# Extreme Heat Vulnerability Index

Oxford Consultants for Social Inclusion (OCSI)

August 2026

## Contents

# Extreme Heat Vulnerability Index - Methodology

## Introduction

This section presents the conceptual framework behind the Extreme Heat Vulnerability Index. The Index has been developed to identify neighbourhoods where communities may be particularly vulnerable to the impacts of extreme heat, bringing together data on the characteristics of local populations, their capacity to prepare for and respond to heatwaves, the accessibility of places that can provide respite from heat, the characteristics of the outdoor environment and the characteristics of the housing in which people live.

Extreme heat is an increasingly important public health and climate adaptation challenge in England. Climate change is increasing the frequency, duration and magnitude of extreme heat events, including heatwaves. UK climate observations already show increases in both annual mean and peak temperatures, with maximum temperatures rising more rapidly than mean temperatures (POST, 2024).

Recent heat events demonstrate the potentially severe consequences for public health. Researchers from Imperial College London, the Met Office and LSHTM estimated that more than 2,700 people died from heat-related causes during the May and June 2026 heatwaves in England and Wales. Approximately 42% of these deaths were estimated to be attributable to the additional heat associated with human-induced climate change. The research also found that the rate of estimated deaths in the Midlands was similar to that in southern England despite lower temperatures, highlighting that the consequences of extreme heat depend not only on the temperatures experienced but also on the vulnerability and adaptation of the populations exposed (Imperial College London et al., 2026).

However, the impacts of extreme heat are not distributed evenly across the population or across places. The Parliamentary Office of Science and Technology identifies three broad ways in which vulnerability can increase: factors can make individuals more physiologically sensitive to heat, increase their exposure to high temperatures, or impair their ability to adapt. These vulnerabilities can also overlap, meaning that some people and communities experience multiple sources of risk simultaneously (POST, 2024).

Older people, young children and people with existing health conditions or disabilities may be particularly susceptible to the adverse health effects of extreme heat. At the same time, social and economic circumstances influence people’s capacity to prepare for and respond to heatwaves. People experiencing poverty may have fewer financial resources available to purchase cooling equipment or make adaptations to their homes. People living in rented accommodation may have less control over physical adaptations to their properties, such as installing external blinds, canopies, shutters or air-conditioning systems. Language barriers may make it more difficult for some residents to receive or act upon heat-health warnings and advice, while accessibility of healthcare can affect the ability to obtain support when heat exposure results in adverse health effects.

The characteristics of neighbourhoods can also exacerbate or mitigate exposure. Green and blue spaces can provide opportunities for respite during periods of extreme heat, while trees provide shade and can contribute to local cooling. Conversely, poor air quality can compound the health impacts associated with high temperatures. The changing climate also means that the degree to which neighbourhoods are exposed to very hot days is itself changing over time.

Housing represents another important component of vulnerability. People spend a substantial proportion of their time in their homes and the characteristics of the housing stock can affect exposure to high indoor temperatures. Poorly insulated or energy-inefficient homes, overcrowding and a lack of access to private outdoor space can all affect residents' ability to maintain comfortable conditions or find relief during periods of extreme heat. Longer-term research on heat-related mortality similarly emphasises that future health outcomes will depend not simply on rising temperatures but on how society adapts, including the way cities and homes are designed and how vulnerable populations are supported (LSHTM, 2025).

The Extreme Heat Vulnerability Index has therefore been developed as a multi-dimensional, place-based measure of vulnerability. Its conceptual framework is informed by Friends of the Earth's Which neighbourhoods are most vulnerable to heatwaves? research, which identifies neighbourhood vulnerability as the product of multiple, overlapping factors relating to people's susceptibility, their ability to prepare and respond, and characteristics of the places in which they live.

Building on this framework, the Extreme Heat Vulnerability Index brings together indicators across five domains:

- Low ability to respond or prepare for heatwaves – capturing socio-economic and practical barriers that may limit residents' ability to prepare for, respond to and recover from periods of extreme heat.
- Access to cool spaces – capturing the extent to which residents can access green and blue spaces that may provide opportunities for respite and cooling during hot weather.
- Enhanced physical risk – identifying populations whose age, health or disability characteristics may make them particularly susceptible to the adverse health effects of extreme heat.
- The outdoor environment – capturing characteristics of the local environment that may exacerbate or mitigate heat exposure and associated health risks, including tree cover, air quality and projected changes in exposure to very hot summer days.

- Housing – capturing characteristics of homes and living conditions that may increase exposure to high indoor temperatures or constrain residents' ability to obtain relief from heat.

