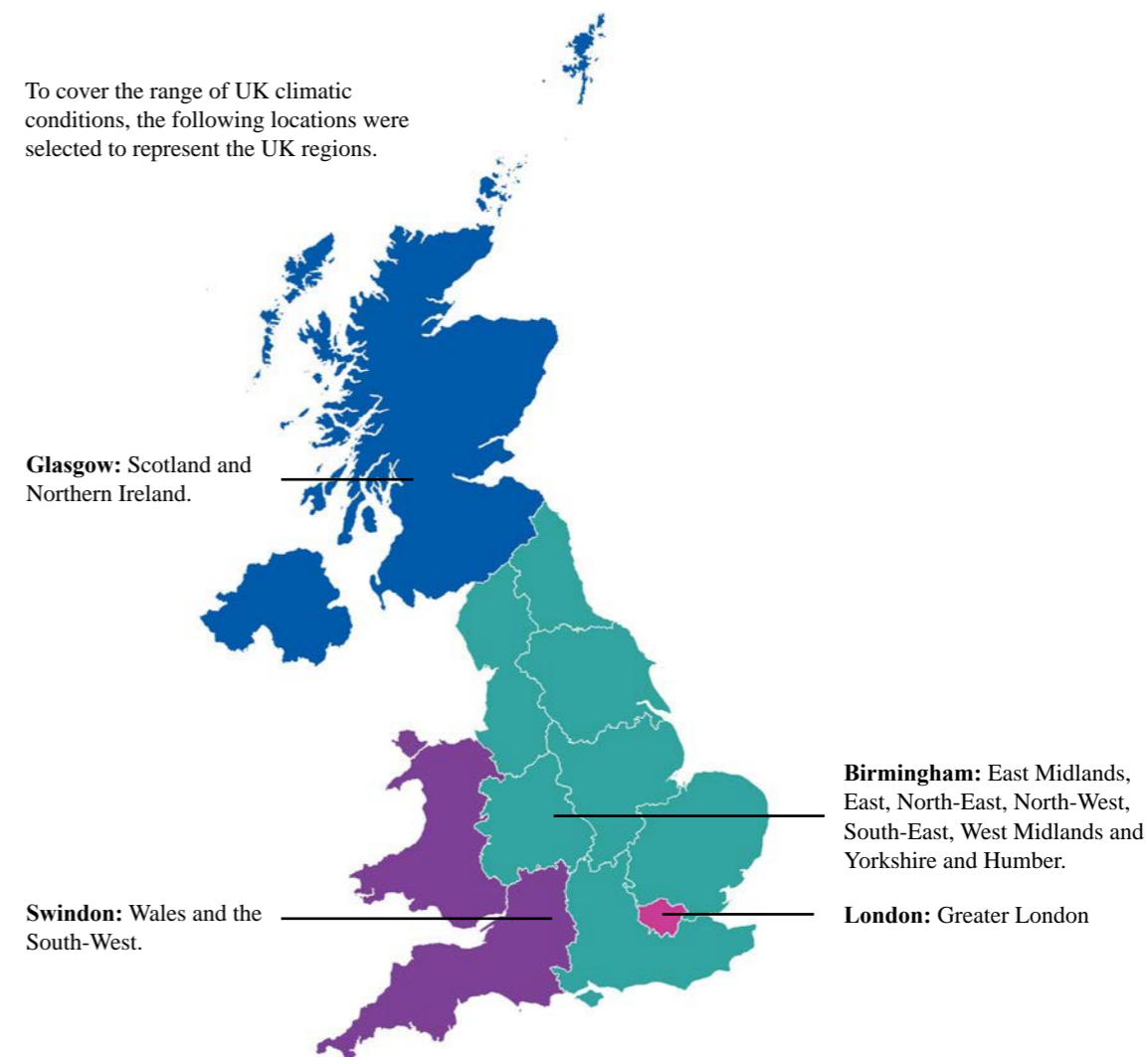


Figure A.2: UK regions.

Urban typologies

The urban form has a big impact on localised temperature due to the urban heat island effect. It was not feasible to represent all variations of urban form across the UK within this modelling approach. Instead, a set of urban typologies was created which all UK urban LSOAs could be mapped to for analysis.

Twelve urban typologies were selected to represent the range of urban and suburban land use archetypes across the UK, derived from the Local Climate Zone (LCZ) scheme [2]. The existing LCZ classifications were modified to be more representative of UK urban characteristics. A detailed explanation of how this was carried out and how UK urban LSOAs were mapped to each typology is provided in Box 1.

The urban typologies were used for the SUEWS urban climate analysis which is discussed in more detail in Section A.1.7.

Figure A.3 presents the final urban typologies used in this study.

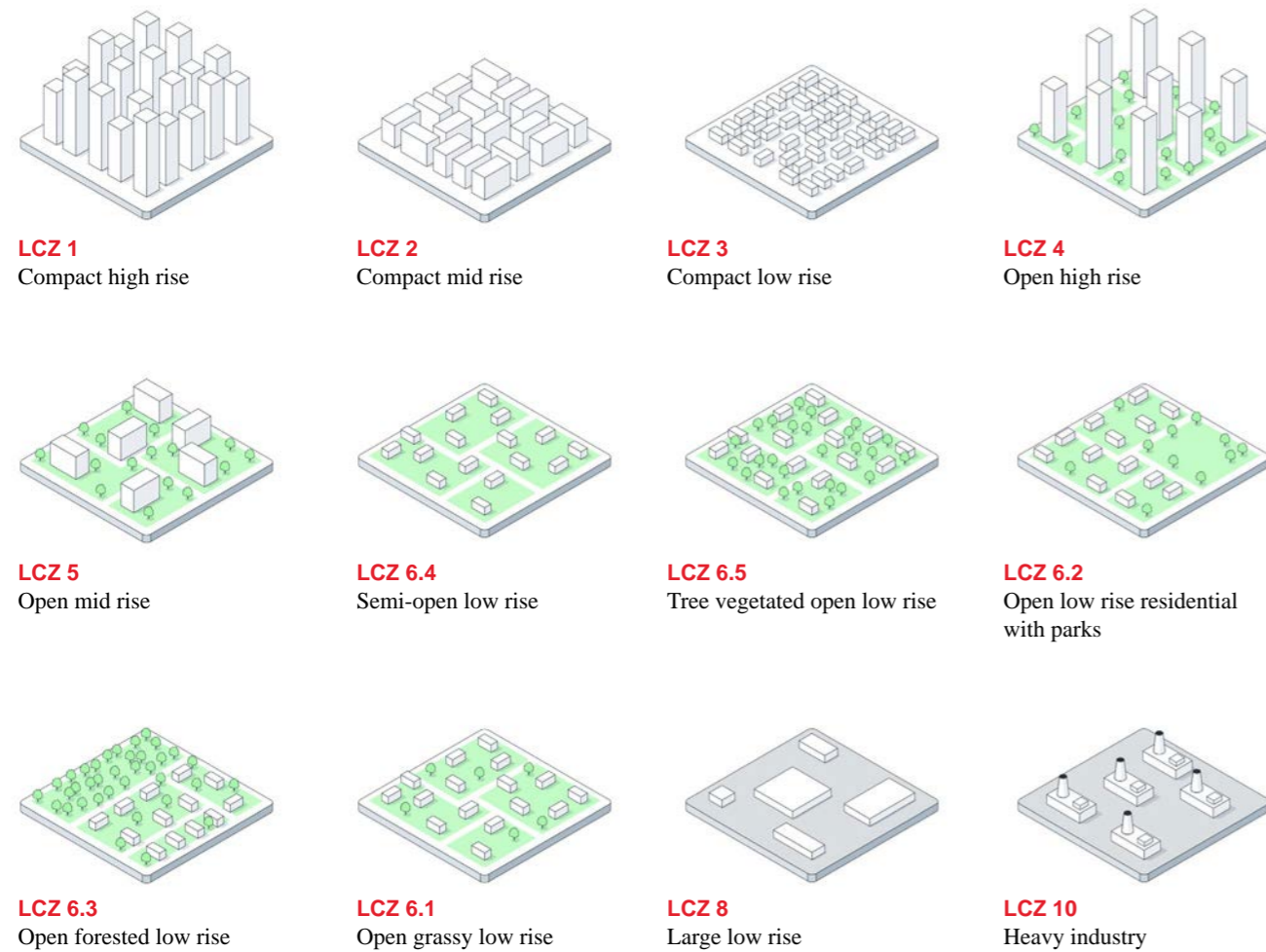


Figure A.3: Summary of urban typologies developed for analysis.



Box 1: Mapping to Local Climate Zones

Heat differs widely across the UK, with additional variation arising from differences in urban density. A typology-based approach was adopted to classify urban areas and enable a UK-wide assessment. Urban typologies are classifications of different urban forms or city layouts, based on land cover characteristics.

Twelve typologies were identified to represent the range of urban and suburban land use archetypes across the UK, derived from the LCZ scheme defined by Stewart and Oke. [3]

The LCZ scheme classifies urban and natural land areas based on land cover characteristics, providing a standardised way to describe urban areas for climate studies. There are ten urban LCZ classes and seven rural classes, each defined by variables such as land cover, building height, and materiality.

For this study these LCZs have been used as the basis for defining urban typologies across UK urban areas. The LCZs are mapped across UK urban LSOAs and reclassified such that they are more representative of the UK urban built environment, using the following steps:

- Data collection: Data for all urban LSOAs across the UK was obtained and combined into a geodatabase with surface cover and building height information.
- LCZ aggregation: The global LCZ dataset was aggregated to the LSOA level, with each LSOA assigned a single LCZ definition based on the primary area-averaged coverage.
- Reclassification: LCZ definitions were reclassified to be specific to the UK's urban areas. LCZ class 6 (Open Low Rise) covers more than 80% of the urban LSOAs in the UK, so was split into several subclasses to increase granularity.

- Twelve urban typologies: The final selection included twelve urban typologies corresponding to the ten urban LCZs, with LCZ 6 split into five subcategories. Note that LC7 does not exist in the UK.
 - Climate modelling: The SUEWS urban heat climate model was run for each urban typology for each of the UK's climate zones, with results used as input data for building-scale models. [4]
- The methodology ensures that the impacts of the urban heat island effect are adequately accounted for, providing a comprehensive framework for urban heat analysis across the UK.

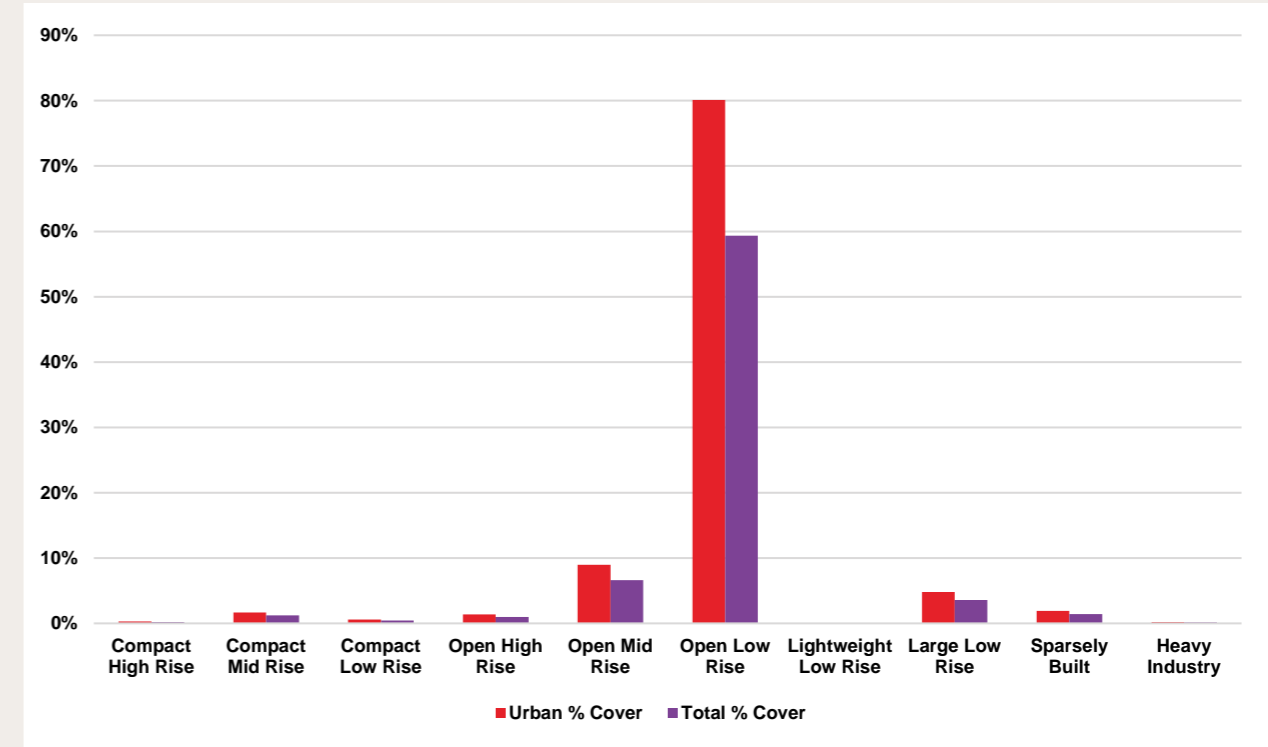


Figure A.4: Classification of all UK urban zones by LCZ.

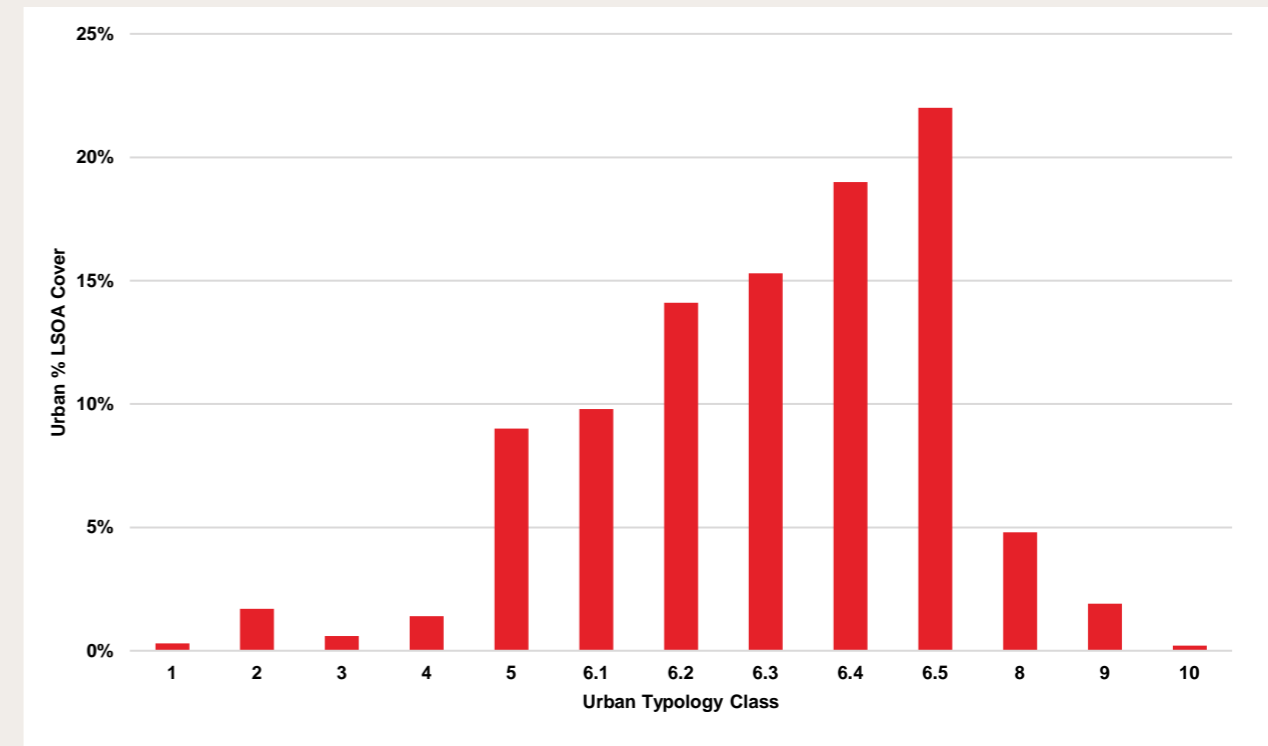


Figure A.5: Re-classification, including additional levels for LCZ 6.

Building archetypes

Both heat-related mortality and productivity impacts can occur indoors, where people spend the majority of their time. For mortality, the most important setting is the home. While other indoor environments (such as care homes or hospitals) can also be significant, it was not feasible to model all building types within this study. Care homes and hospitals were specifically covered by another study for Well-Adapted UK, by Edge Health and Greencroft Economics [5]. In this study it was assumed that all heat-related deaths take place in homes. The analysis focused on three representative residential archetypes. A semi-detached house was selected as it is the most common dwelling type in the UK, and a mid-terrace property was included as the second most common. A modern flat was also chosen because it is among the most at-risk building types for overheating, as identified in Arup and the CCC's previous study 'Addressing Overheating Risk in Existing UK Homes' [5].

For productivity impacts, heat can affect a wide range of indoor workplaces. To keep the analysis manageable and consistent, a typical naturally ventilated office was modelled, representing the type of workplace most likely to experience overheating. Mechanically cooled or mechanically ventilated offices were assumed not to experience productivity loss impacts under baseline conditions to avoid unnecessary complexity in the modelling framework. Note that outdoor workplaces were also included in this project, and the climate conditions for these settings were assumed to be equivalent to the baseline outdoor climate (i.e. no shading assumed).



Figure A.6: Residential building archetypes.

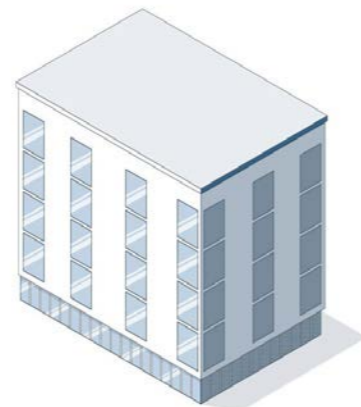


Figure A.7: Naturally ventilated office archetype.

A.1.3 Impact metrics and calculations

An extensive literature review was undertaken to identify robust metrics for quantifying heat-related health and productivity impacts and their corresponding monetised impact in the UK. Mortality and productivity loss were selected as the primary indicators, as they are the most evidence based measures available and supported by established methodologies suitable for this study.

A.1.3.1 Calculating mortality and associated monetised impact

Heat-related mortality impacts

The method used to quantify the impact of urban heat on mortality was adopted from an established academic study. Most research methods use risk relationships and daily average outdoor air temperatures, to calculate heat-related deaths. The risk relationship refers to the quantitative link between temperature and the risk of death. It is usually derived from epidemiological studies and is the core input used to estimate how many deaths are attributed to heat.

Risk relationships were taken from the latest study available, which was Murage et al. 2024 [7]. The research provided risk relationships for heat-related mortality by UK region and across four age categories (0-64, 65-74, 75-84, 85+). The methodology is based on the relationship between all-cause deaths and average air temperature (see Box 2 for the equation and further details).

Box 2: Technical details on heat-related mortality calculation

The equation below describes the relationship used to derive heat-related mortality.

$$M = \sum_{i=1}^N DM_i (1 - e^{-b\Delta T_i}) \quad [8]$$

M is the calculation of heat-related mortality.

DM is total all-cause mortality.

The calculation is done for each day (*i*) and summed to calculated total heat deaths in a year (*N*).

ΔT is the difference between the daily mean temperature and a 93rd percentile regional temperature.

For calculating **b**, the inputs are **RR**, which is the relative risk and ΔT which is the difference between a 99th and 93rd percentile regional temperature.

Data inputs and assumptions

- The 93rd and 99th percentile regional temperatures and relative risks were obtained from Murage et al. 2024 [8]. These provided regional risk relationships for four age categories (0-64, 65-74, 75-84, 85+).
- Relative risks less than one (resulting in reduced mortality from heat) were adjusted. These arise in the paper due to the statistical nature of the study. For the North East, the over 85s risk was adjusted to Scotland, and for the South West, the under 65 risk was adjusted to the South East relative risks.
- Daily average temperatures were input as outdoor air temperature from each climate scenario.
- Heat-related deaths were calculated from all-cause deaths, available regionally across England and Wales, for data zones for Scotland and across the whole of Northern Ireland. These all-cause deaths were distributed to LSOA level based on population data in each LSOA for the different age categories.