The Index is not intended to predict where individual cases of heat-related illness or mortality will occur. Rather, it provides a consistent measure of the underlying factors that can make neighbourhoods and their populations more vulnerable when extreme heat occurs. It can therefore help identify communities where there may be a greater need for preventative action, investment and adaptation.

This technical report provides an outline of the methodology for creating the Extreme Heat Vulnerability Index, including its conceptual framework, component indicators and domains, and the methodological decisions taken in constructing the measure.

# Creating the Extreme Heat Vulnerability Index at neighbourhood level

The Extreme Heat Vulnerability Index has been created as an area-based measure that can be explored at neighbourhood level using indicators drawn from established research and nationally available data sources.

This approach recognises that vulnerability to extreme heat is multi-dimensional. It is shaped not only by the temperatures to which people are exposed, but also by the characteristics of people, homes and neighbourhoods that influence how severely heat is experienced and the extent to which residents can prepare for and respond to it.

The sections below outline the approach taken to develop the Index..

## Identifying domains of Extreme Heat Vulnerability

The conceptual framework for the Index is informed by Friends of the Earth's research into neighbourhood vulnerability to heatwaves. This work highlights that vulnerability is determined by a combination of physical susceptibility, ability to prepare and respond, and characteristics of homes and neighbourhoods which can increase or mitigate exposure.

The framework has been adapted for the Extreme Heat Vulnerability Index to reflect the availability of robust, nationally consistent neighbourhood-level data and to distinguish between different dimensions of vulnerability that may require different forms of intervention.

Five domains have been identified.

## Low ability to respond or prepare for heatwaves

This domain captures factors that may constrain people's capacity to take preventative action before or during a heatwave, respond effectively to extreme temperatures or access support if they experience adverse health effects.

Financial resources are an important component of adaptive capacity. Households experiencing income deprivation may have less capacity to purchase fans or other cooling equipment, make adaptations to their homes or meet additional costs associated with keeping themselves cool.

Housing tenure can also affect people's ability to adapt their home environment. Residents living in either privately or socially rented accommodation generally have less control over structural changes to their properties than owner-occupiers. They may, for example, be unable to install or make significant changes involving external blinds, shutters, canopies, air-conditioning or other measures designed to reduce overheating without the involvement or permission of their landlord.

The ability to receive and act upon public health information is also important. Residents with limited English proficiency may face additional barriers to accessing heat-health warnings and advice. Access to healthcare provides a further component of resilience where exposure to extreme heat results in adverse health effects.

The domain therefore incorporates measures of income deprivation, private rented housing, social rented housing, English language proficiency and connectivity to healthcare.

## Access to cool spaces

Access to cooler environments can help reduce exposure during periods of high temperatures. Green infrastructure can provide shade and local cooling, while blue spaces can provide cooler environments and opportunities for respite during hot weather.

This domain captures neighbourhood differences in access to these resources through measures of access to greenspace and accessibility of blue space.

It is important to distinguish this domain from the broader characteristics of the outdoor environment. The focus here is specifically on residents' ability to access places that may provide relief from heat, rather than the environmental conditions experienced across the neighbourhood as a whole.

## Enhanced physical risk

Extreme heat does not affect all population groups equally. Physiological characteristics, age and underlying health conditions can increase the likelihood that exposure to high temperatures results in illness or mortality. POST's review of the evidence similarly identifies advanced age and physical and mental health conditions among the factors associated with greater vulnerability to heat (POST, 2024).

Older people are particularly vulnerable to heat-related mortality and morbidity. Young children are also more susceptible because of differences in thermoregulation and their dependence on others to manage their exposure to heat. People with disabilities or limiting long-term health conditions may face increased physiological risks and can also experience additional barriers to adapting their behaviour or environment during extreme heat.

This domain therefore identifies neighbourhoods with larger proportions of residents aged 75 and over, children aged under five, and residents whose day-to-day activities are limited by disability or long-term health conditions.

## The outdoor environment

The physical characteristics of neighbourhoods influence both current and future exposure to heat and the extent to which the local environment can moderate its effects.

Tree canopy can provide shade and contribute to cooling through evapotranspiration. Areas with limited tree cover may therefore have fewer natural mechanisms for mitigating high temperatures. Air pollution represents a further environmental risk because poor air quality can compound health risks during periods of extreme heat.

The Index also incorporates projected changes in the number of very hot summer days. This introduces a forward-looking component into the Index, identifying areas where exposure to days exceeding 28°C is projected to increase most strongly relative to a historical baseline. Together, these indicators capture aspects of the outdoor environment that can either exacerbate vulnerability to extreme heat or provide some protection from it.

## Housing

Housing conditions can play an important role in determining exposure to extreme heat because people spend a substantial proportion of their time within their homes.

The thermal performance of a property influences the temperatures experienced indoors. The Index therefore includes a measure of dwellings with lower Energy Performance Certificate (EPC) ratings as an indicator of housing conditions potentially associated with poorer thermal performance. While EPC ratings are principally designed to measure energy efficiency rather than overheating risk directly, they provide a nationally available measure of the characteristics and energy performance of the housing stock.

Overcrowding can make it more difficult for residents to find cooler rooms or spaces within the home, while a lack of private outdoor space can reduce opportunities to obtain relief from uncomfortable indoor temperatures.

The Housing domain therefore incorporates measures of dwellings with low energy efficiency, household overcrowding and lack of private outdoor space.

The five domains provide a framework for understanding the different mechanisms through which neighbourhoods may experience greater vulnerability to extreme heat. They should be interpreted as interconnected components of vulnerability rather than as independent causes of heat-related harm.

## Selecting the geographic unit of analysis

The Extreme Heat Vulnerability Index has been designed as an area-based measure. In the absence of consistent individual or household-level data covering all of the factors associated with heat vulnerability, neighbourhood characteristics provide a means of identifying places where larger proportions of the population may face heightened risks or where characteristics of the local environment and housing stock may make adaptation more difficult.

An area can therefore be characterised as having high Extreme Heat Vulnerability where a greater proportion of its residents have characteristics associated with susceptibility to heat, where residents face greater barriers to preparing for or responding to extreme heat, or where characteristics of housing and the physical environment increase exposure or reduce opportunities for cooling.

The selection of geography is particularly important for an Index of this kind. Extreme Heat Vulnerability can vary considerably within Local Authority areas, and analysis at larger geographical scales can conceal pockets of vulnerability. At the same time, the geography selected must be sufficiently large and statistically robust to support the use of a broad range of demographic, socio-economic, housing and environmental indicators.

The following principles were considered when selecting the geographic unit:

- It should align with standard statistical geography boundaries, enabling demographic, socio-economic, housing, environmental and service-access data to be linked consistently.
- It should be sufficiently small to identify neighbourhood-level variation and pockets of vulnerability that may be obscured at Local Authority, ward or other larger geographical scales.
- Geography units should be relatively homogeneous in population size, enabling meaningful comparison between communities.

- The geography should be widely used in the publication of official statistics and other small-area datasets, maximising the range of information that can be linked to the Index.
- The geography should provide a sufficiently robust basis for an area-based measure intended to support the targeting of adaptation activity and resources.

Lower-layer Super Output Areas (LSOAs) were selected as the building block for the Extreme Heat Vulnerability Index.

LSOAs offer several advantages. They are designed to contain populations of broadly comparable size and are substantially smaller than Local Authorities, wards and Middle-layer Super Output Areas (MSOAs), allowing localised concentrations of vulnerability to be identified. This is particularly valuable because both population vulnerability and characteristics such as housing, access to greenspace and the outdoor environment can vary over relatively short distances.

LSOAs are also a standard statistical geography and a wide range of Census, administrative and environmental datasets are available directly at this level. The indicators selected for the Extreme Heat Vulnerability Index are available or have been produced consistently at LSOA level, reducing the need to estimate neighbourhood characteristics from substantially larger geographical units.

Using LSOAs also enables the Index to be linked readily to other neighbourhood-level datasets, including the Indices of Deprivation and Census measures. This increases the analytical value of the Index by allowing patterns of Extreme Heat Vulnerability to be examined alongside wider measures of socio-economic need and neighbourhood characteristics.

The Index uses 2021 LSOA boundaries for England.

# Identifying indicators

A set of measurable indicators has been identified for each of the five domains. Indicator selection was informed by the conceptual framework outlined above, previous research on vulnerability to extreme heat - particularly the Friends of the Earth neighbourhood heat vulnerability framework - and the availability of appropriate nationally consistent small-area data.

Indicators were selected where they met the following broad criteria:

- They have national coverage and are collected or constructed on a consistent basis across England.
- They are available at LSOA level or can be robustly represented at LSOA level.
- They capture a concept with a clear theoretical relationship to vulnerability to extreme heat.
- They represent the most appropriate and, where possible, most up-to-date measure available for the theme.
- They are non-disclosive and suitable for use at neighbourhood level.
- They are sufficiently statistically robust for inclusion within a composite measure intended to support comparative analysis and the identification of areas for potential intervention.

The resulting indicator set is summarised below.