Monetised mortality impact

The monetised value of avoided mortality was represented through “years life lost (YLL)” and “value of life year (VOLY)”. For each age group, YLL was determined by establishing a reduced lifespan due to heat-related impacts (compared with life expectancy). YLL was sourced from the Office of National Statistics (ONS) National life tables 2021 -2023 [8], which measures the average number of years people will live beyond their current age. This was multiplied by the value of life year (VOLY) from the HM Treasury Green Book to calculate a total monetised impact [9]. This VOLY is £65,176 (Green Book figure uplifted to 2023 prices).

Monetised impact for mortality (£) = YLL × VOLY

The YLL was age dependent and was derived from life tables as below:

Box 3: Assumptions used in monetised impact analysis for mortality

Age group	Assumed age	Years of life lost (YLL)
0-64	32	50
65-74	69	17
75-84	79	10
85+	85	6

A.1.3.2 Calculating productivity loss and associated monetised impact

Heat-related productivity impacts

The impact of urban heat on productivity was calculated using a combination of methods presented in literature. Two main sources were utilised to establish the method and metrics used:

- Impacts of higher temperatures on labour productivity and value for money adaptation: lessons from five DFID priority country case studies, Vivid Economics, August 2017 (referred to as ‘the Vivid Economics study’) [10].
- Climate change, heat stress and labour productivity: A cost methodology for city economies, Grantham Research Institute on Climate Change and the Environment Working Paper No. 248, July 2016 (referred to as ‘the Costa study’) [11].

The methods set out in these papers calculate direct productivity loss resulting from workers experiencing heat during working hours. Productivity loss is a function of heat stress, as measured by wet-bulb globe temperature (WBGT). Detailed data inputs and assumptions are presented in Box 4.

Box 4: Detailed calculation of productivity loss

The productivity loss relationship with job sectors was obtained from the Vivid Economics paper (see [10]). The productivity loss curves are based on the High Occupational Temperature Health and Productivity Suppression (Hothaps), as set out in Kjellstrom et al. (2014) [14]. These provide a range of curves related to physical exertion of different job sectors and provide a relationship between WBGT and productivity loss as a proportion of an hour.

Each sector has different assumed levels of physical exertion and hence vulnerability to heat, with physical jobs like construction being the most exposed while more sedentary work such as indoor office sectors were assumed to be the least exposed. For UK urban areas, all job sectors were assumed to be indoors with only construction workers assumed as working outdoors. Table A.1 shows how each job sector is classified by its level of physical exertion and whether it takes place indoors or outdoors.

Data inputs and assumptions

- Employment sectors, based on the ONS Standard Industrial Classification Codes (SIC03), were each assigned a work intensity based on the classification from the Vivid Economics study.
- Construction is the only sector to represent a high work intensity given its exposure to heat. All work in this sector was assumed to take place outside and in direct sunlight, while all other work was assumed to take place indoors.
- Sectors such as manufacturing, health and education were assumed to represent moderate intensity work, while the remaining majority office-based sectors were assumed to be low-intensity work.
- Work in the Agriculture, forestry & fishing, Mining, quarrying & utilities (ABDE) sectors was assumed to take place indoors given that the focus of this study is on urban areas.

Sector	Sector code	Work intensity (Vivid)	Indoor/outdoor
1: Agriculture, forestry & fishing, Mining, quarrying & utilities (A, B, D, E)	ABDE	Moderate	Indoor
3: Manufacturing (C)	C	Moderate	Indoor
4: Construction (F)	F	High	Outdoor
5: Wholesale and retail trade; repair of motor vehicles (Part G)	G	Moderate	Indoor
8: Transport & storage (inc postal) (H)	H	Moderate	Indoor
9: Accommodation & food services (I)	I	Moderate	Indoor
10: Information & communication (J)	J	Low	Indoor
11: Financial & insurance (K)	K	Low	Indoor
12: Property (L)	L	Low	Indoor
13: Professional, scientific & technical (M)	M	Low	Indoor
14: Business administration & support services (N)	N	Low	Indoor
15: Public administration & defence (O)	O	Low	Indoor
16: Education (P)	P	Moderate	Indoor
17: Health (Q)	Q	Moderate	Indoor
18: Arts, entertainment, recreation & other services (R, S, T and U)	RSTU	Moderate	Indoor

Table A.1: Job sector classification.

Monetised productivity impact

The monetised value of productivity loss was represented by loss of Gross Value Added (GVA). GVA loss was calculated by multiplying annual hours lost due to heat stress (from the Vivid Curves) by sectoral productivity per hour, and the number of employees in each sector and region, then summing to estimate the total GVA loss across the UK. This captures differences in heat exposure, sectoral employment and productivity between and across regions.

A.1.4 Creating climate datasets for the UK

Representative, year-long climate datasets were required for both present-day and future scenarios at a granular LSOA resolution. As no single dataset provided this level of detail, the climate inputs had to be derived by combining several complementary data sources. The key requirements were:

- Hourly climate datasets for present-day and future climate scenarios, covering both central and high warming pathways.
- Air temperature for estimating heat-related mortality, and air temperature, humidity and solar radiation for calculating WBGT for productivity impacts.
- LSOA level resolution to reflect localised variations in the urban heat island effect and elevated temperatures in built up areas.

The climate data used in the analysis included:

- European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis 5, referred to as ERA5. A ~30km dataset for historical climate globally, for all climate variables.
- Hadley Centre for the UK, referred to as HadUK-Grid or simply HadUK. Available at 1km for historical climate in the UK, for limited climate variables.
- Chartered Institution of Building Services Engineers Weather Files, referred to as CIBSE files. Standardised weather files used for building modelling across UK locations. CIBSE Climate Projections (CP09) data available for extreme and typical years for several climate change scenarios was used. The data is available on an hourly basis for the four climate zones set out for the analysis.

To ensure extreme heat impacts were accurately captured, the analysis used an exceptionally hot year as the reference. The year 2022 was selected as it represents the most recent extreme heat event across the UK, making it a suitable baseline for present day climate conditions.

Note that the primary analysis was conducted for “extreme” present day and future climate years. Outputs for “typical” present-day and future climates were then derived using conversion factors applied to these extreme-year results. See Section A.1.7.7.

A.1.4.1 Downscaling to create present day climate data

Heat impacts were quantified for each hour of the year at LSOA level, meaning a full spatially and temporally granular dataset was required. Because no dataset offered both high spatial and temporal resolution, a downscaling method was used to combine ERA5 and HadUK data. Downscaling refers to taking coarse, large-scale climate data and refining it to reflect conditions at the local scale.

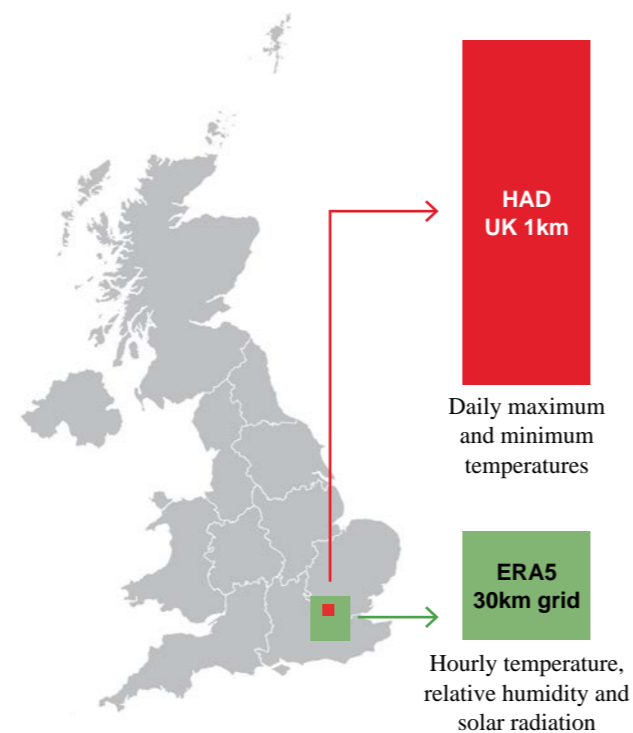


Figure A.8: Downscaling.

Present day (2022) downscaling process

Downscaling for the present day (2022 extreme year) was undertaken by:

- 1. Collecting hourly ERA5 data.** ERA5 data was extracted for four representative UK climate regions—London, Birmingham, Glasgow and Swindon.
- 2. Mapping LSOAs to HadUK 1 km grid cells.** Each urban LSOA was mapped to its nearest HadUK 1 km grid point to provide improved spatial detail.
- 3. Creating daily temperature adjustment factors.** Daily average air temperature from ERA5 and HadUK were compared. The difference formed a daily adjustment factor, which was applied to each hour of ERA5 air temperature data, generating a unique hourly temperature profile for every LSOA.
- 4. Incorporating additional climate variables.** ERA5 provided relative humidity, pressure, wind speed and solar radiation. All were retained as is, except relative humidity which was corrected to ensure consistent moisture content within each climate region.
- 5. Calculating WBGT.** Using air temperature, solar radiation and adjusted humidity, external WBGT was calculated for each LSOA.

This produced a complete hourly dataset for air temperature, humidity and solar radiation for every urban LSOA in the UK for the 2022 baseline.

A.1.4.2 Developing future climate dataset

Future climate datasets were created in a similar way to the present day climate. However, CIBSE climate data was used instead of ERA5 data to capture future climate projections. DSY2 (Design Summer Year 2) CIBSE files were used for future climate analysis. These are based on UKCP09, as the UKCP18 files were not available at the time of analysis [13]. DSY2 is usually the year containing the most intense heat events.

The future climate datasets from UKCP09 CIBSE files were mapped to the different climate scenarios required in this study. These were selected where the UKCP09 SRES scenarios (Special Report on Emissions Scenarios) most closely aligned to the global warming scenarios used in UKCP18 [16].

- +1.5°C for 2030s - 2020s High Scenario (50th percentile model)
- +2°C for 2050s - 2050s Medium Scenario (50th percentile model)
- +2°C in 2030s - 2020s High Scenario (90th percentile model)
- +2.5°C in 2050s - 2050s High Scenario (90th percentile model)

Future scenario downscaling process

Downscaling for the future scenarios was undertaken by:

- 1. Calculating a new adjustment factor.** A new adjustment factor was calculated for each climate region by comparing DSY2 present day air temperature with HadUK air temperature. (Note that DSY2 present day reference years differed by climate region: London 2003; Swindon 2003; Glasgow 1975; Birmingham 2006.)
- 2. Shifting the data.** For each LSOA, air temperature in the future DSY2 file was shifted using the derived adjustment factor to produce an hourly future temperature profile.
- 3. Correcting relative humidity.** Relative humidity was corrected to maintain the original moisture content from the DSY2 file while using the newly adjusted air temperature.
- 4. Solar radiation.** Direct normal solar radiation was corrected using local solar altitude at each LSOA.

The downscaling process produced a complete set of hourly climate variables—air temperature, relative humidity and solar radiation—for every urban LSOA in the UK for extreme climate years relating to:

- Present day (2022)
- 2030s central and high climate scenarios
- 2050s central and high climate scenarios

These datasets form the basis of all heat mortality and productivity modelling presented in this study

A.1.5 Establishing the baseline: Current and future heat risk across the UK's towns and cities

To estimate baseline heat impacts, climate datasets were combined with heat impact metrics and associated monetised metrics for every UK urban LSOA. The steps for calculating mortality and productivity impacts are outlined in this section.

A.1.5.1 Baseline heat-related mortality calculation

Heat-related mortality is related to the external air temperature through the risk relationships described in Section A.1.3.1. The steps to calculate baseline heat mortality (shown in Figure A.9) are as follows:

- 1. Calculate climate metrics.** Average daily air temperature was calculated for every urban LSOA for each climate scenario (present day, future central, and future high).
- 2. Estimate daily heat-related mortality.** Daily heat-related mortality by age group is derived by combining the climate metric with all cause deaths and population age profiles for each LSOA, using the risk relationship from Murage et al. [6]
- 3. Monetise mortality impacts.** The monetised value of heat-related mortality impacts was calculated by assigning the mortality figures a VOLY (Value of a Life Year) to the number of life years lost, by age, for each climate scenario.
- 4. Aggregate results.** Heat related mortality and monetised impacts are aggregated to regional, national, and UK wide totals for each climate scenario.

Key assumptions

- Recorded regional death data for 2022 was used in the baseline present day analysis.
- The all-cause mortality figures were uplifted into the future using ONS population projections for different age categories [14].
- The VOLY figure was not uplifted, to reflect people's rising willingness to pay for added life years, as this was already embedded through the application of a 1.5% health discount rate used to discount avoided mortality costs. Following CCRA3 guidance, applying both an uplift to VOLY and a 1.5% discount rate would double count the same effect. [15]

A.1.5.2 Baseline heat-related productivity impact calculation

Heat-related productivity loss is estimated using productivity loss curves that relate WBGT to a percentage reduction in productive working time. These curves were applied on an hourly basis. To do this, both external and internal WBGT were calculated:

- External WBGT is derived directly from the climate variables in the baseline climate datasets.
- Internal WBGT is estimated using Dynamic Thermal Modelling (DTM), which provided a relationship between outdoor conditions and indoor heat exposure.

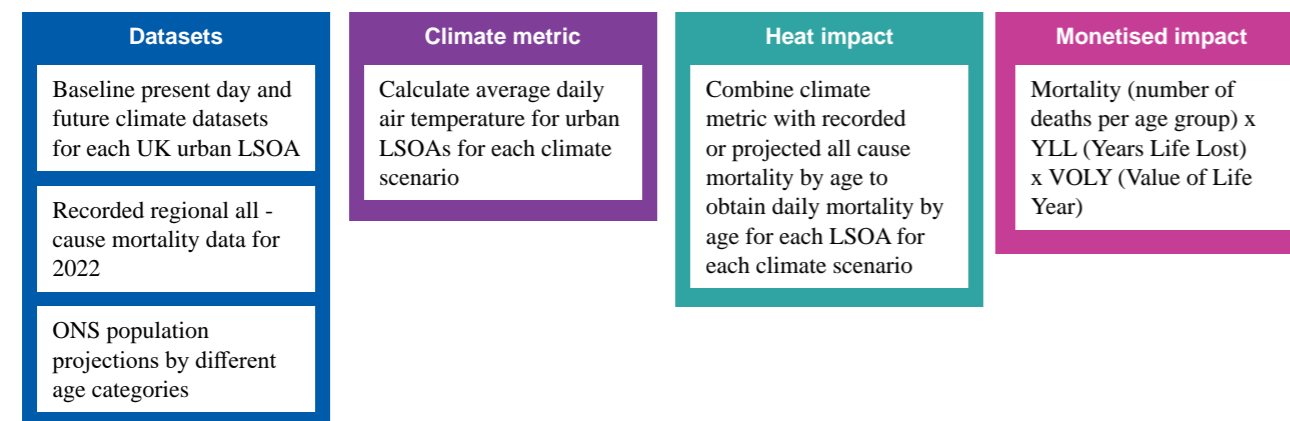


Figure A.9: Key steps for estimating baseline mortality loss and the corresponding monetised impact.

The key steps for estimating baseline productivity loss and the corresponding GVA impact are summarised in Figure A.10 and described below.

1. Calculate climate metrics

- External WBGT: calculated hourly using dry-bulb temperature (air temperature), relative humidity and solar radiation (see Box 5 for full methodology).
- Internal WBGT: estimated using DTM to model how indoor conditions respond to outdoor temperatures (see Box 6 for details).

2. Assign WBGT exposure by work intensity.

Each economic sector is assigned a typical working environment, distinguishing between internal (indoor) and external (outdoor) work intensity. Construction was assumed to be the only outdoor sector. The sectoral mapping can be found in Table A.1.

3. Estimate heat-related lost hours in a given year.

Sector-specific WBGT-productivity loss functions (from the Vivid Economics study) were applied to the relevant WBGT exposure to estimate the percentage reduction in working hours for each sector and LSOA.

4. Estimate sectoral productivity values.

To monetise heat-related productivity loss, sector-specific productivity (GVA per worker per hour) was calculated.

- GVA per employee was calculated for each sector and region. As GVA data is not available at the required spatial granularity, it was assumed that the sectoral GVA per employee at a regional level is the same across all constituent LSOAs.
 - This value is divided by 1,583 working hours per year (leave-adjusted) to estimate GVA per employee per hour for each LSOA and sector.
- 5. Calculate heat-related GVA loss per worker.** The annual lost hours due to heat stress (Step 3) is multiplied by the sectoral GVA per employee per hour (Step 4) to estimate the annual GVA lost per worker due to heat for a given sector and LSOA.
 - 6. Calculate total heat-related GVA loss.** The GVA loss per worker is multiplied by the number of employees in each sector and LSOA to estimate the total annual GVA loss across all urban areas.
 - 7. Aggregate results.** Heat-related productivity loss and associated GVA impacts are aggregated to regional, national and UK-wide totals.

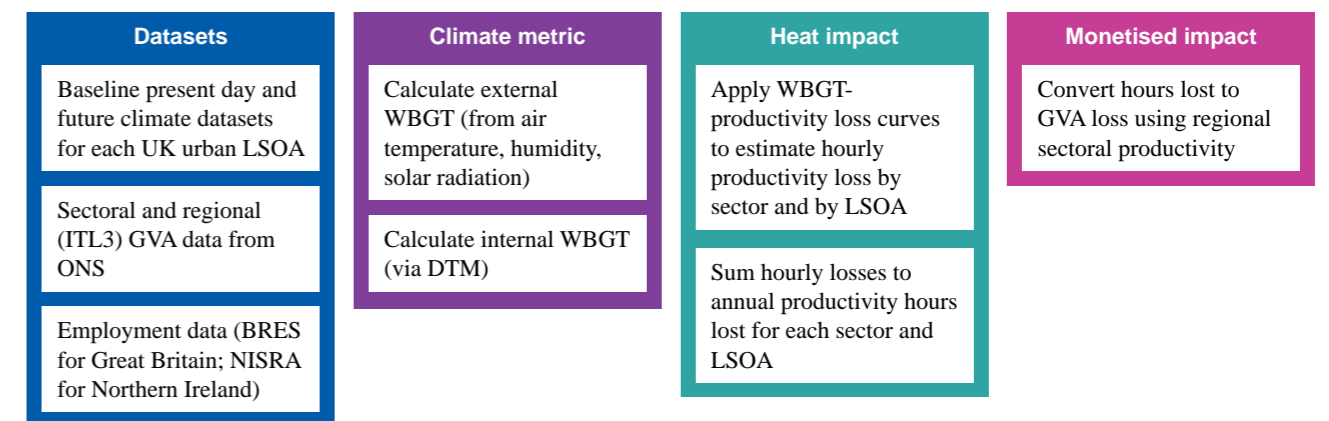


Figure A.10: Key steps for estimating baseline productivity loss and the corresponding GVA impact.

Key assumptions

- Productivity loss was considered for each working hour of the year (assumed as 9am-5pm, Monday-Friday).
- Sectoral and regional (ITL3) GVA data from ONS was combined with employment data [19] [20] (BRES for Great Britain; NISRA for Northern Ireland).
- Values were adjusted using leave-corrected annual working hours to derive sector- and region-specific productivity per hour.
- 65% of UK offices are air-conditioned [21]. Workers in air-conditioned offices were assumed not to experience heat-related productivity losses, to avoid over-estimation.
- Future economic conditions were projected to estimate productivity losses from urban heat until 2059. Employment growth followed the rates set out in the OBR March 2025 Economic Outlook (Labour Market), while productivity growth was based on the central forecast from the OBR March 2025 Economic and Fiscal Outlook. Inherent GVA growth was then derived from the combined growth rates of these two variables, recognising the three variables' interdependence.

Box 5: Calculating external and internal WBGT

WBGT is a heat stress index that combines air temperature, humidity, solar radiation and wind into a single measure of how hot conditions feel to the human body under different working environments [17].

WBGT was calculated for the outdoor and indoor environment using the following equations:

$$\text{Outdoor (external) WBGT} = 0.7T_{\text{nw}} + 0.2T_{\text{g}} + 0.1T_{\text{d}}$$

$$\text{Indoor (internal) WBGT} = 0.7T_{\text{nw}} + 0.2T_{\text{d}}$$

Where T_{nw} is the natural wet-bulb temperature, T_{g} is the globe temperature and T_{d} is the dry-bulb or air temperature.

These variables are complex to derive directly, so standard approximations were used to make the method feasible for a UK-wide LSOA-level analysis:

Wet-bulb temperature was used as a proxy for natural wet-bulb temperature. This substitution is widely accepted in heat stress modelling and has been shown to be a reasonable approximation when detailed wind speed and radiation inputs required for true T_{nw} are not available [18].

It was not feasible to calculate full globe temperature so a simplified model relating T_{g} to direct solar radiation and air temperature was used:

$$T_{\text{g}} = \sqrt[4]{\frac{Q_{\text{s}}}{4\sigma} + T_{\text{d}}^4}$$

where Q_{s} is the direct solar radiation in W/m^2 , σ is the Stefan-Boltzmann constant and T_{d} is in Kelvin.

Box 6: Deriving indoor WBGT

Approach

Detailed Dynamic Thermal Modelling (DTM) simulations were undertaken for the office building archetype for UK climate zones to obtain the internal WBGT. To enable national-scale assessment of indoor heat exposure, a machine-learning-based transfer approach was used to extrapolate DTM outputs from a limited set of simulations to all UK LSOAs.

DTM simulations

Energy Plus and Design Builder were used to carry out parametric simulations of office buildings in four UK climate zones, establishing how indoor WBGT relates to outdoor conditions.

The following combination of modelling parameters was used to run the simulations.

- Four climate regions. DTM was run for the four representative UK climate regions (London, Birmingham, Swindon and Glasgow).
- Five climate scenarios. Present day (2022) and both central and high warming future climate datasets were used for the 2030s and 2050s.
- Twelve urban typologies. The analysis was carried out for each typology to create a large dataset of output files.

The DTM created 240 set of results files which included hourly indoor WBGT.

Machine learning model

A Gradient Boosted Trees regression model was used to learn the relationship between external climate conditions and indoor thermal response captured by the DTM simulations. A separate model was trained for each climate zone, allowing regional climatic differences to be represented explicitly.

The model used external climate variables as inputs, including:

- External air temperature,
- External relative humidity, and
- A week fraction variable to capture diurnal and weekly occupancy-related patterns.

To represent building thermal inertia and heat accumulation, these variables are expanded into a set of lagged features (up to 12 hours) and rolling mean features (15 to 72 hour windows), resulting in a high-dimensional feature set that reflects recent weather history rather than single-hour conditions.

$$\text{WBGT}_{\text{indoor}} = f(T_{\text{db,out}}, \text{RH}_{\text{out}}, \text{SR}_{\text{out}}, t)$$

Where:

$T_{\text{db,out}}$ = external air temperature

RH_{out} = external relative humidity

t = week fraction

Training, validation and quality control

The machine learning models were trained using the full set of DTM simulation outputs across all climate zones and scenarios (present and future). A subset of simulations—including selected future climate runs—were withheld entirely from training and used for validation, ensuring that the models were tested on unseen urban forms and climate conditions. Model performance was assessed using the coefficient of determination (R^2), comparing predicted indoor WBGT values against DTM simulation outputs. Anomalous simulation results identified during quality assurance were excluded from training.

National-scale application

Each UK LSOA was assigned to one of the four climate zones based on geographic location. The corresponding trained machine learning model was then applied to predict hourly indoor WBGT for each LSOA across the summer period, using LSOA-specific external climate time series.

This approach enables the transfer of detailed building physics based insights from a limited number of Building Energy Model (BEM) simulations to national coverage, supporting consistent assessment of indoor heat exposure across baseline and future climate scenarios while maintaining computational efficiency.

A.1.6 Review and appraisal of adaptation measures and selection of adaptation packages

This section outlines the methodology for selecting the most effective adaptation measures to address heat risk across the UK, specifically aiming to reduce risks to health and productivity.

The approach consisted of the following steps:

- 1. Longlisting.** A comprehensive longlist of potential adaptation measures was prepared. This gave a broad understanding of the full range of physical measures that could help reduce heat exposure across buildings and urban scales.
- 2. Multi-criteria assessment.** Each measure was systematically assessed to consider how it will perform in practice. This involved evaluating its ability to reduce heat, its implementation challenges, its co-benefits, and its costs. By applying a consistent multi-criteria framework, we compared and scored measures to determine which could offer the greatest value and are most feasible at scale in the UK context.
- 3. Shortlisting and adaptation packages.** Finally, the highest scoring measures were shortlisted and grouped into adaptation packages for detailed modelling and evaluation. These packages combined building-scale and urban-scale measures that work together, with the potential to deliver more meaningful reductions in heat risk than any single measure alone.

This staged process—from longlisting, to assessment, to packaging—ensured that the adaptation options taken forward are evidence-based and implementable.

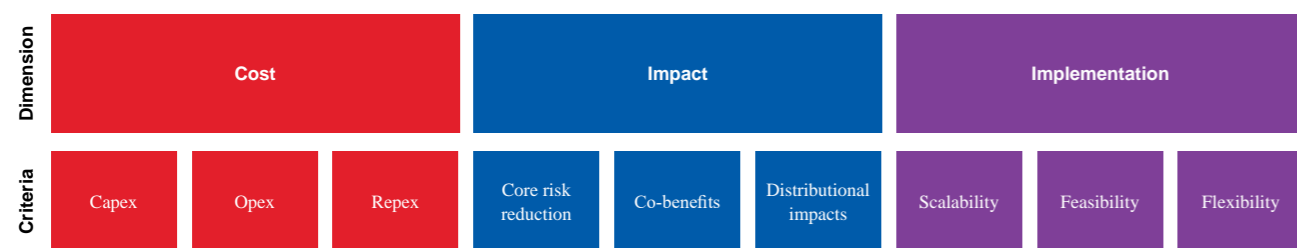


Figure A.11: The longlist of adaptation measures was qualitatively scored across a range of sub-criteria.

A.1.6.1 Longlisting

A comprehensive longlist of 15 building-scale and 12 urban-scale adaptation measures was created. Measures were identified through:

- a literature review
- analysis of previous Climate Change Committee (CCC) research on overheating and urban heat,
- case studies from cities regularly experiencing extreme heat, and
- input from project experts on feasibility within UK contexts

Each measure was categorised according to its mechanism of action (e.g. reducing solar gain, increasing evapotranspiration, improving building insulation, increasing albedo, providing shade, reducing anthropogenic heat).

The full longlist, including detailed descriptions of each measure and how they reduce heat, is provided in Table 6 and 7 in the main report.

A.1.6.2 Multi-criteria analysis of solutions

The longlist of measures was evaluated to create a prioritised shortlist of measures considered most suitable for the UK context.

A multi-criteria analysis (MCA) framework was used, structured around three key dimensions: impact (including risk reduction), implementation and cost, enabling us to assess the effectiveness of each measure. The longlist of adaptation measures was qualitatively scored across a range of sub-criteria (Figure A.11) under these key dimensions.



A.1.6.3 Scoring strategy

To evaluate each adaptation measure on the longlist, a Red-Amber-Green (RAG) rating system was applied across different criteria relating to the three dimensions: impact, implementation and cost. This system allowed for straightforward comparison of measures based on their suitability and effectiveness. Where a measure was found to have a negative impact under a specific criterion, a score of -1 was assigned to reflect its disbenefit.

The scoring process was grounded in evidence from the literature review, high-level modelling, and expert judgement. Comprehensive details of the underlying data sources and methodologies are provided in Box 7.

To enable fair and consistent comparison across all measures within the MCA, the scoring was standardised by applying it to a set reference case: a semi-detached house and a representative compact low-rise block urban typology, LCZ3.

Box 7: Details on the MCA scoring

Adaptation measures were assessed across three dimensions, each comprising a defined set of criteria and sub-criteria:

Impact (measures scored between -1 and 2)

- Core heat risk reduction: indoor overheating reduction, outdoor temperature reduction, speed of benefit realisation
- Co-benefits: biodiversity, carbon sequestration, embodied carbon, stormwater flooding, air quality, amenity value, recreational value
- Distributional impacts: access to, and ownership of, benefits across different groups

Implementation (measures scored between 0 and 2)

- Scalability: suitability and applicability of actions across building and urban typologies, planning constraints and delivery timeframes
- Flexibility: lock-in risk and ease of adaptation or replacement
- Feasibility: supply chain maturity, technical complexity, impact on building design and appearance

Cost (measures scored between 1 and 3)

- Capital expenditure (capex): upfront investment requirements
- Operational expenditure (opex): ongoing maintenance and running costs
- Replacement expenditure (repex): frequency and cost of replacement

Each measure was scored at sub-criterion level using an ordinal scale of 0 to 2, where scoring ranges were tailored to each sub-criterion and made quantitative where possible.

Determining risk reduction

To assess the heat risk reduction of each adaptation measure, a combination of literature and small-scale modelling was applied. This process produced a single score for each measure across the three sub-criteria: indoor overheating reduction, outdoor temperature reduction, speed of benefit realisation.

A reference urban typology of LCZ3 and reference building archetype of a semi-detached house were used to determine relative risk reductions across the full set of measures.

For building-scale adaptation measures the *Addressing overheating risk in existing UK homes* [24] report was referred to obtain relative risk reductions.

For urban-scale adaptation measures, the risk reduction was obtained through small scale testing using SUEWS to obtain the impact the measure will have on the air temperature and the WBGT. For instance, when assessing measures against the outdoor risk reduction sub-criterion, measures were given a score of 2 if the peak reduction in air temperature of WBGT was 2°C or higher, while a score of 1 was given if it generated a peak reduction of air temperature of 0.5-2°C. If there was a minimal reduction (<0.5°C) on outdoor temperatures, the measure was scored 0. Lastly, measures were given a score of -1 if it had the potential to increase outdoor temperatures, which was the case for active cooling.

Weighting

Sub-criteria were first aggregated within each criterion using weighted averages, before an overall score was calculated across impact, implementation and cost:

- Within the impact dimension, greater weight was placed on the core heat risk reduction of each measure, which accounted for 60% of the impact score, followed by co-benefits at 30% and distributional impacts at 10%. The risk reduction score was further disaggregated, with indoor and outdoor risk reduction each weighted at 40%, and benefit realisation at 20%.
- Within the cost dimension, capex, opex and repex were weighted at 50%, 25% and 25% respectively, as upfront capex is most important with budgetary constraints.
- All implementation sub-criteria were equally weighted.

A.1.6.4 Combining scores and categorising adaptation measures

The overall effectiveness of each adaptation measure was then assessed by creating a final scoring matrix.

The scoring matrix used weighted impact against cost (with all cost parameters weighted equally), which is vital to ensure that proposed measures are realistic and achievable within the UK context. Additionally, co-benefits and risk reductions were given equal weighting, supporting a holistic approach that rewards adaptation measures delivering broad and balanced advantages.

To account for deliverability, the impact score was adjusted by the implementation score, with the two multiplied to generate a weighted impact score. This ensures that measures which are more feasible, scalable and flexible were prioritised over those that may perform well in principle but are difficult to implement in practice.

The matrix used for this analysis was divided into four distinct quadrants, each denoting a category of adaptation measures:

- Quick wins – measures with high impact and low cost
- Complementary – measures with low impact and low cost, which could supplement other higher impact measures
- Transformative – measures with high impact and high cost
- Deprioritised – measures with low impact and high cost.

The results in A.13 show the strongest performing adaptation measures are in the top left quadrant, notably construction site shading, low g-value window film or curtains, and internal blinds. These measures combine relatively high impact, which can include heat risk reduction, co-benefits and the ease of implementation, with low cost. Several shading measures and glazing upgrades also achieve high impact but at higher cost, placing them in the transformative category. In contrast, measures such as green roofs, blue infrastructure, and pedestrianisation deliver lower implementation-weighted impact relative to their cost and were therefore classed as deprioritised.

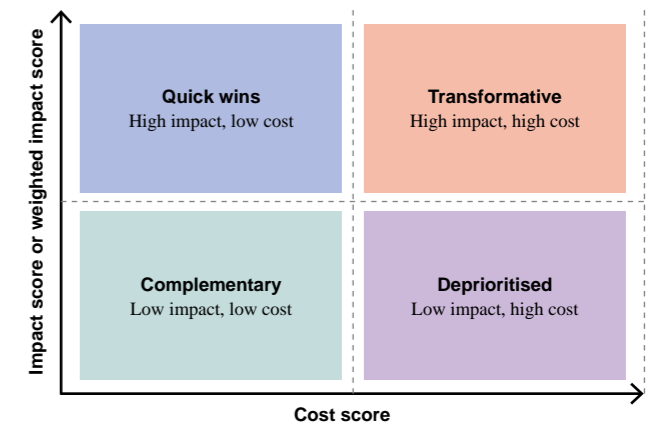


Figure A.12: The matrix used for this analysis was divided into four distinct quadrants.

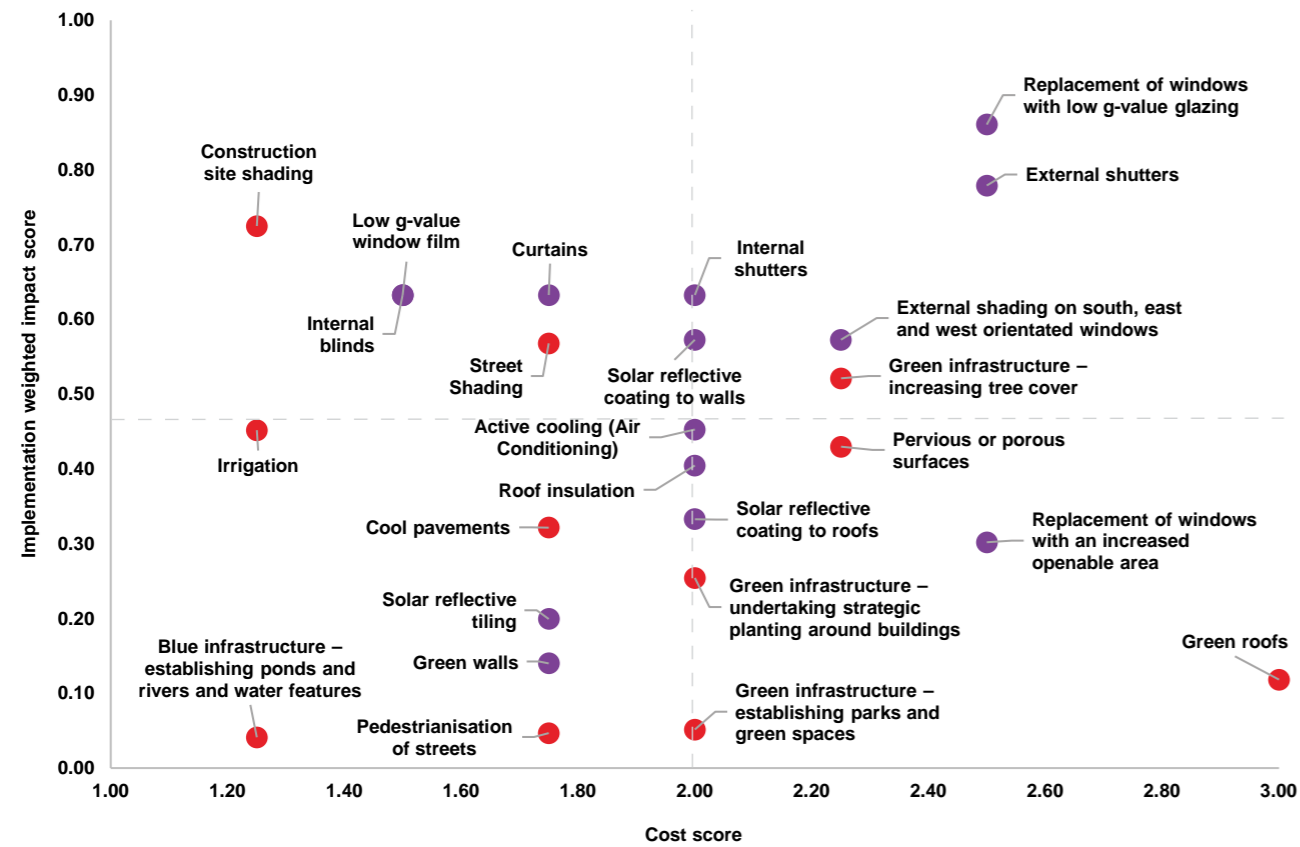


Figure A.13: Core result of the MCA used to shortlist adaptation measures. Red dots refer to urban-scale measures while purple dots refer to building-scale measures.

Sensitivity studies

Several sensitivity tests were conducted to test how different adaptation actions performed under varying MCA scoring assumptions. This informed the selection of measures that make up the packages.

Table A.2 shows how the classification and prioritisation of adaptation measures shift under each sensitivity scenario. The core scenario represents the central case, where both implementation and co-benefits are incorporated alongside impact.

The sensitivity scenarios test alternative priorities:

- Sensitivity 1: A simple baseline considering heat risk reduction only when considering impact, with no implementation effects included (no co-benefits)
- Sensitivity 2: Risk reduction only, but adjusted for implementation (no co-benefits)
- Sensitivity 3: Same assumptions as core scenario, including both implementation and co-benefits, but with cost focused entirely on capex
- Sensitivity 4: Co-benefits included but implementation effects excluded.

The sensitivity analysis shows that adaptation measures generally perform similarly with differing weighting assumptions. Measures such as construction site shading and ceiling fans consistently rank as quick wins, while external shutters and low g-value glazing remain transformative across all scenarios. Some measures, particularly green infrastructure, green walls, and cool pavements, are more sensitive to assumptions and generally achieve better scores moving from left to right, as co-benefits are included. A few measures, such as increased window opening area, are consistently deprioritised.

Adaptation measure	Sensitivity 1 No implementation 100% risk reduction	Sensitivity 2 Implementation weighted 100% risk reduction	CORE Implementation weighted Co-benefits incorporated	Sensitivity 3 Implementation weighted Co-benefits incorporated 100% capex	Sensitivity 4 No implementation Co-benefits incorporated
Construction site shading	Quick win	Quick win	Quick win	Quick win	Quick win
Green walls	Quick win	Complementary	Deprioritised	Complementary	Quick win
Cool pavements	Quick win	Complementary	Complementary	Complementary	Quick win
Pervious or porous surfaces	Transformative	Transformative	Transformative	Quick win	Transformative
External shutters	Transformative	Transformative	Transformative	Transformative	Transformative
Replacement of windows with low g-value glazing	Transformative	Transformative	Transformative	Transformative	Transformative
Green infrastructure – increasing tree cover	Transformative	Deprioritised	Transformative	Quick win	Transformative
Internal blinds	Complementary	Quick win	Quick win	Quick win	Complementary
Curtains	Complementary	Quick win	Quick win	Quick win	Complementary
Solar reflective coating to walls	Complementary	Quick win	Quick win	Transformative	Complementary
Internal shutters	Complementary	Quick win	Quick win	Transformative	Complementary
Low g-value window film	Complementary	Quick win	Quick win	Quick win	Complementary
Active cooling (air-conditioning)	Complementary	Quick win	Complementary	Deprioritised	Complementary
Irrigation	Complementary	Complementary	Complementary	Complementary	Quick win
Pedestrianisation of streets	Complementary	Complementary	Complementary	Complementary	Quick win
Green infrastructure – establishing parks and green spaces	Complementary	Complementary	Complementary	Complementary	Quick win
Green infrastructure – undertaking strategic planting around buildings	Complementary	Complementary	Complementary	Complementary	Complementary
Blue infrastructure – establishing ponds and rivers and water features	Complementary	Complementary	Complementary	Complementary	Complementary
Solar reflective coating to roofs	Complementary	Complementary	Complementary	Deprioritised	Complementary
Solar reflective tiling	Complementary	Complementary	Deprioritised	Complementary	Complementary
Roof insulation	Complementary	Complementary	Complementary	Deprioritised	Complementary
External shading on south, east and west orientated windows	Deprioritised	Transformative	Transformative	Transformative	Deprioritised
Replacement of windows with an increased openable area	Deprioritised	Deprioritised	Deprioritised	Deprioritised	Deprioritised
Green roofs	Deprioritised	Deprioritised	Deprioritised	Deprioritised	Transformative

Table A.2: Sensitivity testing results: how different MCA assumptions lead to different prioritisations of adaptation measures.

Removing non viable combinations

An interdependency analysis was carried out to avoid unrealistic or redundant combinations (e.g. internal blinds and curtains would not generally be applied together, or there may be contradictory urban realm options). The highest-scoring adaptation measure where there is overlap was prioritised.