## Low ability to respond or prepare for heatwaves

| Indicator | Description | Source | Date |
|---|---|---|---|
| IoD 2025 Income Score (Rate) | Measures the proportion of the population experiencing deprivation relating to low income, including people out of work and people in work with low earnings who receive means-tested benefits. Higher values indicate greater income deprivation and therefore potentially lower financial capacity to adapt to extreme heat. | Ministry of Housing, Communities and Local Government (MHCLG), Indices of Deprivation 2025 | 2025 |
| Social rented housing and private rented housing | Proportion of households renting from a Local Authority, Housing Association or Registered Social Landlord, private landlord, letting agency or other private source. Residents in rented accommodation may have less control over adaptations to their homes that could reduce overheating, including the | Census 2021 | 2021 |

| Indicator | Description | Source | Date |
|---|---|---|---|
| | installation of external blinds, shutters, canopies or air-conditioning. | | |
| Main language is not English: cannot speak English well or at all | Proportion of residents aged three and over whose main language is not English and who report that they cannot speak English well or at all. Captures potential barriers to receiving and acting upon heat-health warnings and advice. | Census 2021 | 2021 |
| Connectivity: Healthcare (overall) | DfT Connectivity Score measuring ease of access to healthcare facilities. Scores take account of transport networks, service timetables, destinations within reach and propensity to travel by different transport modes. | Department for Transport (DfT) | 2025 |

## Access to cool spaces

| Indicator | Description | Source | Date |
|---|---|---|---|
| IMED Lack of Access to Greenspace Rank | Measures relative lack of household access to greenspace using Natural England's Accessible Green Infrastructure standards. The measure considers access to neighbourhood, local and doorstep greenspaces according to specified size and distance thresholds. | Natural England | 2026 |
| AHAH Blue Space | Average drive time to the nearest accessible blue space, including qualifying water bodies, coastline and river features. Greater travel time represents poorer access to blue spaces that may provide opportunities for cooling and respite. | Geographic Data Service, Access to Healthy Assets and Hazards (AHAH) v5.1 | May 2026 |

## Enhanced physical risk

| Indicator | Description | Source | Date |
|---|---|---|---|
| Population aged 75+ | Proportion of the total resident population aged 75 years and over. Older people experience increased physiological susceptibility to heat-related morbidity and mortality. | Census 2021 | 2021 |

| Indicator | Description | Source | Date |
|---|---|---|---|
| Population aged 0-4 | Proportion of the total resident population aged under five. Young children are particularly susceptible to high temperatures because of their developing thermoregulatory capacity and dependence on others to manage heat exposure. | Census 2021 | 2021 |
| Disabled under the Equality Act: day-to-day activities limited a little or a lot | Proportion of residents who are disabled under the Equality Act and report that their day-to-day activities are limited a little or a lot by a long-term physical or mental health condition or disability. | Census 2021 | 2021 |

## The outdoor environment

| Indicator | Description | Source | Date |
|---|---|---|---|
| Tree cover | Percentage of neighbourhood land covered by tree canopy. Tree canopy is derived principally from Environment Agency National LiDAR Programme data, supplemented by Forestry Commission National Forest Inventory data. Greater tree cover can provide shade and contribute to local cooling. | Friends of the Earth / Terra Sulis Research CIC | 2022 |
| IoD 2025 Air Quality Indicator | Composite estimate of concentrations of benzene, nitrogen dioxide, PM2.5 and sulphur dioxide. Pollutant concentrations are compared with selected standards and combined to produce an LSOA-level measure of air-quality deprivation. | Ministry of Housing, Communities and Local Government (MHCLG), Indices of Deprivation 2025 | 2025 |
| IMED Projected Increase in Summer Days over 28˚C Rank | Measures projected change in exposure to very hot summer days by comparing the number of summer days exceeding 28˚C in the 2030s with a 1980s baseline, based on CHESS-SCAPE RCP4.5 climate projections. It identifies areas projected to experience the greatest relative increase rather than predicting exact future temperatures. | Natural England | 2026 |

## Housing

| Indicator | Description | Source | Date |
|---|---|---|---|
| Dwellings with low energy efficiency (D-G rating) | Proportion of domestic Energy Performance Certificates rated D-G among EPC lodgements over the preceding ten-year period. Included as an indicator of housing conditions and thermal performance potentially associated with vulnerability to high indoor temperatures. EPC ratings measure energy efficiency rather than overheating directly and should therefore be interpreted as a proxy measure within the Housing domain. | Ministry of Housing, Communities and Local Government (MHCLG), Energy Performance Certificate data | 2024 |
| Overcrowded housing | Proportion of households with an occupancy rating for rooms of -1 or below, indicating that the household has at least one fewer room than required under standard occupancy definitions. Overcrowding may reduce residents' ability to find cooler spaces within the home during periods of extreme heat. | Census 2021 | 2021 |
| IoD 2025 Housing Lacking Private Outdoor Space Indicator | Property-based measure capturing the extent to which residential properties lack private outdoor space or have private outdoor space below the national median for houses with such space. Properties without private garden space receive the highest deprivation value. | Ministry of Housing, Communities and Local Government (MHCLG), Indices of Deprivation 2025 | 2025 |