Exclusions

- Measures that could not be applied to existing buildings (e.g. building orientation and massing) were excluded from package development.
- The metric used to assess heat-related mortality considers only air temperature, while productivity loss is measured by WBGT, which incorporates air temperature, relative humidity, and solar radiation. Any solutions that affect other climate parameters are not included in this study, as their impacts cannot be quantified. For example, although indoor fans may help alleviate overheating indoors, it is not possible to accurately determine their effect on reducing mortality risk or productivity loss; therefore, they have not been considered.

A.1.6.5 Development and structuring of adaptation packages

Shortlisting the measures enabled the development of adaptation packages where sets of measures are grouped for joint implementation.

Building-scale and urban-scale measures were considered separately due to their distinct effects on heat risk reduction and unique implementation considerations. The final adaptation packages comprised a combination of both building-scale and urban-scale measures, reflecting a comprehensive approach to mitigating heat-related risks.

Within each package, adaptation measures targeting the reduction of heat-related mortality risk were separated from those aimed at reducing productivity loss due to heat. This distinction was necessary because the location and application of adaptation measures for productivity loss differs from those for mortality. For the purposes of this study, mortality risk was assumed to occur primarily within homes, so adaptation measures for this risk focused on building-scale solutions for residences and urban-scale measures that help lower internal temperatures. In contrast, adaptation measures for productivity loss were selected for their applicability to office buildings (representing indoor workplaces) and outdoor urban areas where workers are present.

The final five adaptation packages were selected based on several parameters: the spectrum from passive to active cooling, the scoring matrix categorisation, their application at either building or urban scale, and the combination of measures designed to reduce both mortality and productivity loss due to heat. The packages are presented in Box 8.

The five packages developed represent a structured set of options – low regret, quick win measures through to more transformative nature-focused and active cooling approaches – providing a clear range of choices for different levels of ambition and investment.

The next stage of the study assessed the heat reduction effects of implementing these packages across UK urban areas under various future climate scenarios. The goal was to compare the effectiveness of each package against the baseline to obtain the reduction in heat-related mortality and productivity impacts.

A.1.7 Estimating the heat risk reduction of adaptation packages

The approach to modelling adaptation combines urban heat analysis and building-scale models to assess how each adaptation package reduces heat risk. Adaptation packages were applied only to future climate scenarios. This approach produced updated temperature estimates, which were then used to recalculate future heat-related mortality and productivity impacts.

To understand the impact of urban-scale adaptation measures, the urban climate analysis methodology simulated how each measure changes local outdoor conditions. To understand how building-level adaptation measures would affect indoor conditions, dynamic thermal modelling was used for three common housing types: flats, terraced homes, and semi-detached homes. Offices were not modelled, because all adaptation packages assume that offices use active cooling, which prevents any productivity losses. When an adaptation package also included urban-scale measures, the updated outdoor temperature estimates from the urban modelling were fed into the building models.

The modelling of adaptation measures generated new climate conditions, which were fed into the same mortality and productivity analysis process used in the baseline assessment. This allowed updated estimates of heat-related deaths and productivity losses and captured the impact of the adaptation packages.

Box 8: Five adaptation packages

Package	Details	Adaptation measures	
		Mortality [applied to residential areas]	Productivity loss [applied to workplaces]
A – Foundational	A lightweight package composed of quick win low impact adaptation measures	Building-scale Internal blinds Low g-value window film Solar reflective coating to external walls Urban-scale None	Building-scale Active cooling Urban-scale Construction site shading
B – Enhanced	A medium package with quick wins and complementary measures	Building-scale Internal blinds Low g-value window film Solar reflective coating to external walls Solar reflective coating to roofs Roof/loft insulation Urban-scale Cool pavements Parks and green spaces Irrigation Blue infrastructure	Building-scale Active cooling Urban-scale Construction site shading Cool pavements Parks and green spaces Irrigation Blue infrastructure
C – Enhanced Nature	A more comprehensive package of actions combining nature-based solutions with urban and building cooling measures	Building-scale External shutters Solar reflective coating to external walls Solar reflective coating to roofs Roof/loft insulation Urban-scale Cool pavements Parks and green spaces Irrigation Blue infrastructure Increasing impervious surfaces Increasing tree cover	Building-scale Active cooling Urban-scale Construction site shading Parks and green spaces Irrigation Blue infrastructure Increasing impervious surfaces Increasing tree cover
D – Active Cooling	Focused on building scale active cooling.	Building-scale Active cooling – room unit Urban-scale None	Building-scale Active cooling Urban-scale Construction site shading
E – Integrated Cooling	Building-scale active cooling complemented by some passive measures	Building-scale Active cooling – room unit Internal blinds Roof/loft insulation Urban-scale None	Building-scale Active cooling Urban-scale Construction site shading

A.1.7.1 Calculating the impact of urban-scale measures

To quantify the temperature reduction from urban-scale adaptation measures, the [Surface Urban Energy and Water Balance Scheme \(SUEWS\)](#) climate model was utilised.

The heat reduction effects of the urban-scale measures in Package B (Enhanced) and Package C (Enhanced Nature) were derived using the SUEWS model. These packages influence local air temperature and relative humidity, which in turn affect daily average temperatures linked to heat-related mortality and WBGT associated with productivity loss.

Heat differs widely across the UK, with additional variation arising from differences in urban density. The impact of adaptation on local temperature will vary depending on local urban characteristics. To capture this the modelling used the urban typologies described in Section A.1.2.2 and a suite of parametric SUEWS models. SUEWS is a transient urban-climate model and was run over the series of climate datasets. The full analysis process is described in Box 9. Note that the impact of construction site shading, which is included in all adaptation packages, was not modelled using SUEWS because the model does not account for shade. Instead, an adjustment was applied directly to the solar radiation variable used in the WBGT calculation. Further details are provided in Box 9.

Box 9: Detailed urban climate analysis process using SUEWS

Urban temperature reductions were modelled using SUEWS, a transient urban climate model that simulates how heat is stored, released and transferred within cities. SUEWS is an open-source model developed by Professor Sue Grimmond's team at the University of Reading [19]. It accounts for a wide range of factors that influence how heat is stored, released and moves in urban areas, including building heights, reflectivity of surfaces, the amount of green and blue infrastructure, the extent of hard surfaces, population density and the local climate conditions.

The analysis used the urban typologies defined in Section A.1.2.2. Each typology was modelled under baseline and adaptation conditions to reflect typical urban forms across the UK.

1. Modelling parameters

- Four climate regions: SUEWS was run for the four representative UK climate regions. Running the model for every individual LSOA was not feasible, so climate region outputs were spatially mapped back to LSOAs.
- Four climate scenarios: Both central and high climate change projections were used for the 2030s and 2050s.
- Three modelling cases:
 - Baseline (No Adaptation) — each urban typology simulated with no proactive heat adaptation.
 - Package B (Enhanced) — typology parameters modified to incorporate Package B measures.
 - Package C (Enhanced Nature) — typology parameters modified to incorporate Package C measures.

2. Heat reduction calculation

For each climate region and scenario:

- Baseline SUEWS run generated hourly air temperature and humidity.
- Adaptation SUEWS run (Package B or C) generated a modified climate profile.
- Heat reductions were calculated as the difference between adaptation and baseline runs.

This produced heat reduction factors for each:

- climate region (x 4)
- climate scenario (x 4)
- adaptation package (x 2)
- urban typology (x 12)

3. Mapping reductions across the UK

Each urban LSOA was assigned reduction values based on:

- its corresponding climate region, and
- the climate scenario and adaptation package being assessed.

The result was a full set of adaptation adjusted temperature profiles for every urban LSOA for the 2030s and 2050s.

Calculating WBGT under adaptation

To estimate the impact of urban adaptation measures on WBGT, the adaptation-adjusted temperature profiles were used to update relative humidity for each climate dataset, while keeping moisture content constant.

Although SUEWS simulates changes in relative humidity, it was not feasible within the scope of this project to generate fully multivariate climate adjustments (temperature + humidity + radiation) at UK-wide LSOA resolution.

Therefore, a simplified and consistent approach was used:

- adjust adapted temperatures,
- recalculate relative humidity assuming fixed moisture content,
- and then recompute external WBGT using the adapted climate variables.

This ensured WBGT estimates remained consistent with the underlying physics while staying computationally feasible at a national scale.

Calculating the impact of shade

One limitation of SUEWS is that it does not account for the cooling effects of shade, which is important for reducing heat exposure for outdoor workers. Because shading affects solar radiation rather than air temperature directly, an additional step was used to estimate its impact on WBGT, which underpins the productivity loss calculations.

Shading from construction site solutions was included under all adaptation packages. Since shade reduces heat primarily by reducing incident solar radiation, we applied an adjustment within the proxy globe temperature equation used for WBGT.

The globe temperature approximation used in this study is:

$$T_g = \left(\frac{Q_s}{4\sigma} + T_d^4 \right)^{1/4}$$

To represent shading, 90% of direct solar radiation was removed, consistent with deep shade conditions typical of construction site canopies:

$$Q_s \rightarrow 0.1Q_s$$

The adaptation adjusted globe temperature was then used to recalculate WBGT for all climate regions, scenarios and adaptation packages.

A.1.7.2 Calculating the impact of building-scale measures

The impact of building-scale measures that modify indoor temperatures was assessed using Dynamic Thermal Modelling (DTM). The process followed the same general steps used to model indoor conditions for the baseline productivity assessment in the office archetype.

All adaptation packages include air-conditioning for indoor work settings. It was therefore assumed that mechanical cooling eliminates heat-related productivity loss in offices under all scenarios. As a result, DTM was not required to estimate productivity benefits for workplaces, since productivity loss was assumed to be reduced by 100% wherever cooling is installed.

However, DTM was required to quantify the heat reduction effects of residential building-scale adaptation measures, where indoor overheating directly influences heat-related mortality. The detailed steps of this modelling process are provided in Box 10.

As with indoor work settings, Package D and Package E also include air-conditioning for residential buildings. For these packages the risk reduction is also assumed to be 100%. Although DTM is not needed to obtain indoor temperature, it has been used to calculate energy usage and subsequent operational costs used for the cost benefit analysis. This process is detailed in Box 11.

Box 10: Deriving the heat reductions from residential building-scale adaptation

Residential building models

The impact of adaptation measures on reducing internal heat was obtained using Dynamic Thermal Modelling (DTM). Energy Plus via Design Builder is a software that runs parametric simulations for dynamic thermal models, using building models and weather files as input. Parametric simulations were essential to handle the large number of simulations needed for a UK-wide analysis.

The modelling used the three residential archetypes: flats, terraced houses and semi-detached houses to represent UK housing stock. Each building archetype was modelled under baseline (no proactive heat adaptation) and with adaptation packages applied.

1. Modelling parameters:

- Four climate regions: DTM was run for the four representative UK climate regions. Running the model for every individual LSOA was not feasible, so temperature changes from adaptation measures were spatially mapped back to LSOAs.
- Four climate scenarios: Both central and high climate change projections were used for the 2030s and 2050s.
- Four modelling cases:
 - Baseline (“no adaptation”) — each residential archetype simulated with no proactive heat adaptation.
 - Package A (Foundational) — residential archetype parameters modified to incorporate Package A measures.
 - Package B (Enhanced) — residential archetype parameters modified to incorporate Package B measures.
 - Package C (Enhanced Nature) — residential archetype parameters modified to incorporate Package C measures.

Note that packages D (Active Cooling) and package E (Integrated Cooling) were modelled separately to obtain an estimate of energy usage and related operational cost. This process is described in the next section.

2. Heat reduction calculation

For each climate region, scenario and residential building archetype:

- Baseline (no adaptation) DTM runs generated hourly internal air temperature.
- Adaptation DTM runs (Package A, B or C) generated a modified internal temperature profile (i.e. with reduced temperatures).
- Temperature reductions were calculated as the difference between adaptation and baseline analysis. For instance, the baseline and Package A results for a terraced house in London in the 2030s would be compared to obtain the heat reduction produced as a result of applying building-scale adaptation measures within Package A.

This produced internal heat reduction factors for each:

- climate region
- climate scenario
- adaptation package
- residential archetype.

3. Mapping reductions across the UK

Each LSOA was assigned three daily average indoor air temperature reduction profiles or temperature shifts, $\Delta T_{int}^{a,r,s,p}$, corresponding to the three residential housing archetypes. These profiles varied by climate region r , climate scenario s , and adaptation package $p(A-C)$.

Calculating equivalent outdoor air temperature under adaptation

The DTM gave us a reduction in indoor air temperature when building-scale adaptation is applied. Literature showed a link between outdoor air temperature and mortality, but no direct connection between indoor conditions and heat-related deaths. Further steps had to be taken to connect the reductions in indoor heat to a reduction in heat-related mortality. The concept of an *equivalent outdoor temperature* was utilised to do this.

For each housing archetype, climate region, climate scenario, adaptation package and LSOA, the equivalent outdoor temperature was calculated by applying the modelled indoor temperature shift to the corresponding baseline outdoor temperature profile:

$$T_{out,eq}^{a,r,s,p}(t) = T_{out,base}^{r,s}(t) - \Delta T_{int}^{a,r,s,p}$$

where:

$T_{out,eq}^{a,r,s,p}(t)$ is the equivalent outdoor dry-bulb temperature or air temperature,

$T_{out,base}^{r,s}(t)$ is the baseline outdoor air temperature time series, and

$\Delta T_{int}^{a,r,s,p}$ is the daily average indoor temperature reduction obtained from the DTM.

This equivalent outdoor temperature represented the outdoor condition that would result in the same level of heat exposure as the adapted indoor environment. Established outdoor temperature–mortality relationships from the literature can then be applied to $T_{out,eq}$ to re-estimate heat-related mortality, accounting for the effect of building-scale adaptation measures. Note that the equivalent outdoor temperature is a mathematical construct introduced to translate reductions in indoor heat exposure into changes in heat-related mortality risk. It should not be interpreted as a physically realised outdoor temperature.

Box 11: Calculating energy usage from residential air-conditioning

Package D (Active Cooling) and Package E (Integrated Cooling) both included active cooling in the form of air-conditioning. DTM (using Design Builder) was carried out for both of these packages to determine the energy usage from active cooling and the corresponding operational cost (opex) which was later used in the cost-benefit analysis.

- 1. Modelling parameters.** As with packages A-C, the DTM models were carried out for the three housing archetypes across the four UK climate zones and for each climate scenario.
- 2. Cooling operation period.** Active cooling was modelled between 1 May and 30 September.
- 3. Cooling setpoints and occupant behaviour.** The cooling setpoint for air-conditioning was 26°C. When internal air temperature is:
 - 24–26°C: occupants rely on window opening for thermal comfort.
 - Above 26°C: windows were assumed to be closed, and air-conditioning is used with a setpoint of 26°C.
- 4. Nighttime operation (at 11pm):**
 - If internal temperature is greater than 23°C, air-conditioning was assumed to operate overnight with a setpoint of 26°C.
 - If internal temperature is ≤ 23°C, cooling is switched off and windows were assumed to be closed.
- 5. Scope of cooled space.** Cooling was assumed to be applied to a single room only, rather than the whole dwelling. A 2.6kW unit was assumed.
- 6. Mapping the results across the UK.** An annual cooling load was obtained for each dynamic thermal model. The results were mapped to UK urban LSOAs with each area assigned three cooling loads (corresponding to the three housing archetypes).
- 7. Obtaining operational costs.** The operational costs were calculated by applying the CCC-provided residential electricity price series (LRVCs, p/kWh), confirmed as consistent with the assumptions underpinning the CB7.

A.1.7.3 Existing measures for buildings

The analysis accounted for the presence of existing and anticipated cooling-related measures within the UK building stock, recognising that these reduce the number of buildings and occupants exposed to heat impacts.

At present-day baseline, most UK homes were assumed not to have active cooling, reflecting the historically low penetration of domestic air-conditioning.

Looking forward, uptake of air source heat pumps (ASHPs) was assumed to increase by 2030 and further by 2050, in line with wider decarbonisation pathways for buildings [26]. A proportion of ASHPs were assumed to be installed and operated in a mode that can provide cooling or enhanced thermal comfort (i.e. air to air ASHPs) and a proportion of dwellings were therefore assumed to experience avoided heat impacts. Accordingly, this proportion of dwellings are treated as fully mitigated within the analysis. The calculation utilised a combination of CB7 data [26] and projected future cooling demand from the Weather for Power Dataset (WPD v4) [27], estimating air to air ASHP uptake in UK households at 7% by 2030 and 34% by 2050.

For the non-domestic sector, it was assumed that air-conditioning is already prevalent across much of the existing office stock (65% assumed [21]). In addition, by 2030, 25% of offices were assumed to be equipped with ASHP-based systems, further reducing the proportion of office floor area exposed to heat impacts [26].

Note that the update of ASHPs is not included in the baseline analysis and is only included as part of the adaptation scenarios. The impact on costing is discussed in Section A.1.8.6.

A.1.7.4 Combining urban and building-scale adaptation measures

Urban-scale measures change outdoor climate conditions, while building-scale measures change indoor temperatures. For adaptation packages that include measures at both scales, the modelling process needs to combine these effects so that indoor conditions reflect the cooler external environment as well as the building-scale improvements.

Because SUEWS and DTM operate at different scales, a two-stage sequential method was used:

- 1. Apply urban-scale adaptation (SUEWS).** Urban-adapted outdoor climate files were generated using outputs from the SUEWS (Box 9) urban climate analysis for all relevant packages (e.g. Packages B and C). These files incorporate the effects of greening, trees and surface changes, and other urban modifications on temperature.
- 2. Apply building-scale adjustment factors.** Apply the building-adaptation adjustment factors derived earlier from DTM runs

(see Box 10) to the urban-adjusted files.

This is carried out for all UK urban LSOAs and produced the final climate datasets used in the risk reduction assessment.

Construction site shading was not included in this combined process as it affects only outdoor exposure; its effects were applied directly to the WBGT calculation (see Box 9).

Box 12 shows how the urban and building-scale analysis was applied to each adaptation package.

Box 12: Application of urban and building-scale analysis to each adaptation package.

Package	Urban-scale adaptation adjustment	Building-scale adaptation adjustment
A – Foundational	Not applied (no urban scale measures influencing outdoor temperatures)	Applied (passive building measures only)
B – Enhanced	Applied (urban scale measures included)	Applied (passive building measures included)
C – Enhanced Nature	Applied (urban scale nature based measures included)	Applied (passive building measures included)
D – Active Cooling	Not applied (no urban scale temperature modifying measures)	Not applied — active cooling assumed to eliminate all indoor heat risk
E – Integrated Cooling	Not applied (no urban scale temperature modifying measures)	Not applied — active cooling assumed to eliminate all indoor heat risk



A.1.7.5 Calculating post-adaptation mortality impacts

Heat-related mortality was recalculated using the adaptation adjusted daily temperatures from the process above. The same mortality risk function (Murage et al.) was applied to the new temperature series to produce a set of post adaptation mortality estimates for each LSOA, climate scenario and adaptation package.

Risk reduction was then calculated as:

Mortality Risk Reduction = Baseline Mortality – Post-Adaptation Mortality

These values were aggregated to regional, national and UK-wide totals to generate the reduction in heat related deaths, and monetised mortality impacts (using VOLY), relative to the baseline.

A.1.7.6 Calculating post-adaptation productivity impacts

For productivity, adaptation adjusted WBGT was used to recalculate hourly productivity loss for the construction sector for each LSOA. This followed the same method as the baseline analysis, but with the adapted WBGT values substituted.

Annual productivity hours lost were then recalculated and converted to monetised impacts (GVA loss) using the same sectoral productivity per hour approach as the baseline.

Risk reduction was calculated as:

Productivity Risk Reduction = Baseline GVA Loss – Post-Adaptation GVA Loss

Note that for all indoor job sectors we assumed that office air-conditioning - which was applied to all adaptation packages - removed all productivity losses.

This provided the reduction in annual productive hours lost and total GVA loss, at LSOA, regional and UK levels.

A.1.7.7 Converting from extreme to typical year

The primary analysis was conducted for extreme present day (2022) and future climate periods (2030s and 2050s CIBSE Design Summer Year files).

Equivalent results for typical present-day and future climates were derived using conversion factors applied to these extreme year results. This was required for the purpose of the cost-benefit analysis, where year-by-year monetised risk reduction values were required from the implementation start date through to the end of the appraisal period (2059).

We converted from extreme to typical year through the following steps:

1. The extreme year risk reduction estimates were adjusted to represent a more typical year in both the 2030s and 2050s. A set of adjustment factors was developed to translate peak event impacts into annualised values. The climate adjustment were derived by comparing conditions from the CIBSE typical meteorological year (TMY) weather files with those from the extreme design summer year (DSY2). For each of the four modelling locations (Glasgow, London, Swindon and Birmingham), an adjustment factor was calculated to represent the difference between the typical and extreme years. This factor was then applied to our analysis, which was originally based on DSY2, to convert the extreme year results to reflect a typical year.
2. The benefit-cost ratio (BCR) requires a continuous annual series from 2030 to 2059. Risk reduction values were interpolated linearly between the 2030 and 2050 points, and between 2050 and 2059 in line with the study assumptions.

This approach provided a practical method for the purposes of this study. However, its limitations are acknowledged, particularly with respect to the simplifications required to annualise extreme year results. Further refinement would be beneficial in future work.

A.1.8 Cost-benefit analysis and determining a cost-effective package

The analysis described in this section was designed to evaluate the comprehensive value of each package by first selecting an implementation rollout percentage for testing measures, followed by calculating the benefit-cost ratio (BCR) metric. These measures facilitated the identification of the most cost-effective package and informed strategies for its efficient deployment across the UK.

A.1.8.1 Approach to cost effectiveness assessment

The assessment evaluated the comprehensive value of each adaptation package by:

3. Establishing an initial implementation rollout to test packages based on the spatial distribution of baseline heat-related risks; and
4. Calculating the BCR for each adaptation package and rollout scenario.

Box 13: Key definitions for the cost benefit analysis

Key definitions:

- Chosen or selected rollout: This refers to a targeted implementation approach where adaptation measures are prioritised in areas with the highest heat risk, rather than being deployed uniformly across all locations. For example, urban districts with elevated heat exposure or vulnerable populations would be the first to receive solutions, thereby maximising the effectiveness and efficiency of resource allocation.
- Cost-effective package: This is the set of adaptation measures that delivers the greatest benefit for the least cost, considering not only heat risk reduction but also additional co-benefits and implementation expenses. The selection process compares multiple packages to determine which achieves the highest net value when accounting for all relevant factors.
- The BCR is a quantitative indicator used to assess the cost-effectiveness of adaptation packages. It is calculated by dividing the total estimated benefits (such as avoided mortality, productivity gains, and co-benefits) by the total associated costs (including capital, operational, and replacement expenses). A BCR greater than 1 indicates that benefits outweigh costs, supporting the case for investment.

A.1.8.2 Benefit–Cost Ratio (BCR)

A cost benefit analysis was carried out to determine the BCR for the adaptation packages. The BCR was calculated as the total discounted benefits divided by the total discounted costs over the time horizon 2025-2059, discounted to present value terms:

$$BCR = \frac{\text{Present value (Benefits)}}{\text{Present value (Costs)}}$$

A BCR greater than 1 indicated that adaptation generated net benefits.

The BCR brought together the following components:

- Risk reduction: The primary focus was on reducing heat-related mortality and productivity loss. The assessment spanned from the start of implementation (assumed as 2030) to the end of the analysis period (2059), covering various climate scenarios. In addition, we also carried out an additional high level assessment looking at how adaptation can improve sleep quality during hot periods and the knock-on productivity gains this may generate.
- Co-benefits: Many of the measures that help cool buildings and urban areas—particularly nature-based solutions—also deliver wider climate and societal benefits, such as increased biodiversity, improved air quality and reduced surface water flood risk. These co-benefits were recognised qualitatively during the MCA; here they were quantified at a high level where possible.
- Costs: Costs formed the other side of the equation. While earlier sections quantified the monetised impacts of heat and the scale of benefits that adaptation can unlock, these needed to be weighed against the capital, operational and replacement costs associated with delivering the packages across UK buildings and urban areas. By bringing these elements together, this metric identified which adaptation packages offer the strongest return on investment.

The cost–benefit analysis followed HM Treasury Green Book guidance and applies best practice in cost estimation, discounting, sensitivity testing and uncertainty management. Data inputs and assumptions are presented in Box 14.

Box 14: Cost benefit analysis details

Key assumptions:

- All annual costs and benefits were discounted and aggregated to present-value (PV) terms.
- In line with HM Treasury Green Book guidance, a standard 3.5% discount rate (years 1–30) was applied to avoided productivity losses, carbon sequestration, stormwater mitigation and recreational value co-benefits, as well as all cost categories.
- The 1.5% health discount rate (years 1–30) was applied to avoided mortality impacts and air pollution removal co-benefits.
- All benefits and costs were profiled from 2022 to 2059, expressed in real terms. The profile used goes from 2025 as the base year.
- The BCR for each package was calculated as the ratio of total discounted benefits to total discounted costs.

A.1.8.3 Implementation rollout

Figure A.14 presents the baseline (2022) present-day monetised impact on mortality and productivity arranged by cumulative impact, compared with the percentage of LSOAs included from highest to lowest monetised impact. This framing showed how cumulative national impact increases as a greater proportion of the country is considered.

The resulting cumulative loss curve allows an optimal intervention point to be estimated, where the gradient of the curve equals 1; indicating that each additional LSOA contributes proportionally to total cumulative loss. Beyond this point, the marginal benefit of adaptation diminishes.

Key insights from the dataset included:

- The highest-risk 20% of LSOAs account for 50% of total monetised heat-related impacts across the UK.
- The highest-risk 30% of LSOAs account for 62% of impacts.
- The highest-risk 40% of LSOAs account for 71% of impacts.
- The highest-risk 60% of LSOAs account for 85% of impacts.

On the basis of this analysis, a 30% rollout scenario was selected to compare the cost-effectiveness for the different adaptation packages.

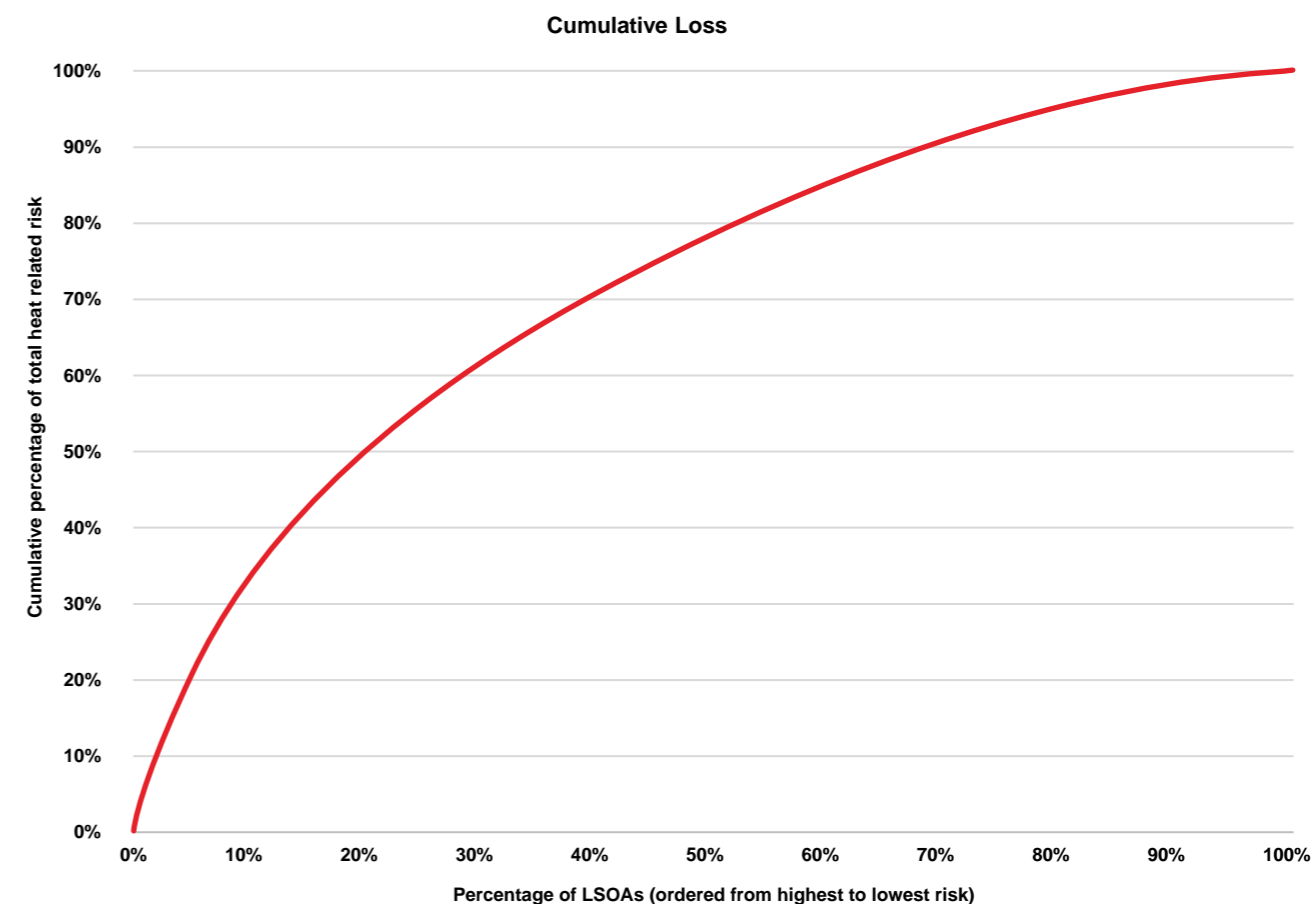


Figure A.14: Cumulative monetised heat impact of LSOAs across the UK, ordered according to relative heat risk.



A.1.8.4 Quantifying the relationship between heat, sleep and productivity

In addition to heat-related mortality and productivity impacts, the effect of heat on sleep deprivation was estimated as a secondary impact. This considered how heat contributes to sleep deprivation and its subsequent effect on productivity loss. This assessment was conducted for both the baseline scenario and all adaptation packages to demonstrate additional risk reduction achieved through adaptation strategies. The technical methodology used for this calculation is described in Box 15.

There is a notable lack of UK-specific studies directly examining the link between heat, sleep deprivation, and next-day productivity. However, anecdotal evidence points to a negative effect of excessive heat on sleep quality and the resulting impact on daily functioning.

To quantify this impact, two separate studies were referenced to establish a robust method:

- Nighttime ambient temperature and sleep in community-dwelling older adults, Amir Baniassadi, Brad Manor, Wanting Yu, Thomas Trivison, Lewis Lipsitz [20] - explores the relationship between total sleep duration and bedroom nighttime temperature, which allows for the estimation of total sleep hours lost due to heat stress across the UK.
- Why Sleep Matters—The Economic Costs of Insufficient Sleep, Hafner M, Stepanek M, Taylor J, Troxel WM, van Stolk C. [21] - which quantifies the association between reduced sleep and lost work hours, thereby enabling calculation of the resulting annual economic loss.

By combining approaches from these studies, a baseline for heat-related sleep deprivation and resulting productivity loss was established (see Box 15 for details). This baseline was then used to assess how different adaptation packages mitigate these impacts, based on a scenario where 30% of households in the UK implement the measures.

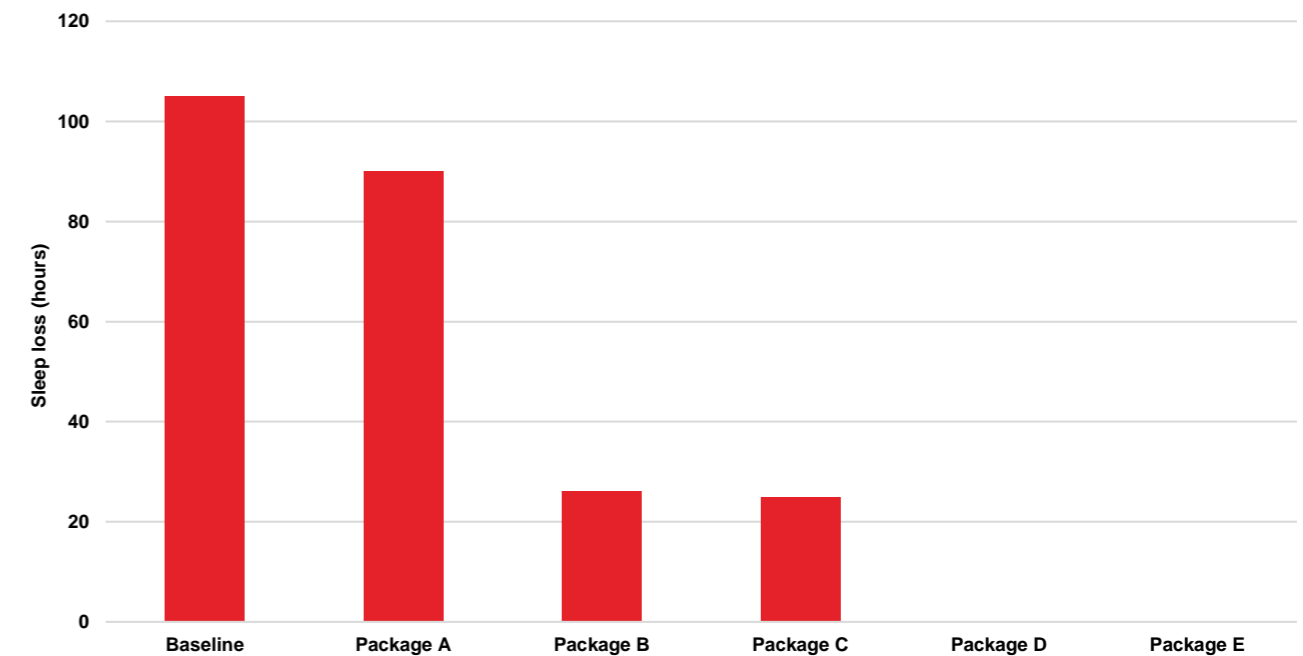


Figure A.15: Residual sleep loss (hours per year per person) under the baseline and adaptation packages in the 2050s. These have been averaged across the UK and for the three residential building types.

Box 15: Method: Estimation of heat-related sleep productivity loss

This analysis quantified the impact of heat-related sleep disruption on labour productivity using a chained evidence-based approach. A direct empirical relationship linking nighttime heat exposure, sleep loss and productivity loss was not available in the literature; therefore, two complementary evidence streams were combined.

- 1. Estimation of indoor nighttime temperatures.** Indoor nighttime air temperatures were obtained for residential buildings using outputs from the BEM analysis for the building archetypes (flats, terraced and semi-detached dwellings) under baseline present and future climate scenarios. Night-time hours were defined as 22:00–07:00. Indoor temperature profiles were obtained for each climate zone for each building archetype.
- 2. Calculation of sleep duration as a function of temperature.** A temperature–sleep relationship was applied to estimate total sleep time (hours per night) as a function of average indoor nighttime temperature. This relationship was derived from nighttime ambient temperature and sleep in community-dwelling older adults [28] examining the effect of bedroom or ambient nighttime temperature on total sleep duration. For each climate zone and day, the modelled nighttime temperature was converted into estimated total sleep time.
- 3. Estimation of sleep hours lost due to heat.** Daily sleep loss was calculated as the difference between estimated total sleep time under heat exposure and a baseline (cool-night) sleep duration. Daily values were aggregated to produce annual sleep hours lost per person for each climate zone.
- 4. Translation of sleep loss into productivity loss.** Sleep duration bands were mapped to productivity impacts using *Why Sleep Matters—The Economic Costs of Insufficient Sleep* [29] which links insufficient sleep to reduced work output. Percentage productivity losses associated with reduced sleep duration were converted into lost working hours per worker, assuming a standard working day.

- 5. Aggregation of annual productivity loss.** Lost working hours attributable to sleep disruption were aggregated annually by climate zone. Results were averaged across residential building types and scaled to regional population levels.
- 6. Monetisation of productivity impacts.** Annual lost working hours were monetised using regional gross value added (GVA) per worker to estimate the monetised impact of heat-related sleep productivity loss. Results were reported as annual monetised impact for present and future climate scenarios.
- 7. Assessing the impact of adaptation measures.** Modelled indoor nighttime temperatures for each residential archetype under each adaptation package were used to estimate changes in heat-related sleep deprivation and the associated productivity loss. Differences between baseline and adaptation scenarios were then used to quantify the potential risk reduction delivered by each adaptation package.

Sleep-related productivity impacts were calculated at climate-zone resolution and treated as an additional risk and co-benefit. This analysis provided an indicative estimate of sleep-related productivity loss.

A.1.8.5 Assessing co-benefits of green measures
Many of the measures that help cool buildings and urban areas — particularly nature-based solutions — also generate wider climate and societal benefits. These include increased biodiversity from additional green and blue spaces, improvements in local air quality, and reductions in surface water flood risk through more permeable surfaces and better water management.

For this study, four key co-benefits were quantified where suitable evidence was available:

- Carbon sequestration
- Stormwater mitigation
- Air pollution removal
- Recreational value.

The methods and data sources used to monetise these benefits are summarised below.

Valuing parks, green space and larger scale nature-based measures

The environmental benefits of parks and green space measures were monetised using the Natural Capital Register and Account Tool (NCRAT), developed by the Environment Agency [11]. NCRAT provided social value estimates for:

- carbon sequestration
- air pollution removal
- recreational value.

Recreational benefits were benchmarked using the Outdoor Recreation Valuation Tool (ORVal) [12], developed by the University of Exeter. ORVal provided visit-based valuation derived from national patterns of park use relative to land area and therefore offers a robust approximation of recreational value associated with expanded green space.

NCRAT is well-suited to large, landscape-scale solutions, but it is not appropriate for isolated changes such as individual street trees. These cases required a different approach.

Valuing increased urban tree cover

To estimate the benefits of changes in urban tree cover, the i Tree tool [13] was used. i Tree calculates annual benefits per tree for:

- carbon sequestration
- air pollution removal
- stormwater mitigation.

These per tree values were then scaled to the UK level to estimate total benefits associated with changes in urban canopy cover. It is important to note the coverage limitations of each tool:

- Stormwater benefits are only captured through i Tree (NCRAT does not quantify these).
- Recreational benefits are only captured through NCRAT/ORVal (i Tree does not quantify recreation).

As a result, the combined approach is likely to underestimate both stormwater mitigation and recreational value.

A.1.8.6 Costing adaptation packages

For each adaptation package, capital (capex), operational (opex) and replacement (repex) costs were calculated for all building-scale and urban-scale measures.

Costs were derived on a unit-rate basis. For buildings, the costs of implementing building-scale measures were calculated separately for each of the housing archetypes used in this study—flats, terraced houses, semi-detached houses—as well as for office buildings.

For urban-scale measures, unit costs were derived and then applied to each urban typology in varying amounts depending on the existing land cover.

These two sets of costs were combined and applied to every urban LSOA included in the study. Total costs therefore varied by LSOA, reflecting several key factors:

- Regional cost variation: Regional adjustment factors were applied to reflect differences in construction and delivery costs across the UK [28].
- Building stock within the LSOA: Data on the number and type of homes in each LSOA was used to estimate total building-scale costs.
- Urban typology: The application and scale of some urban-scale measures differ slightly by typology resulting in marginal cost variations.

The cost estimates are indicative, order-of-magnitude values prepared for representative building archetypes and urban typologies. They are based on generic assumptions regarding construction methods, asset condition and service capacity, and exclude professional fees, statutory approvals, abnormal works and inflation. Costs are provided to support strategic comparison of heat adaptation packages rather than site-specific feasibility or detailed decision making.

Details of the costs utilised in this study are provided in Box 16.

Box 16: Detailed costing of adaptation measures

Building-scale

For building-scale measures, cost data was either provided by the CCC or taken from estimates prepared by Rider Levett Bucknall (RLB) for the project.

Where available capital, operational, and replacement costs for residential building-scale adaptation measures were derived using standard unit rates provided by the CCC. These costs were supplied to ensure alignment with the assumptions used in the Seventh Carbon Budget (CB7), including expected background rollout of fabric measures linked to Net Zero delivery. Unit costs were defined for typical UK residential archetypes (flats, mid-terraced and semi-detached houses) and applied consistently across the analysis.

Operational costs associated with active cooling in residential buildings were estimated separately using dynamic thermal modelling to capture climate-dependent electricity demand under future scenarios. These costs were calculated by applying the CCC-provided residential electricity price series (LRVCs, p/kWh), confirmed as consistent with the assumptions underpinning the CB7, to the modelled cooling energy demand (kWh).

Costs for building measures not included in CB7 were estimated by Rider Levett Bucknall (RLB) for the project, based on UK building archetypes and agreed assumptions, and applied directly within the analysis.