These indicators capture distinct but related aspects of vulnerability. Some describe the characteristics of residents, such as age, disability, income and English-language proficiency; others describe the characteristics of housing and neighbourhoods, including energy efficiency, tree cover, air quality and private outdoor space; and others capture the accessibility of resources that can support adaptation, including healthcare, greenspace and blue space.

As a result, the Index should be understood as a place-based measure of vulnerability rather than a measure of the vulnerability of every individual resident within an LSOA. A high score indicates that an area has a comparatively greater concentration of characteristics associated with vulnerability to extreme heat; it does not imply that every resident of that neighbourhood is individually vulnerable.

# Overview of the methodology used to construct the Extreme Heat Vulnerability Index

This section provides an overview of the methodology used to construct the Extreme Heat Vulnerability Index. As outlined in the preceding sections, the Index has been developed using a conceptual framework informed by existing research on vulnerability to extreme heat, together with a review of the availability and suitability of neighbourhood-level indicators.

The earlier stages of the methodology identify the five domains of Extreme Heat Vulnerability, select Lower-layer Super Output Areas (LSOAs) as the unit of geography and identify the indicators used to represent each domain. The subsequent data-processing stages combine these indicators into domain scores and, ultimately, an overall Extreme Heat Vulnerability Index.

The remaining stages of construction are as follows:

- Shrinkage estimation is applied to improve the reliability of indicator estimates at small-area level.
- Indicators are oriented so that a higher value consistently represents greater vulnerability.
- Individual indicators are standardised by ranking and transforming them to a normal distribution.
- Indicators are combined into the five domains, using either equal weighting or weights derived from Maximum Likelihood Factor Analysis, depending on the characteristics of the indicators within each domain.
- Domain scores are ranked and transformed to a specified exponential distribution.
- The five exponentially transformed domain scores are combined using equal domain weights to create the overall Extreme Heat Vulnerability Index.
- The resulting Index score is ranked, with a rank of 1 representing the neighbourhood with the highest level of Extreme Heat Vulnerability.

The following sections describe each of these data-processing stages in more detail.

## Applying shrinkage to improve the robustness of indicators

Where an indicator for a small area is based on relatively small numbers, the resulting estimate may be more susceptible to chance fluctuations and therefore provide a less reliable representation of the underlying characteristics of the neighbourhood.
To reduce this effect, shrinkage estimation has been applied to all indicators included in the Extreme Heat Vulnerability Index.

Shrinkage is a statistical technique which allows small-area estimates to ‘borrow strength’ from a larger geographic area. The approach moderates potentially unreliable LSOA-level values by moving them towards the corresponding Local Authority value, with the extent of this adjustment dependent on the estimated reliability of the individual LSOA observation.

The basic principle is that more statistically robust LSOA estimates remain relatively close to their original value, while less reliable estimates are moved further towards the Local Authority average. This reduces the influence of unusually high or low values that may arise because of small populations or small numbers of observations, while retaining genuine variation between neighbourhoods.

Two forms of shrinkage have been used, depending on the format of the underlying indicator.

For proportion or percentage-based indicators, shrinkage is applied to the numerator and denominator used to construct the rate. The LSOA proportion is converted to an empirical logit and combined with the corresponding Local Authority estimate. The weighting given to the LSOA estimate reflects its statistical precision and the level of variation between LSOAs within the Local Authority. The resulting shrunk estimate is then transformed back to a proportion.

This approach has been applied to:

- Population aged 75 and over
- Population aged 0–4
- Disabled under the Equality Act: day-to-day activities limited a little or a lot
- Dwellings with low energy efficiency (EPC D–G)
- Overcrowded housing
- Main language is not English and cannot speak English well or at all
- Rented housing
- IoD 2025 Income Score

For indicators expressed as a score or other continuous measure, an equivalent score-based shrinkage procedure has been used. The LSOA score is combined with the corresponding Local Authority mean, with the weighting again determined by the reliability of the LSOA estimate and the variation between LSOAs within the Local Authority.