The costs used and the sources are provided in Table A.6. Assumptions applied to the costing are provided further in Box 16.

Adaptation measures	Capex	Opex	Repex	Source
Internal blinds	£490	-	£32	CCC
Low g-value window film	£2,300	-	£150	CCC
Solar reflective coating to external walls	£2,010	-	£140	RLB
Solar reflective coating to roofs	-	-	-	-
Roof/loft insulation	-	-	-	-
External shutters	£6,200	-	£250	CCC
Active cooling	£380	-	£1,300	CCC

Table A.3: The cost of building-scale adaptation measures for a flat.

Adaptation measures	Capex	Opex	Repex	Source
Internal blinds	£760	-	£51	CCC
Low g-value window film	£3,500	-	£240	CCC
Solar reflective coating to external walls	£3,300	-	£220	RLB
Solar reflective coating to roofs – tiles	£3,200	-	£40	RLB
Solar reflective coating to roofs – paint	£2,800	-	-	RLB
Roof/loft insulation	£260	-	£4	CCC
External shutters	£9,700	-	£390	CCC
Active cooling	£380	-	£1,300	CCC

Table A.4: The cost of building-scale adaptation measures for a terraced house.

Adaptation measures	Capex	Opex	Repex	Source
Internal blinds	£1,200	-	£77	CCC
Low g-value window film	£5,400	-	£360	CCC
Solar reflective coating to external walls	£5,000	-	£330	RLB
Solar reflective coating to roofs – tiles	£2,800	-	£35	RLB
Solar reflective coating to roofs – paint	£2,200	-	£1,500	RLB
Roof/loft insulation	£430	-	£5	CCC
External shutters	£15,00	-	£590	CCC
Active cooling	£380	-	£1,300	CCC

Table A.5: The cost of building-scale adaptation measures for a semi-detached house.

Adaptation measures	Capex	Opex	Repex	Source
Air-conditioning	£3,700,000	£77,000	£ 6,900,000	RLB

Table A.6: The cost of building-scale adaptation measures for an office.

Box 16: Detailed costing of adaptation measures (continued)

Data inputs and assumptions

- Opex was not included for passive measures.
- Where measures can be reasonably self-installed (i.e. DIY) labour costs have been removed.
- The cost of scaffolding was only included once per package, assuming that all measures would be installed together for a given package.
- A periodic replacement frequency was assumed for each measure (provided below).
- All residential archetype costs were adjusted to account for a 6% future population growth by the 2030s compared to present-day.[17].
- All office archetype costs were adjusted for future workforce growth by 2030.
- Location factors were applied using the 3Q 2025 Building Cost Information Location Indices, for the whole of the UK [30].
- Roof or loft insulation for residential properties: It was assumed that 62% of UK residential properties already have roof or loft insulation installed; for these dwellings, no additional insulation costs were applied. A further 20% of properties were assumed to have partial insulation, for which a top-up insulation cost equal to 86% of the full installation cost was applied. The total cost for each LSOA was adjusted accordingly to reflect this distribution [31].
- Air Source Heat Pumps (ASHPs) for residential properties: Costing and analysis of ASHPs were informed by projections from the CCC CB7. Using a combination of (i) total residential cooling demand estimated in CB7 [26] and (ii) the modelled cooling demand for an average UK terraced house [27], the proportion of dwellings assumed to have air-to-air ASHPs by the 2030s was calculated. This proportion was estimated to be 7% of UK residential properties. Dwellings assumed to have air-to-air ASHPs installed by the 2030s were assumed not to require additional adaptation measures, so packages were not applied to this proportion of homes and the total costs of the adaptation packages were reduced accordingly. In addition, the cost associated with ASHP

were not included here as they were assumed to be accounted for within the UK's Net Zero goals. Note that costs were not reduced for ASHP installations occurring in the 2050s, as package implementation was assumed to be completed in the 2030s.

- ASHP for offices. Consistent with the approach adopted for residential buildings, it was assumed that 25% of UK office buildings have an ASHP installed by 2030 based on CB7 pathways [26]. Office buildings assumed to have ASHPs were therefore considered to already benefit from active cooling capability, and the total cost of office adaptation measures was reduced proportionally to reflect this assumed level of uptake.
- Existing air-conditioning in offices. It was assumed that 65% of UK office floor space is already air-conditioned [21]. As a result, the costs of additional active cooling adaptation were applied only to the remaining 35% of offices that do not currently have air-conditioning installed.
- Cool roofs for residential properties. For properties with a flat-roof extension, the cool roof adaptation measure was applied only to the extension area rather than the full dwelling. This was assumed to take the form of a solar-reflective roof coating (cool roof paint), which is suitable for flat roofs. The underlying assumption is that treating the extension can provide a sufficiently cooled space for a portion of the home, delivering partial thermal benefit. Based on national housing statistics, 17% of UK houses were assumed to have a flat-roof extension [32], and application of the measure was limited to this subset accordingly.

		London	South East	South West	East	North West	Wales	West Midlands	East Midlands	Yorkshire and The Humber	Scotland	Northern Ireland	North East
Construction site shading	Capex	1,537	192	177	176	177	181	174	181	160	161	108	158
	Opex	10	29	27	26	27	27	26	27	24	24	16	24
	Repex	2,305	383	355	351	355	362	348	362	319	323	216	316
Parks and green space	Capex	111	99	92	91	92	94	90	94	83	84	56	82
	Opex	13	11	11	10	11	11	10	11	9	10	6	9
	Repex	9	8	7	7	7	7	7	7	7	7	4	7
Cool pavements	Capex	215	192	177	176	177	181	174	181	160	161	108	158
	Opex	32	29	27	26	27	27	26	27	24	24	16	24
	Repex	429	383	355	351	355	362	348	362	319	323	216	316
Irrigation	Capex	158	141	131	130	131	133	128	133	118	119	80	116
	Opex	8	8	7	7	7	7	7	7	6	6	4	6
	Repex	237	212	196	194	196	200	192	200	176	178	120	174
Blue infrastructure	Capex	180	161	149	147	149	152	146	152	134	135	91	132
	Opex	18	16	15	15	15	15	15	15	14	14	9	13
	Repex	216	193	179	177	179	182	175	182	161	162	109	159
Increasing impervious surfaces	Capex	334	298	276	273	276	282	271	282	249	251	169	246
	Opex	22	19	18	18	18	18	18	18	16	16	11	16
	Repex	540	482	446	442	446	455	437	455	402	406	272	397
Increasing tree cover	Capex	158	141	130	129	130	133	128	133	117	119	79	116
	Opex	284	253	235	232	235	239	230	239	211	213	143	209
	Repex	32	28	26	26	26	27	26	27	23	24	16	23

Table A.7: The cost of urban-scale adaptation measures (£ per sqm).

Box 16: Detailed costing of adaptation measures (continued)

Data inputs and assumptions

Urban-scale costs were applied to each urban typology in varying proportions, depending on the existing land cover associated with that typology. Each UK Lower-layer Super Output Area (LSOA) is mapped to a specific urban typology, and the corresponding solution costs were applied, adjusted by the region in which the LSOA is located.

– Area assumptions of construction site shading. The area of construction site shading required within each LSOA is estimated using the number of construction workers located within that LSOA. A density factor of 10m² per person is applied [33]. It is further assumed that only 25% of construction workers would use shaded areas at any one time, in order to limit the total extent of shading provision.

Repex Frequency

The repex frequencies for each measure were informed by a review of available evidence, supplemented by professional judgement. The resulting assumptions are presented in Table A.8.

Measure	Repex frequency (years)
Internal blinds	15
External shutters	25
Low g-value window film	15
Solar reflective coating to walls	15
Solar reflective coating to roofs	15
Solar reflective tiling to roofs	80
Roof insulation	50
Active cooling	20
Green infrastructure - parks and green spaces	150
Green infrastructure - increasing tree cover	150
Green infrastructure - strategic planting around buildings	150
Blue infrastructure - ponds, rivers and water features	150
Pervious or porous surfaces	150
Irrigation	20
Cool pavements	15
Street shading	25
Air-conditioning	10

Table A.8: Repex frequency for adaptation measures.



A.2 Results tables

Region	2022			2030s			2050s		
	Total heat deaths	Monetised impact (£m)	Impact per capita (£)	Total heat deaths	Monetised impact (£m)	Impact per capita (£)	Total heat deaths	Monetised impact (£m)	Impact per capita (£)
East Midlands	180	150	30	270	210	39	610	430	72
East of England	360	260	41	510	350	52	1,100	700	96
London	460	430	47	620	550	57	1,600	1,200	120
North East	180	220	81	280	310	110	530	500	170
North West	310	230	31	550	400	51	1,200	770	92
Northern Ireland	80	59	31	140	97	48	310	190	94
Scotland	130	140	25	190	180	31	400	310	51
South East	1,100	740	80	1,800	1,200	120	3,700	2,100	200
South West	590	420	72	910	610	98	1,900	1,100	170
Wales	200	210	64	300	280	84	600	490	140
West Midlands	210	250	40	330	360	56	670	670	93
Yorkshire and The Humber	140	120	20	210	170	29	430	310	50
Total	4,000	3,200	-	6,100	4,700	-	13,000	8,900	-

Table A.9: Baseline and future baseline heat-related mortality results for an extreme year.

Region	2022					2030s					2050s				
	0-64 years	65-74 years	75-84 years	85+ years	Total	0-64 years	65-74 years	75-84 years	85+ years	Total	0-64 years	65-74 years	75-84 years	85+ years	Total
East Midlands	17	22	45	92	180	22	32	71	140	270	37	45	160	370	610
East of England	21	43	88	210	360	26	56	120	310	510	41	83	260	750	1,100
London	61	55	140	210	460	72	79	190	270	620	120	160	510	820	1,600
North East	40	31	36	71	180	53	50	58	120	280	78	53	110	290	530
North West	19	37	120	140	310	29	65	210	250	550	46	83	440	620	1,200
Northern Ireland	5	9	30	36	80	6	17	48	66	140	9	25	94	180	310
Scotland	25	9	25	75	130	31	13	37	110	190	40	16	64	280	400
South East	55	80	320	670	1,100	76	120	500	1,100	1,800	110	160	970	2,400	3,700
South West	34	54	170	340	590	43	79	260	530	910	64	99	510	1,200	1,900
Wales	37	7	54	100	200	47	9	81	160	300	71	11	150	370	600
West Midlands	41	41	67	57	210	56	68	100	97	330	98	97	240	240	670
Yorkshire and The Humber	8	29	73	31	140	10	44	110	48	210	16	58	230	120	430
Total	360	420	1,200	2,000	4,000	470	640	1,800	3,200	6,100	720	890	3,700	7,700	13,000

Table A.10: Heat-related mortality per age group for the baseline and future baseline, for an extreme year.

Region	2022		2030s		2050s	
	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)
East Midlands	540	26	940	39	3,800	210
East of England	650	36	1,400	66	6,100	390
London	2,900	180	4,300	220	9,400	670
North East	160	8	71	3	640	37
North West	770	39	1,100	51	5,800	340
Northern Ireland	24	2	19	1	59	4
Scotland	130	6	200	8	880	47
South East	740	54	2,100	120	8,600	650
South West	380	25	1,800	110	5,000	390
Wales	140	7	550	21	1,700	87
West Midlands	550	31	1,400	58	5,500	320
Yorkshire and The Humber	580	29	600	25	3,000	170
Total	7,500	450	14,000	720	50,000	3,300

Table A.11: Baseline and future baseline heat-related productivity loss results for an extreme year.

Region	2030s					2050s				
	Total heat-related deaths									
	No package (baseline)	Package A	Package B	Package C	Package D & E	No package (baseline)	Package A	Package B	Package C	Package D & E
East Midlands	270	230	130	110	0	610	560	310	290	0
East of England	510	460	280	240	0	1,100	1,100	610	590	0
London	620	560	270	230	0	1,600	1,500	710	620	0
North East	280	250	180	160	0	530	500	350	340	0
North West	550	500	320	280	0	1,200	1,100	700	670	0
Northern Ireland	140	130	85	79	0	310	290	200	190	0
Scotland	190	170	130	120	0	400	370	270	260	0
South East	1,800	1,700	1,200	1,100	0	3,700	3,500	2,500	2,400	0
South West	910	860	580	550	0	1,900	1,800	1,300	1,200	0
Wales	300	280	170	150	0	600	560	370	340	0
West Midlands	330	290	160	140	0	670	610	320	310	0
Yorkshire and The Humber	210	180	110	92	0	430	390	230	220	0
Total	6,100	5,600	3,600	3,300	0	13,000	12,000	7,900	7,400	0
<i>Total change from future baseline</i>	-	-500	-2,500	-2,800	-6,100	-	-840	-5,200	-5,600	-13,000

Table A.12: Impact of adaptation packages on heat-related mortality for an extreme year.

Region	2030s					2050s				
	Monetised impact (£m)									
	No package (baseline)	Package A	Package B	Package C	Package D & E	No package (baseline)	Package A	Package B	Package C	Package D & E
East Midlands	210	180	100	89	0	430	390	210	430	0
East of England	350	320	190	170	0	700	650	380	700	0
London	550	500	250	210	0	1,200	1,100	540	1,200	0
North East	310	290	210	190	0	500	470	340	500	0
North West	400	360	230	210	0	770	720	460	770	0
Northern Ireland	97	90	60	55	0	190	180	120	190	0
Scotland	180	170	120	120	0	310	290	210	310	0
South East	1,200	1,100	780	730	0	2,100	2,000	1,500	2,100	0
South West	610	580	390	370	0	1,100	1,100	760	1,100	0
Wales	280	260	160	150	0	490	460	300	490	0
West Midlands	360	320	190	160	0	670	620	330	670	0
Yorkshire and The Humber	170	150	88	75	0	310	290	170	310	0
Total	4,700	4,300	2,800	2,500	0	8,900	8,300	5,300	8,900	0
<i>Total change from future baseline</i>	-	-380	-1,900	-2,200	-4,700	-	-580	-3,600	-3,900	-8,900

Table A.13: Impact of adaptation measures on monetised impact from heat-related mortality for an extreme year (£million).

Region	2030s				2050s			
	Total lost hours (1000 hours)							
	No package (baseline)	PA, PD, PE	PB	PC	No package (baseline)	PA, PD, PE	PB	PC
East Midlands	940	9.0	0.0	0.0	3,800	62	2.7	4.4
East of England	1,400	4.2	0.0	0.0	6,100	21	0.3	1.1
London	4,300	120	9.8	10	9,400	260	49	52
North East	71	0.0	0.0	0.0	640	0.0	0.0	0.0
North West	1,100	1.6	0.0	0.0	5,800	49	0.9	2.5
Northern Ireland	19	0.0	0.0	0.0	59	0.1	0.0	0.0
Scotland	200	1.2	0.0	0.0	880	6.5	0.0	0.0
South East	2,100	13	0.0	0.1	8,600	109	6.0	8.7
South West	1,800	6.4	0.0	0.1	5,000	67	1.9	3.2
Wales	550	0.4	0.0	0.0	1,700	18	0.1	0.2
West Midlands	1,400	4.7	0.0	0.0	5,500	46	2.0	2.7
Yorkshire and The Humber	600	0.1	0.0	0.0	3,000	3.4	0.0	0.0
Total	14,000	160	10	10	50,000	650	63	75
<i>Total change from future baseline</i>	-	-14,000	-14,000	-14,000	-	-50,000	-50,000	-50,000

Table A.14: Impact of adaptation on heat-related productivity loss for an extreme year (1000 hours).

Region	2030s				2050s			
	Total lost hours (£m)							
	No package (baseline)	PA, PD, PE	PB	PC	No package (baseline)	PA, PD, PE	PB	PC
East Midlands	39	0.5	0.0	0.0	210	4.8	0.2	0.3
East of England	66	0.2	0.0	0.0	390	1.6	0.0	0.1
London	220	8.9	0.8	0.8	670	26	4.8	5.1
North East	3	0.0	0.0	0.0	37	0.0	0.0	0.0
North West	51	0.1	0.0	0.0	340	3.5	0.1	0.2
Northern Ireland	1	0.0	0.0	0.0	4	0.0	0.0	0.0
Scotland	8	0.1	0.0	0.0	47	0.4	0.0	0.0
South East	120	1.1	0.0	0.0	650	11	0.6	0.9
South West	109	0.7	0.0	0.0	390	6.8	0.3	0.4
Wales	21	0.0	0.0	0.0	87	1.2	0.0	0.0
West Midlands	58	0.3	0.0	0.0	320	3.7	0.2	0.2
Yorkshire and The Humber	25	0.0	0.0	0.0	170	0.3	0.0	0.0
Total	720	12	1	1	3,300	59	6	7
<i>Total change from future baseline</i>	-	-708	-720	-720	-	-3,300	-3,300	-3,300

Table A.15: Impact of adaptation on monetised impact from heat-related productivity loss for an extreme year (£million).

Core study								
Climate scenario	No package (baseline)		PA, PD, PE		PB		PC	
	Total heat deaths	Monetised impact (£m)	Total heat deaths	Monetised impact (£m)	Total heat deaths	Monetised impact (£m)	Total heat deaths	Monetised impact (£m)
2030s Central	6,100	4,700	5,600	4,300	3,600	2,800	3,300	2,500
2050s Central	13,000	8,900	12,000	8,300	7,900	5,300	7,400	5,000
2030s High	7,800	6,000	7,200	5,600	4,900	3,700	4,400	3,300
2050s High	21,000	14,000	20,000	14,000	14,000	9,200	13,000	8,700
High socioeconomic vulnerability: older age structure								
Climate scenario	No package (baseline)		PA, PD, PE		PB		PC	
	Total heat deaths	Monetised impact (£m)	Total heat deaths	Monetised impact (£m)	Total heat deaths	Monetised impact (£m)	Total heat deaths	Monetised impact (£m)
2030s Central	6,100	4,700	5,600	4,300	3,600	2,800	3,300	2,500
2050s Central	13,000	8,800	12,000	8,300	7,900	5,300	7,500	5,000
2030s High	7,800	6,000	7,300	5,600	4,900	3,700	4,400	3,300
2050s High	21,000	14,000	20,000	14,000	14,000	9,200	13,000	8,700

Table A.16: Heat-related mortality results for socioeconomic sensitivity study on older age structure in the future, for extreme years.

Core study								
Climate scenario	No package (baseline)		PA, PD, PE		PB		PC	
	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)
2030s Central	14,000	720	160	12	10	1	10	1
2050s Central	50,000	3,300	650	59	63	6	75	7
2030s High	39,000	2,100	400	29	19	2	25	2
2050s High	160,000	10,000	4,400	380	910	82	1,100	95
High socioeconomic vulnerability: older age structure								
Climate scenario	No package (baseline)		PA, PD, PE		PB		PC	
	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)	Total lost hours (1000 hours)	Total GVA loss (£m)
2030s Central	14,000	730	160	12	10	1	10	1
2050s Central	50,000	3,300	650	59	63	6	75	7
2030s High	39,000	2,100	400	30	19	2	25	2
2050s High	160,000	10,000	4,400	380	910	82	1,100	95

Table A.17: Heat-related productivity results for socioeconomic sensitivity study on higher productivity in the future, for extreme years.



A.3 Sensitivity studies

This appendix presents the results for the sensitivity studies, for extreme years where impacts of adaptation packages are all assuming a 100% rollout scenario.

A.3.1 High climate change scenario

In the core study, a climate scenario for the 2030s and 2050s was modelled, which is referred to as the ‘central scenario’ and which relates to global warming of 1.5°C in the 2030s and 2°C for the 2050s. A higher rate of warming was tested for the 2030s and 2050s, called the ‘high scenario’ and relating to global warming rates of 2°C in the 2030s and 2.5°C in the 2050s. These results are presented in Section 7 in the main report.

A.3.1.1 Mortality

As with the analysis in the core study, packages D and E are the most effective at reducing mortality, as all deaths were assumed to be avoided through home air-conditioning. When comparing the high 2030s and 2050s climate scenarios to the central scenarios, heat-related deaths increase but so do the avoided deaths from adaptation (presented in Figure A.17)

A.3.1.2 Productivity

As with the analysis in the core study, all packages are relatively similar in reducing productivity loss, as all include office air-conditioning and construction site shading. When comparing the high 2030s and 2050s climate scenarios to the central scenarios, the productivity loss increases, as does the reduction in productivity loss from adaptation presented in Figure A.18.

A.3.1.3 Total monetised impacts of adaptation

The total monetised risk reduction from a 100% UK rollout of adaptation packages includes avoided losses from heat-related mortality and productivity impacts. The higher climate scenarios give a greater monetised risk reduction than the central scenarios, as adaptation packages result in greater risk reduction in a warmer climate, and thus greater monetised benefits.

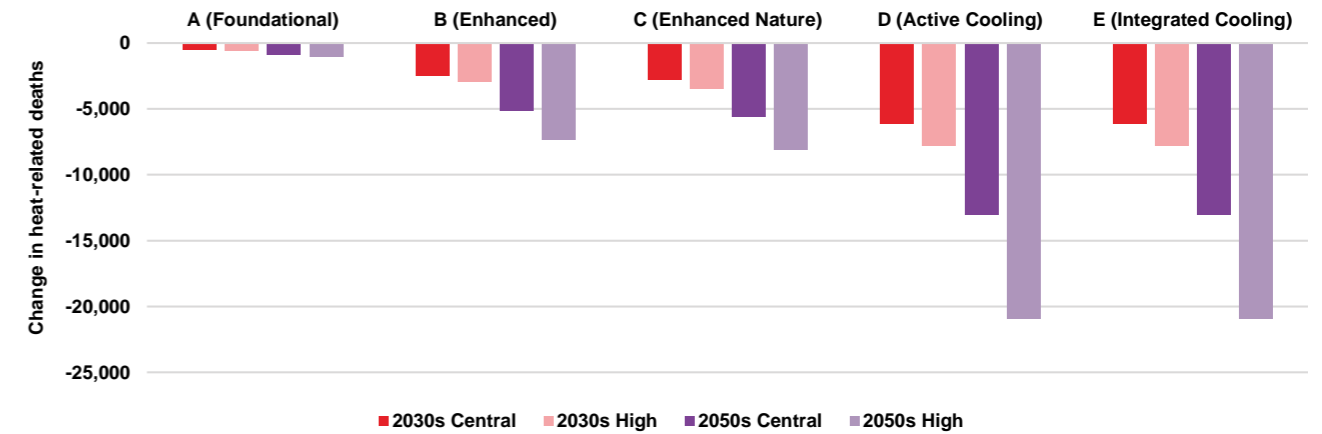


Figure A.16: Change from the baseline (no adaptation) of heat-related deaths from adaptation packages for the four climate scenarios.

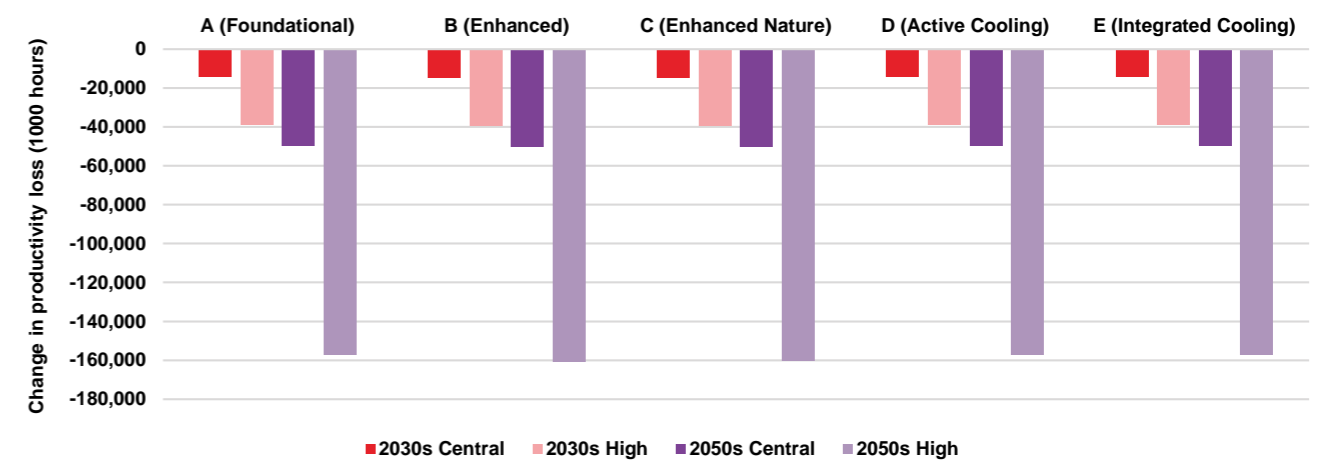


Figure A.17: Change from the baseline (no adaptation) of productivity loss hours from adaptation packages for the four climate scenarios.

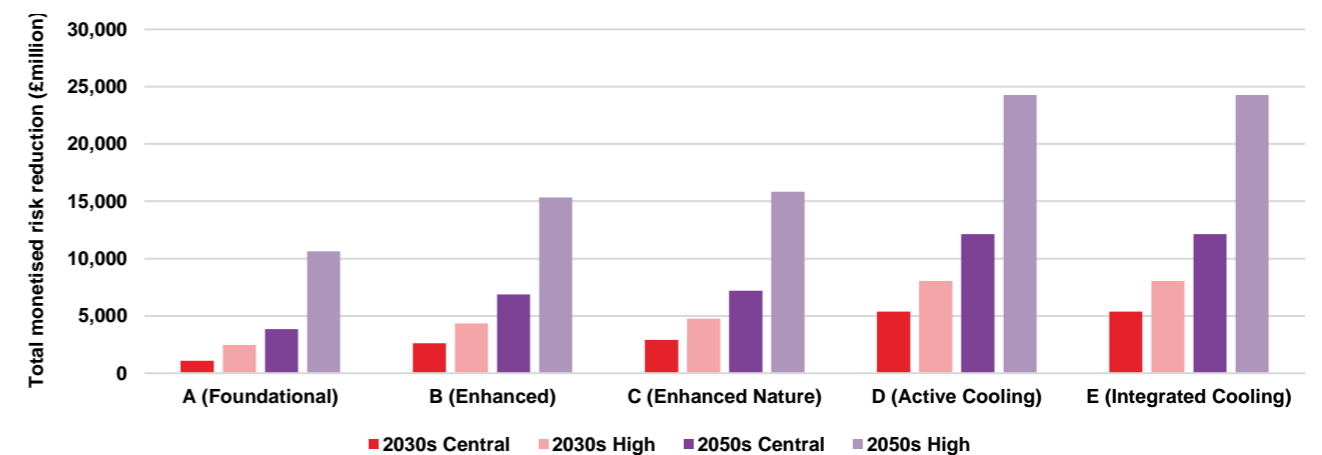


Figure A.18: Total monetised impacts of adaptation packages, accounting for heat-related deaths and productivity loss for the four climate scenarios.

A.3.2 High socioeconomic sensitivity

A.3.2.1 Mortality

Future mortality in the study was estimated using projected population changes, with future population figures applied to uplift the 2022 all-cause mortality data in order to calculate heat-related deaths. To test the influence of socio-economic assumptions, we examined how age-related vulnerability—and specifically an ageing population—might affect the results. Population projections were taken from the ONS UK Population Projection Explorer, using the Old Age Structure variant. [34] Compared with the principal ONS projections used in the main study, this variant showed smaller population increases for the 0–64 age group and larger increases for those aged 65 and over by the 2030s and 2050s. As a result, the ageing population scenario leads to higher projected heat-related mortality among older age groups in the future baseline.

The results comparing the older age structure to the main study show a larger number of deaths for the high socioeconomic scenario. This is due to the larger number of older people at risk from heat-related mortality. Packages D and E are not shown, as in both the core and sensitivity study, all heat-related deaths are avoided.

Whilst there was a greater number of deaths in the sensitivity study, the monetised impact from mortality was lower. In the 2050s, the higher socioeconomic sensitivity case reduced monetised impact from heat-related deaths by £14 million for the baseline and Package A, compared to the core study. This difference was £8 million for Package B and £5 million for Package C. This was because the VOLY was multiplied by YLL (Years Life Lost) for each age category. For the older age categories, the YLL is lower, thus overall monetised impact was lower.

The high socioeconomic scenario for mortality in this study results in a lower monetised impact from heat-related deaths.

A.3.2.2 Productivity

The high-socioeconomic scenario assumes a higher productivity workforce in the future than values used in the main study. This matters because higher assumed productivity increases the economic value of each hour worked, meaning that the same number of hours lost to heat results in a larger overall loss to the economy.

The number of hours lost in each climate scenario and package remains constant between the main study and high productivity analysis. In the high productivity scenario, workers generate a higher output (GVA) per hour worked. Therefore, the GVA loss increases, even when hours lost remains the same.

The total monetized impact between sensitivity and the core study are in the order of hundreds of thousands of pounds. A higher productivity workforce sees greater economic benefits from adaptation measures to mitigate productivity loss.

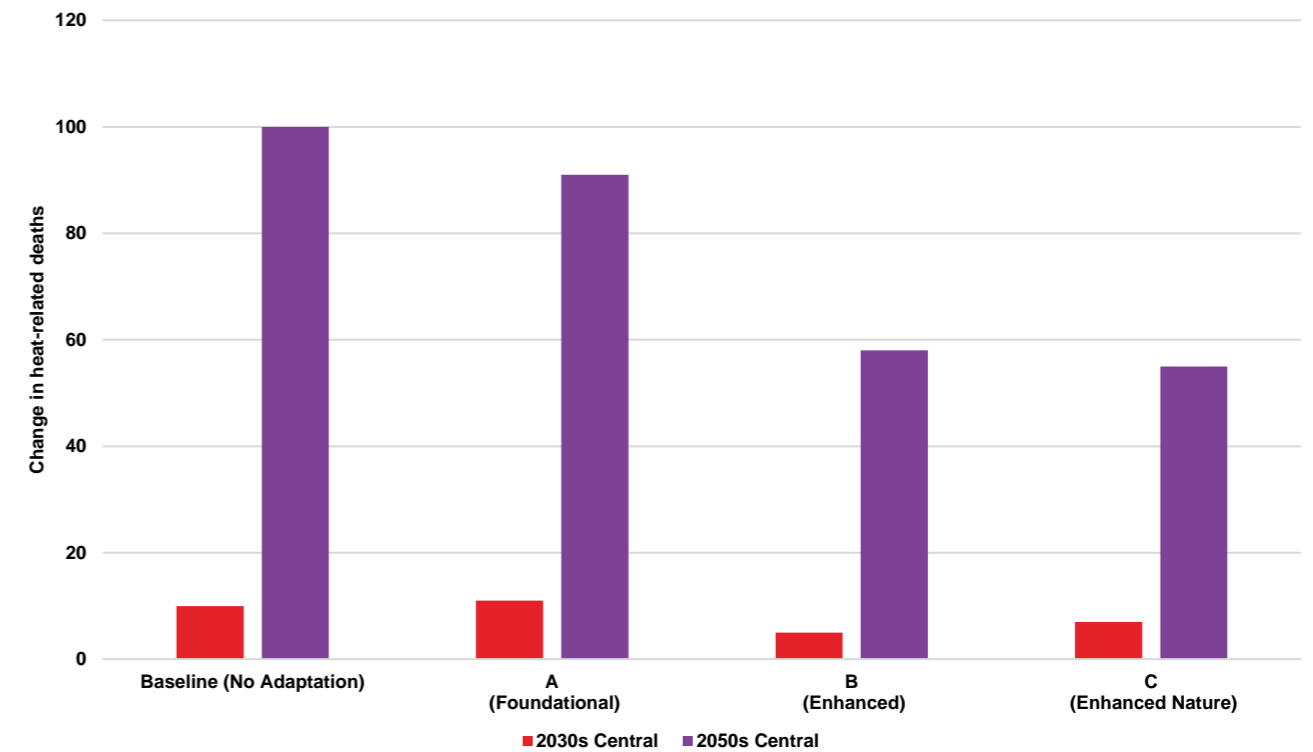


Figure A.19: Change from the core study in future heat-related deaths, assuming an older age population structure in the future, for the central climate scenarios.

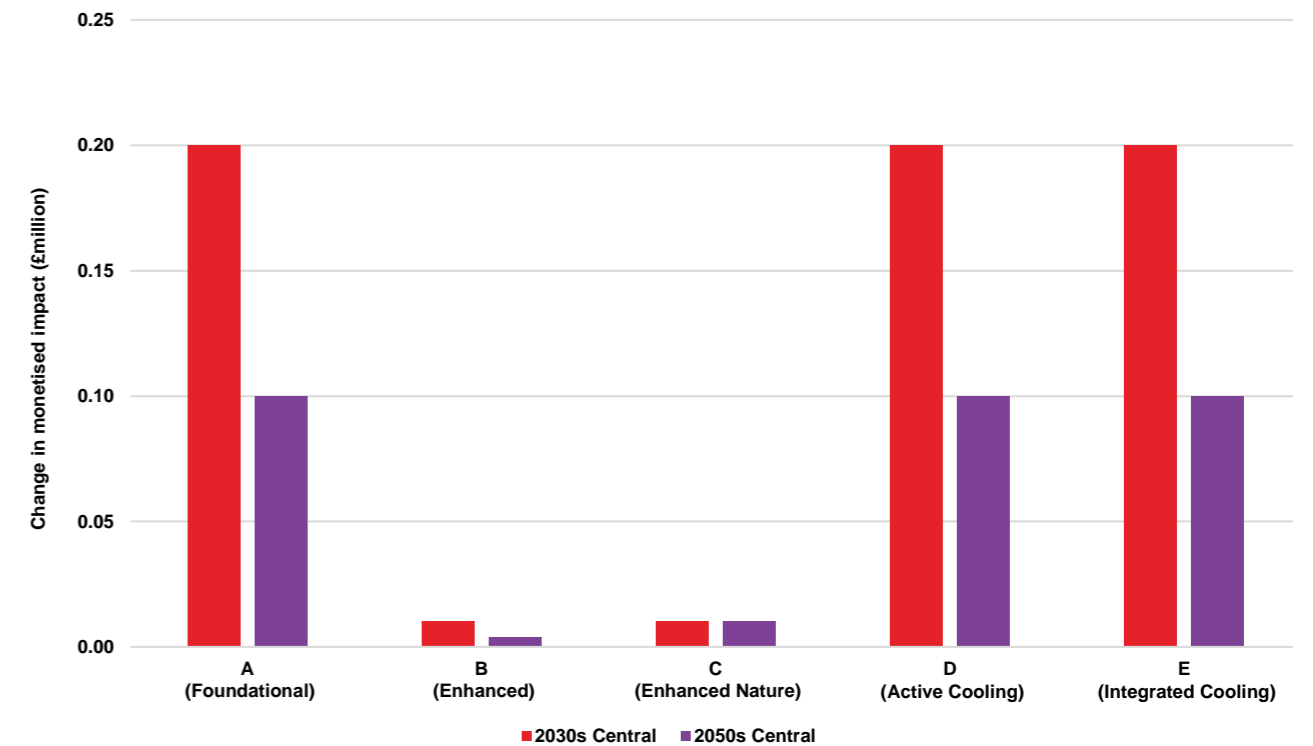


Figure A.20: Change from the core study in monetised impact from heat-related productivity loss, assuming a higher productivity workforce (£million).

A.3.3 High impact sensitivity

The high-impact sensitivity combined both high climate change and high socio-economic scenarios, relating to a reasonable worst case.

A.3.3.1 Mortality

The results in Table A.18 comparing the high impact sensitivity to the main study showed a higher number of heat-related deaths and a greater total monetised loss. While an older population tends to reduce the monetised value of mortality, the increase in deaths is driven by more extreme climate change dominates the results. Packages D and E are not shown, as in both the core and sensitivity study, all heat-related deaths are avoided.

A.3.3.2 Productivity

The results in Table A.19 comparing the high impact sensitivity to the main study showed a higher number of lost hours and a greater total GVA loss.

A higher productivity workforce in a more extreme climate sees greater monetized impact from adaptation measures to mitigate productivity loss.

	Baseline (No Adaptation)		A (Foundational)		B (Enhanced)		C (Enhanced Nature)	
	Change in deaths	Change in monetised loss (£million)	Change in deaths	Change in monetised loss (£million)	Change in deaths	Change in monetised loss (£million)	Change in deaths	Change in monetised loss (£million)
2030s	1,700	1,400	1,700	1,300	1,300	1,000	1,090	840
2050s	8,010	5,500	7,800	5,300	5,800	3,900	5,500	3,700

Table A.18: Change from the core study in future heat-related deaths and monetised loss, assuming a higher climate scenario and older age population structure in the future.

	Baseline (No Adaptation)		A (Foundational)/ D (Active Cooling)/ E (Integrated Cooling)		B (Enhanced)		C (Enhanced Nature)	
	Total lost hours	Total GVA loss (£million)	Total lost hours	Total GVA loss (£million)	Total lost hours	Total GVA loss (£million)	Total lost hours	Total GVA loss (£million)
2030s	25,000	1,400	250	18	9	1	15	1
2050s	110,000	7,000	3,700	320	840	76	990	87

Table A.19: Change from the core study in future lost working hours and GVA loss, assuming a higher climate scenario and a higher productivity workforce in the future.

A.3.4 'Building-only' variants

The 'building-only' study focused on lighter weight versions of Packages B (Enhanced) and C (Enhanced Nature). This sensitivity study removes the large-scale urban measures from these packages to focus on building-scale measures which were applied directly to people's homes.

The productivity results are effectively the same for the original Packages B and C and their building-only variants, indicating that most productivity benefits come from office cooling and construction-site shading.

In contrast, the differences between these variants are more pronounced for mortality outcomes. Packages B (Enhanced) and C (Enhanced Nature), which include urban-scale measures, achieve greater reductions in heat-related mortality than their building-only counterparts. This showed that urban-scale measures do help reduce mortality, however the majority of avoided deaths arise from the building-scale measures.

Package	Details	Adaptation measures	
		Mortality [applied to residential areas]	Productivity loss [applied to workplaces]
B – Enhanced (building-only variant)	A medium package with quick wins and complementary measures	Building-scale Internal blinds Low g-value window film Solar reflective coating to external walls Solar reflective coating to roofs Roof/loft insulation	Building-scale Active cooling Urban-scale Construction site shading
C – Enhanced Nature (building-only variant)	A more comprehensive package of actions combining nature-based solutions with urban and building cooling measures	Building-scale External shutters Solar reflective coating to external walls Solar reflective coating to roofs Roof/loft insulation	Building-scale Active cooling Urban-scale Construction site shading

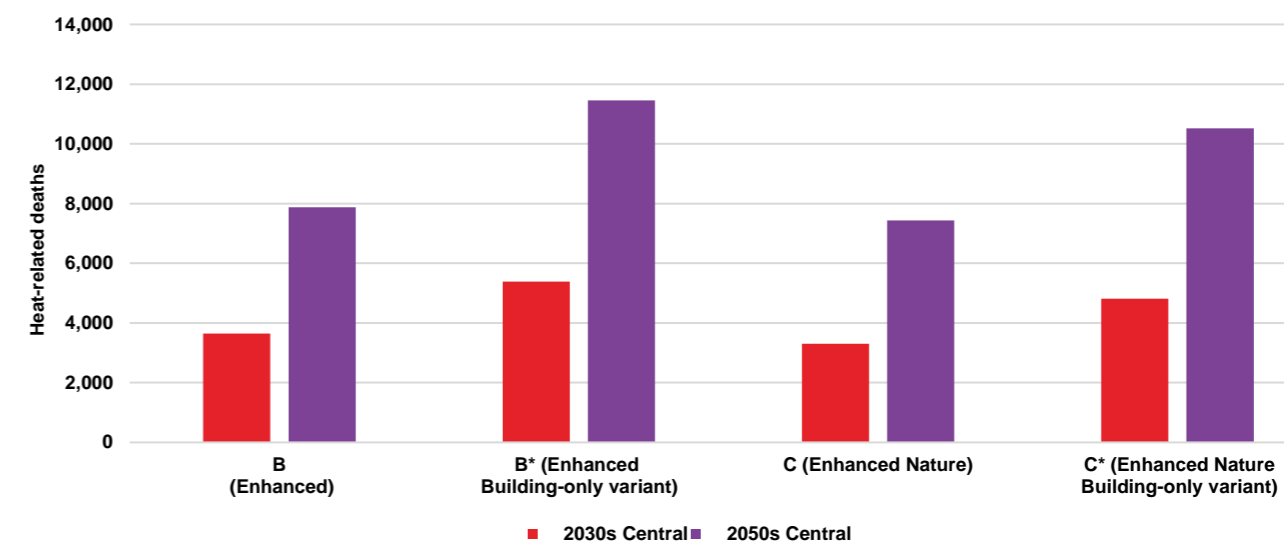


Figure 21: Heat-related deaths from adaptation Packages B (Enhanced) and C (Enhanced Nature) compared to a building-only variant.