This approach has been applied to:

- Lack of Access to Greenspace Rank
- AHAH Blue Space
- IoD 2025 Housing Lacking Private Outdoor Space Indicator
- Connectivity: Healthcare
- IoD 2025 Air Quality Indicator
- Projected Increase in Summer Days over 28˚C Rank
- Tree cover

Where the shrinkage calculation itself produces a missing LSOA value, the Local Authority mean is used within the shrinkage procedure. Following this process, any remaining missing values are set to zero before the indicators are standardised.

## Ensuring that all indicators are ‘pointing in the same direction’

To combine different indicators into a composite measure, it is necessary for them to have a consistent direction of interpretation.
For the Extreme Heat Vulnerability Index, a higher standardised score is intended to represent a more negative outcome and therefore greater vulnerability to extreme heat.

Most of the selected indicators are already expressed in this direction. For example, higher levels of income deprivation, overcrowding or poor air quality are associated with greater vulnerability.

However, three indicators are expressed in the opposite direction in their source data and are therefore reversed prior to standardisation:

- Lack of Access to Greenspace Rank
- Connectivity: Healthcare
- Projected Increase in Summer Days over 28˚C Rank

The polarity of these indicators is reversed by multiplying the shrunk indicator score by -1. This ensures that, once standardised, higher values across all indicators consistently represent greater Extreme Heat Vulnerability.

## Standardisation

The indicators included within the Extreme Heat Vulnerability Index are measured using different units and have different underlying distributions. For example, the Index includes population proportions, accessibility measures, environmental measures and rank-based indicators.

It is therefore necessary to standardise the indicators before they can be combined. Without standardisation, indicators with a wider numerical range or greater variance could exert greater influence over a domain score simply because of the scale on which they are measured.

Each indicator is first ranked across all 33,755 LSOAs in England, with higher ranks representing greater vulnerability. These ranks are then transformed to a normal distribution using the inverse normal distribution function.

For an LSOA with indicator rank (R), the transformed score is calculated from its position in the national distribution using:
Inverse normal [ R / (N + 1) ] where N = 33,755, the total number of LSOAs included in the Index.

This procedure produces indicator scores on a common normally distributed scale. It ensures that the original unit of measurement does not determine an indicator's influence when it is subsequently combined with other indicators.

The use of ranks also means that the Index primarily captures the relative position of neighbourhoods rather than the absolute numerical distance between their original indicator values.

## Weighting and combining indicators into domains

Because the Extreme Heat Vulnerability Index is a composite measure, a decision is required about the relative weight assigned to indicators when they are combined into domains.

There are a number of possible approaches to weighting. The simplest is to give each indicator an equal weight. An alternative is to use a statistical method to identify whether the indicators within a domain appear to represent a common underlying factor and, where appropriate, use the strength of those relationships to derive weights.

The suitability of the indicators for factor analysis was explored by examining the relationships between the standardised indicators within each domain.

### Domains using equal indicator weights

Equal weighting is used for three domains:

- Access to cool spaces
- Enhanced physical risk
- Low ability to respond or prepare for heatwaves

Access to cool spaces contains only two indicators and was therefore considered unsuitable for factor analysis.

For Enhanced physical risk, the relationships between disability or limiting long-term illness, the population aged 0–4 and the population aged 75 and over did not identify a sufficiently clear common underlying factor. Although all three indicators are conceptually relevant to physical susceptibility to extreme heat, they capture different population groups and forms of vulnerability.

Similarly, no clear common factor was identified between the indicators comprising Low ability to respond or prepare for heatwaves. These indicators capture distinct aspects of adaptive capacity, including language barriers, rented housing, low income and access to healthcare.

For these three domains, the normally transformed indicator scores are therefore summed, giving each indicator an equal contribution to its respective domain.

The domains are constructed as follows:
Access to cool spaces

- Lack of Access to Greenspace
- AHAH Blue Space

Enhanced physical risk

- Disabled under the Equality Act: day-to-day activities limited a little or a lot
- Population aged 0–4
- Population aged 75 and over

Low ability to respond or prepare for heatwaves

- Main language is not English and cannot speak English well or at all
- Rented housing
- IoD 2025 Income Score
- Connectivity: Healthcare

## Domains using Maximum Likelihood Factor Analysis

For the Housing and Outdoor Environment domains, the constituent indicators were considered conceptually related and showed sufficient relationships to explore the use of factor analysis.

A Maximum Likelihood Factor Analysis is therefore used to derive indicator weights for these two domains.
Factor analysis seeks to identify an underlying factor which explains the shared variation between a group of indicators. A one-factor Maximum Likelihood model is fitted and the resulting factor loadings are standardised to derive the relative contribution of each indicator to the domain score. Each normally transformed indicator is then multiplied by its corresponding standardised factor loading and these weighted indicator scores are summed to create the domain.

The Housing domain comprises:

- Dwellings with low energy efficiency (EPC D–G)
- Overcrowded housing
- IoD 2025 Housing Lacking Private Outdoor Space Indicator

The Outdoor Environment domain comprises:

- IoD 2025 Air Quality Indicator
- Projected Increase in Summer Days over 28˚C
- Tree cover

This mixed weighting approach reflects the different statistical relationships found within the five domains. Equal weighting is retained where there is insufficient evidence of a common statistical factor, while factor-derived weights are used where the constituent indicators support this approach.

## Standardising the domains

Once the individual indicators have been combined, five domain scores are available:

- Access to cool spaces
- Enhanced physical risk
- Housing
- Low ability to respond or prepare for heatwaves
- Outdoor Environment

These domain scores cannot be combined directly because their distributions differ. This is particularly important because three domains have been constructed using equally weighted standardised indicators, while two incorporate factor-analysis weights.
The five domains are therefore standardised onto a common distribution before the overall Index is produced.

Each domain score is first ranked across the 33,755 LSOAs in England. The resulting ranks are then transformed to a specified exponential distribution ranging from approximately 0 to 100, with higher scores representing greater vulnerability.
For an LSOA, the domain rank is first scaled as:
$R = \text{rank} / N$
where $N = 33{,}755$.
The exponentially transformed score is then calculated using a scaling constant of 23:
$\text{Transformed score} = -23 \times \ln[1 - R \times (1 - \exp(-100/23))]$

The exponential transformation serves two purposes. First, it places all five domains onto a common distribution so that they can be combined without differences in their original scale determining their contribution to the overall Index.

Second, the transformation places greater emphasis on neighbourhoods at the high-vulnerability end of each domain distribution. This limits the extent to which very low vulnerability in one domain can completely compensate for very high vulnerability in another. As a result, neighbourhoods experiencing particularly high vulnerability on one aspect of the Index remain more visible within the overall measure.

## Combining the domains to create the Extreme Heat Vulnerability Index

Following exponential transformation, the five domain scores are combined to produce the overall Extreme Heat Vulnerability Index.
Each of the five domains is given equal weight in the final Index. The overall score for each LSOA is therefore calculated as the sum of:

- Exponentially transformed Access to cool spaces score
- Exponentially transformed Enhanced physical risk score
- Exponentially transformed Housing score
- Exponentially transformed Low ability to respond or prepare for heatwaves score
- Exponentially transformed Outdoor Environment score

Giving equal weight to the five domains reflects the multi-dimensional conceptual framework underpinning the Index. No single domain is treated as inherently more important than another in determining neighbourhood vulnerability to extreme heat.

The resulting Extreme Heat Vulnerability Index score is then ranked across all 33,755 LSOAs in England.

For the final Index rank, 1 represents the LSOA with the highest Extreme Heat Vulnerability, with progressively larger rank values representing lower relative levels of vulnerability.

The resulting Index therefore provides a relative measure of Extreme Heat Vulnerability across neighbourhoods in England. An area's position reflects its combined performance across the five domains and should be interpreted relative to other LSOAs rather than as an absolute measure of heat-related risk.

# Extreme Heat Vulnerability Index – summary analysis

This section explores the geographical patterns of Extreme Heat Vulnerability across England.

## Extreme Heat Vulnerability is concentrated in Inner London, but different types of vulnerability affect different parts of the country

The Extreme Heat Vulnerability Index highlights a striking geography of vulnerability across England. The neighbourhoods and Local Authorities with the highest overall vulnerability are overwhelmingly concentrated in London, and particularly within the dense inner urban core of the capital. In contrast, many of the areas with the lowest overall vulnerability are rural and semi-rural communities outside the South East.

This pattern reflects the multi-dimensional nature of the Index. London's high overall vulnerability is not primarily driven by the Enhanced physical risk domain. Indeed, many central London boroughs have comparatively low vulnerability on this domain because they have younger populations and lower prevalence of some of the age- and health-related risk factors captured by the Index. Instead, London's position is driven principally by the interaction of housing pressures, characteristics of the outdoor environment, limited access to cool spaces and, in some communities, lower ability to prepare for and respond to extreme heat.

Elsewhere, the pattern is different. Coastal communities feature much more prominently among the areas with high Enhanced physical risk, reflecting older populations and higher levels of limiting long-term illness or disability. This demonstrates why vulnerability to extreme heat cannot be understood from temperature or the physical environment alone: the factors increasing vulnerability vary substantially between different types of place.