A.4 Data Sources

Parameter	Application	Details	Data Summary	Data Source
Climate				
Current Climate Data	Present day climate	Used for modelling present day of 2022	Obtained from ERA5 for Glasgow, London, Swindon and Birmingham. Shifting methodology applied to obtain data for UK urban LSOAs using HadUK	2022 climate data for Glasgow, London, Swindon and Birmingham (ERA5) and nationwide (HadUK)
Current Climate Data	Present day climate	Use of CIBSE weather files - design summer years (DSY)	Baseline DSY2 used for London (2003), Birmingham (2006), Swindon (2003) and Glasgow (1975)	CIBSE Baseline DSY2 (obtained from CIBSE)
Climate Projections	Future Climate	Use of UKCP09 CIBSE weather files - design summer years (DSY)	Future DSY2 used for London, Birmingham, Swindon and Glasgow for the future scenarios – +1.5°C for 2030s - 2020s High Scenario (50th percentile model) – +2°C for 2050s - 2050s Medium Scenario (50th percentile model) – +2°C in 2030s - 2020s High Scenario (90th percentile model) – +2.5°C in 2050s - 2050s High Scenario (90th percentile model)	CIBSE Future DSY2 (obtained from CIBSE)
Mortality				
Baseline mortality England & Wales	Used for mortality calculation to obtain excess mortality due to heat	Total recorded deaths (daily, 2022)	Present day baseline is obtained for England and Wales based on a spatial resolution of Regions. Data is available split by age groups required for analysis- 0-64, 65-74, 75-84, 85+	https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/adhocs/1724dailydeathoccurrencesenglandandwales2021and2022
Baseline mortality Scotland	Used for mortality calculation to obtain excess mortality due to heat	Total recorded deaths (daily, 2022)	Present day baseline is obtained for Scotland based on a spatial resolution of Council Areas. Data is available split by age groups required for analysis- 0-64, 65-74, 75-84, 85+	Sent directly from NRS Scotland statisticscustomerservices@nrscotland.gov.uk
Baseline mortality Northern Ireland	Used for mortality calculation to obtain excess mortality due to heat	Total recorded deaths (daily, 2022)	Present day baseline is obtained for Northern Ireland based on a spatial resolution for the whole country. Data is available split by age groups required for analysis- 0-64, 65-74, 75-84, 85+	Sent directly from Nisra demography@nisra.gov.uk

Parameter	Application	Details	Data Summary	Data Source
Residential House Type England and Wales	Distribution of housing types per LSOA England and Wales	Used to distribute population into different housing types depending on proportion of each type of housing	All categories collated into three energy models - semi detached houses, flats and mid-terrace houses	ONS - https://www.ons.gov.uk/datasets/TS044/editions/2021/versions/1/filter-outputs/cb6acbd0-6a34-49d0-a9ca-1bc158fd119c#get-data
Residential House Type Scotland	Distribution of housing types per Data Zone Scotland	Used to distribute population into different housing types depending on proportion of each type of housing	All categories collated into three energy models - semi detached houses, flats and mid-terrace houses	Scottish Government Scotland's Census 2022 - National Records of Scotland Table UV402 - Accommodation type - Households All occupied households
Residential House Type Northern Ireland	Distribution of housing types across Northern Ireland	Used to distribute population into different housing types depending on proportion of each type of housing	All categories collated into three energy models - semi detached houses, flats and mid-terrace houses	NISRA - https://build.nisra.gov.uk/en/custom/data?d=HOUSEHOLD&v=ACCOMMODATION_TYPE
Risk Relationships	Regional relationships linking temperature and mortality	Used to calculate mortality from heat	Risk relationships split by age categories 0-64, 65-74, 75-84, 85+ across UK Regions.	Obtained from 2024 paper (Murage et al.) https://www.sciencedirect.com/science/article/pii/S0013935124014701
Population for England and Wales, Scotland and Northern Ireland	Population by age group by Region	Population projections used to calculate increased all-cause mortality figures, to calculate mortality from heat in the future	Population data not used in baseline as all-cause mortality data is used. Future population data based on UK ONS projections.	ONS Population Projections - https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2022based
VOLY	Value of Life Years	Used to calculate monetised loss from heat-related deaths	£65,176	Green Book (2022) figure, uplifted to 2025 (base year) prices From the Green Book A1.62: https://assets.publishing.service.gov.uk/media/6645c709bd01f5ed32793cbc/Green_Book_2022_updated_links.pdf
Life expectancy	National life tables (period of expectation of life at each age)	Used to calculate years of life lost (YLL)	Averaged for male and female. Available at each age and averaged for the categories: 0-64, 65-74, 75-84, 85+	ONS: National Life Tables, UK (2021-2023) https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/datasets/nationallifetablesunitedkingdomreferencetables

Parameter	Application	Details	Data Summary	Data Source
Productivity				
Productivity loss functions	Relationship between WBGT exposure and the heat-related percentage reduction in working hours	Used to quantify the relationship between WBGT exposure and the heat-related percentage reduction in working hours across sectors in order to calculate estimate GVA loss.	Three sectoral functions that chart the relationship between WBGT and lost working hours based on three sectoral work intensities: low, medium and high	Impacts of higher temperatures on labour productivity and value for money adaptation: lessons from five DFID priority country case studies, Vivid Economics, August 2017 (referred to as 'the Vivid Economics study')
GVA for England & Wales	Gross Value Added at LSOA level	Used to calculate monetised impact of productivity loss	<p>The highest granularity available of sectoral GVA is at a regional (ITL3) level, but employment is available at LSOA level.</p> <p>We estimated GVA at LSOA level by first finding sectoral GVA per worker at a regional (ITL3) level.</p> <p>We then applied the regional and sectoral GVA per worker to the employment by sector data, which is available at LSOA level. This provides an estimate of sectoral GVA at an LSOA level</p> <p>This assumes that there is no variation in productivity per worker across LSOAs within the same region.</p>	<p>ONS Regional gross value added (balanced) by industry - Table 3c (ITL3)</p> <p>https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry/current</p> <p>Employment data at ITL3 and LSOA level is sourced from the Business Register and Employment Survey</p> <p>https://www.nomisweb.co.uk/datasets/newbres6pub</p>
GVA for Scotland	Gross Value Added at Datazone level	Used to calculate monetised impact of productivity loss	<p>The highest granularity available of sectoral GVA is at a regional (ITL3) level, but employment is available at Datazone level.</p> <p>We estimated GVA at Datazone level by first finding sectoral GVA per worker at a regional (ITL3) level.</p> <p>We then applied the regional and sectoral GVA per worker to the employment by sector data, which is available at Datazone level. This provides an estimate of sectoral GVA at an Datazone level</p> <p>This assumes that there is no variation in productivity per worker across LSOAs within the same region.</p>	<p>ONS Regional gross value added (balanced) by industry - Table 3c (ITL3)</p> <p>https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry/current</p> <p>Employment data at ITL3 and Datazone level is sourced from the Business Register and Employment Survey</p> <p>https://www.nomisweb.co.uk/datasets/newbres6pub</p>

Parameter	Application	Details	Data Summary	Data Source
GVA for Northern Ireland	Gross Value Added at Datazone level	Used to calculate monetised impact of productivity loss	<p>Employment by sector cannot be found at Datazone (LSOA equivalent) level. The highest granularity of employment and GVA by sector in Northern Ireland is found at the District Council Area (DCAs) level, equivalent to ITL3.</p> <p>Therefore, to apportion regional GVA across constituent Datazones in NI, we:</p> <ol style="list-style-type: none"> 1. Mapped NI and Scottish Datazones to urban typology (LCZ) types. 2. Calculated the proportion of employment that occurs in each urban typology (LCZ) for each sector in Scotland. 3. Applied the sectoral employment distribution from Scotland to apportion GVA across LCZ typologies in each Northern Irish region. 4. Apportioned the sectoral GVA allocated to each LCZ type across the number of datazones in that NI region. <p>This gives an estimate of GVA at LSOA level based upon Scottish employment activity across differing urban typologies</p>	<p>Regional GVA: ONS Regional gross value added (balanced) by industry - Table 3c (ITL3)</p> <p>https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry/current</p>
Employment for England & Wales	At LSOA level	Used to calculate monetised impact of productivity loss	Employment by sector at LSOA level	<p>ONS Business Register and Employment Survey</p> <p>https://www.nomisweb.co.uk/datasets/newbres6pub</p>
Employment for Scotland	At Datazone level	Used to calculate monetised impact of productivity loss	Employment by sector at Scottish Datazone level	<p>ONS Business Register and Employment Survey</p> <p>https://www.nomisweb.co.uk/datasets/newbres6pub</p>

Parameter	Application	Details	Data Summary	Data Source
Employment for Northern Ireland	At Datazone level	Used to calculate monetised impact of productivity loss	<p>Employment by sector cannot be found at Datazone (LSOA equivalent) level. The highest granularity of employment and GVA by sector in Northern Ireland is found at the District Council Area (DCAs) level, equivalent to ITL3.</p> <p>Therefore, to apportion regional employment across constituent Datazones in NI, we:</p> <ol style="list-style-type: none"> 1. Mapped NI and Scottish Datazones to urban typology (LCZ) types. 2. Calculated the proportion of employment that occurs in each urban typology (LCZ) for each sector in Scotland. 3. Applied the sectoral employment distribution from Scotland to apportion employment across LCZ typologies in each Northern Irish region. <p>This gives an estimate of employment at datazones level based upon Scottish employment activity across differing urban typologies.</p>	<p>Northern Ireland Statistics and Research Agency (NISRA) - BRES</p> <p>https://www.nisra.gov.uk/statistics/annual-employee-jobs-surveys/business-register-and-employment-survey</p>



A.5 Further Discussion

Limitations

While the modelling draws on the best available data and methods, there remain areas where further research would deepen understanding and strengthen future analyses.

Key limitations include:

1. **Quantification of broader heat-related impacts on health and productivity.** This work focuses on three key metrics related to heat impacts: mortality, productivity loss and sleep loss. However, there are broader impacts that could not be covered due to a lack of evidence to allow robust quantification. Heat exposure can lead to health issues—such as headaches, dehydration, and exacerbation of chronic conditions—that are not routinely recorded but still have adverse effects. The long-term impacts of consistent heat exposure, either over a single season or year-on-year, are also poorly studied and currently not possible to quantify. Moreover, discomfort and misery caused by heat is widely experienced, and although methods exist to estimate when people feel uncomfortable, it is difficult to link this discomfort to a consequence. This is closely related to the impact of heat on mental well-being, including the aggravation of existing mental health conditions, which again is challenging to quantify. In addition to health, heat can also affect productivity in various ways beyond those quantified in this study. Heat can affect performance through sleep disruption, commuting stress and reduced cognitive capacity. These effects are recognised but not yet quantifiable at a national scale. [23]

2. **Quantification of impact of heat on all vulnerabilities.** It was not possible to fully account for the unequal impacts of heat across different demographics and socioeconomic circumstances. Although age is factored into mortality and work sector into productivity, other factors—such as income deprivation or existing health conditions—can increase vulnerability to heat too. Data on these factors is less available at the national scale, making them difficult to quantify.
3. **Wider heat impacts.** In addition to the health and productivity impacts quantified in this study, extreme heat has many other adverse consequences for towns and cities. Heat can disrupt critical urban infrastructure, including transport, energy and water systems, and can lead to the degradation and long-term damage of physical assets such as buildings, road surfaces and rail lines. It is important to recognise that many of the adaptation measures considered here — particularly passive measures and nature-based solutions — can also help to reduce these broader risks
4. **Analysis approach.** When setting out the technical approach for this project, the most robust and feasible models were selected. Some of the key assumptions are presented in the detailed methodology, but there are several technical limitations that are important to highlight:
 - Indoor conditions and mortality: Most mortality research is based on outdoor temperatures, even though the most vulnerable people typically experience heat indoors. There is limited UK-specific evidence linking indoor temperatures directly to mortality, creating uncertainty around the precise contribution of building characteristics to health outcomes. [24] [25]. To address this, a bespoke process was developed to enable the testing of building-scale adaptation measures.

- Typology approach: Both building- and urban-scale modelling used an archetype and typology-based framework to represent the UK's building stock and urban areas. It was not feasible within this study to model the full diversity of UK buildings or land cover characteristics. As a result, some regional and local differences in building performance and urban environments are not fully captured. For example, a consistent level of construction quality was assumed to define baseline overheating risk in buildings, but in practice buildings within a single archetype may be more or less likely to overheat than the modelled representation. Similarly, actual UK urban areas exhibit far greater variation in land cover, shading, ventilation, and microclimate than can feasibly be represented at a national scale.
- SUEWS limitations: SUEWS was used to assess the cooling impact of urban-scale measures. Although it is a well-established and widely documented academic model, it does not fully represent all components of the urban heat island effect, such as large-scale advection. Capturing these processes accurately would require full city modelling or alternative modelling frameworks.
- Model validation: The methodology for estimating productivity loss is heavily model based, with limited validation against observed empirical data (e.g. measured productivity impacts during heat events).

5. **Data gaps.** The best available data was used for this project, but several important data gaps remain:
 - Use of UKCP09 climate projections: The analysis relied on UKCP09 projections because UKCP18 climate data, in the required format, had not yet been published at the time of modelling. This may limit the robustness of future scenario analysis. Incorporating UKCP18 data when available would strengthen future work.
 - Climate zone simplification: To make data processing feasible, the UK was represented using four climate zones (broadly defined by: Birmingham, Glasgow, Swindon, London). Although results were subsequently adjusted using higher-resolution HadUK data, this approach is a simplification.
 - Climate data at LSOA level: High resolution temperature data was developed for each LSOA, but other key climate variables—such as relative humidity and solar radiation—were not available at this spatial scale. This required assumptions and generalisations that may affect local level accuracy.

6. Uncertainty in future climate projections.

Although UKCP09 provided robust projections, climate models still involve inherent uncertainties, especially concerning extreme short-duration heat events. This introduces uncertainty into future risk assessments.

- Variable data resolution: Input data sets varied in spatial and temporal resolution. Where only coarse data was available, it was redistributed to LSOA level using reasonable assumptions, introducing additional uncertainty. For example, in Northern Ireland GVA and employment by sector data are only available at District Council Area level, so they cannot be directly estimated at Datazone (LSOA equivalent) level. Instead, sectoral GVA was apportioned across Datazones using assumptions based on Scottish employment patterns across urban typologies (LCZ types).
- Where people work and live: Detailed data on the distribution of where people live and work is not available at the level required. For this project, population was mapped from LSOA totals to the local housing stock and evenly distributed across archetypes. Similarly, for workers we assumed a single office archetype. and linked sectoral employment data to associated workplaces. In reality—particularly with the prevalence of working from home—these assumptions may not fully represent actual working patterns.

Opportunities for further research

This study focused on the heat impacts on mortality and productivity that have been thoroughly researched, enabling us to apply a consistent methodology across the UK with confidence. The study highlights a number of opportunities for further investigation in this and related areas:

1. **Explore heat-related morbidity.** While the link between heat and hospitalisations is well-established and has been examined in detail by Edge Health and Greencroft Economics in “Risks to health and health services from extreme heat” [5], other health impacts that do not result in hospitalisations are less well understood and harder to quantify. Further primary research in this area would be beneficial in helping the UK understand the full impact of heat on health.

2. **Broader understanding of heat-related productivity loss.** For many cities, heat impacts daily commutes, leading to delays and fatigue which can reduce productivity. Changing working patterns, with more people working from home, may also influence productivity, though further data would be required to inform this impact. There are indirect effects as well, such as people taking time off to care for others—like sick school children or elderly relatives—which can further reduce productivity.

3. **Further research on a wider range of vulnerabilities to heat.** It was not possible to fully account for the unequal impacts of heat across different demographics and socioeconomic characteristics. Further research linking demographic data and socioeconomic characteristics to heat vulnerability and heat impacts would be valuable to enhance understanding of differentiated risk and equitable approaches to heat adaptation.

4. **Active cooling and the urban heat island effect.** Active cooling systems can result in heat being released to the external environment, which may contribute to the urban heat island effect. This interaction was not explicitly modelled in the current analysis. Further research to better understand these effects would support more optimised design and planning of cooling systems and how they interact with other system changes such as the transition to electric vehicles, which could reduce the urban heat island effect. There is also a clear opportunity to explore integrated approaches that combine passive and active measures to reduce cooling demand and limit heat rejection, with evidence highlighting the benefits of such approaches at the urban scale [38].

5. **Whole-system approach to quantifying heat impact.** It is important to adopt a systems perspective when assessing the impacts of heat. For example, heat does not only affect health and productivity but also influences the performance of critical urban infrastructure including transport, energy and water systems. A more holistic approach would therefore consider how rising temperatures compound pressures across interdependent sectors, how heat interacts with other hazards, and how interdependencies contribute to whole-system risk. Many of the adaptation measures examined in this study—particularly passive measures and nature-based solutions—can contribute to reducing wider risks, although these benefits were not fully assessed here.

6. **Other heat variables.** Heat is influenced by more than just temperature. Variables such as humidity, solar radiation and wind have a significant impact on how heat is experienced and the severity of health and productivity outcomes. Not all impact metrics used in this study fully account for these variables; for example, heat-related mortality is linked only to average daily air temperature. A better evidence base on how humidity, radiation and airflow contribute to heat stress would improve understanding of how different adaptation measures—such as shading, ventilation or fans—can reduce risk. Further research in this area would help strengthen future assessments.

7. **Co-benefits.** This study highlights that many adaptation measures deliver important co-benefits, but only a subset of those could be estimated here. Further research to systematically quantify co-benefits, and to better understand how heat adaptation interacts with other climate and environmental priorities (such as air quality, flooding, nature recovery and health equity), would strengthen future analyses and provide a more complete picture of the value of adaptation. This could go further than just considering risk reduction and wider benefits, but also help to shape an implementation strategy. For example, further work should examine how building-scale measures can deliver holistic benefits for comfort, energy use, carbon emissions and long-term resilience, and how retrofit programmes can be bundled or sequenced to improve affordability.

8. **Explore the role of operational adaptation measures.** While this study focused on physical adaptation measures with long-term benefits, operational actions can provide immediate protection. Operational actions include public communication and heat-health alerts, behaviour change guidance (e.g. around ventilation, hydration), emergency response plans, and cool respite spaces. These measures can be implemented now and provide meaningful benefits while physical upgrades are rolled out over time. The Edge Health and Greencroft Economics in “Risks to health and health services from extreme heat” [5] does cover operational measures with respect to heat-related health impacts.

Further work should investigate how adaptation packages which layer operational and physical solutions could contribute to reducing overall heat-related productivity risk across the UK. These options could include heat-alert systems, adjusted working hours and improved access to rest and hydration.

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Footnotes

- 1 Excess heat deaths not readily reported in other UK nations.
- 2 This is higher than the average 1,500 excess deaths per year from heat episodes reported by the UK Health Security Agency (UKHSA) as the latter only reports data from England for 2016 to 2024
- 3 Intended as share of LSOAs on the total across the UK.
- 4 LSOAs (England and Wales) ~ 1,000-3000 residents [29], Data Zones (Scotland) ~ 500-1000 residents [28] and Super Data Zones (Northern Ireland) ~1000-4000 residents [30]. The term LSOA is used in the report as a convenient shorthand for these statistical urban units, even though it is acknowledged that they are not identical in Scotland and Northern Ireland.
- 5 SUEWS analysis was only carried out for adaptation packages which contained urban-scale measures. Analysis was also carried out for the no adaptation scenario to calculate the impact measures would have across different urban typologies and climate zones across the UK.
- 6 Excess heat-related deaths in other UK regions are not readily reported. This study's analysis of the present day differs from the reported deaths in 2022, as it relies on statistical modelling of heat-related mortality using methods derived from literature. Minor discrepancies are expected.

Credits

This work was undertaken by a technical team of engineers, climate change consultants and cost consultants from Arup.

The following partners provided expert advice on heat modelling, health risks and costs of adaptation:

- Dr Ting Sun, BEng. PhD | University College London
- Professor Zhiwen Luo, BSc, MSc, PhD, | Cardiff University
- Dr Kevin Morgan, BSc, PhD
- Dr Kevin Lomas, BSc (Hons), PhD, DSc
- Rider Levett Bucknall

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