## Inner London dominates the areas with the highest overall Extreme Heat Vulnerability

Eighteen of the 20 Local Authorities with the highest average Extreme Heat Vulnerability are London boroughs. The only exceptions are Cambridge, ranked 14th, and Slough, ranked 19th.

The concentration is particularly pronounced at the top of the Index. The seven Local Authorities with the highest average vulnerability all form part of London's inner urban core: City of London, Kensington and Chelsea, Westminster, Tower Hamlets, Hammersmith and Fulham, Islington and Camden.

City of London has the highest average Extreme Heat Vulnerability in England. Its position is particularly strongly associated with very high vulnerability in access to cool spaces and housing, where it ranks first nationally on both domains, as well as the outdoor environment, where it ranks fourth. By contrast, it has the lowest relative vulnerability in England on Enhanced physical risk and Low ability to respond or prepare. This illustrates how very high vulnerability arising from the characteristics of the built environment can outweigh comparatively low vulnerability among the resident population.

A similar pattern is visible across much of Inner London. Kensington and Chelsea ranks first nationally for vulnerability associated with the Outdoor Environment, fourth for Housing and fourth for Access to cool spaces. Westminster ranks third for both Housing and Outdoor Environment, while Hammersmith and Fulham ranks second for Outdoor Environment and ninth for Housing.

Other London boroughs have a different combination of pressures. Newham has the highest vulnerability in England on Low ability to respond or prepare, while Brent ranks second and Tower Hamlets third. These areas combine factors including higher levels of income deprivation, high proportions of residents living in rented accommodation and greater prevalence of residents who may experience language barriers to receiving or acting upon heat-health advice.

### 20 Local Authorities with the highest average Extreme Heat Vulnerability

| Overall rank | Local Authority | Domains with highest relative vulnerability |
|---|---|---|
| 1 | City of London | Access to cool spaces (1); Housing (1) |
| 2 | Kensington and Chelsea | Outdoor environment (1); Access to cool spaces (4) |
| 3 | Westminster | Housing (3); Outdoor environment (3) |
| 4 | Tower Hamlets | Housing (2); Low ability to respond/prepare (3) |
| 5 | Hammersmith and Fulham | Outdoor environment (2); Housing (9) |
| 6 | Islington | Housing (8); Outdoor environment (8) |
| 7 | Camden | Housing (5); Access to cool spaces (8) |
| 8 | Hackney | Housing (6); Low ability to respond/prepare (7) |

| Overall rank | Local Authority | Domains with highest relative vulnerability |
|---|---|---|
| 9 | Newham | Low ability to respond/prepare (1); Housing (10) |
| 10 | Southwark | Housing (7); Outdoor environment (12) |
| 11 | Lambeth | Access to cool spaces (3); Housing (11) |
| 12 | Brent | Low ability to respond/prepare (2); Access to cool spaces (14) |
| 13 | Haringey | Low ability to respond/prepare (11); Housing (13) |
| 14 | Cambridge | Outdoor environment (5); Housing (26) |
| 15 | Wandsworth | Housing (12); Outdoor environment (14) |
| 16 | Lewisham | Housing (14); Low ability to respond/prepare (23) |
| 17 | Hounslow | Low ability to respond/prepare (17); Housing (18) |
| 18 | Waltham Forest | Housing (19); Low ability to respond/prepare (20) |
| 19 | Slough | Low ability to respond/prepare (8); Housing (20) |
| 20 | Ealing | Low ability to respond/prepare (15); Housing (17) |

*Note: Domain ranks show the domains in which each area experiences its highest relative vulnerability. Rank 1 indicates the highest vulnerability in England.*

## The least vulnerable Local Authorities are predominantly rural and away from London and the South East

The opposite end of the Index has a markedly different geography. Ribble Valley has the lowest average Extreme Heat Vulnerability in England, followed by High Peak, Staffordshire Moorlands and Westmorland and Furness.

Many of the 20 least vulnerable Local Authorities are predominantly rural or contain substantial rural populations, including Derbyshire Dales, North Yorkshire, South Hams, Cotswold, Forest of Dean, Malvern Hills and West Devon. Areas in northern England and the Midlands are particularly well represented.

These areas generally have comparatively low vulnerability across several domains simultaneously. Ribble Valley, for example, ranks towards the low-vulnerability end nationally for access to cool spaces, ability to respond and prepare, the outdoor environment and physical risk.

However, low overall vulnerability does not mean that every domain performs strongly. This is particularly apparent for Enhanced physical risk. West Devon is among the 20 least vulnerable Local Authorities overall but ranks 66th highest nationally for physical risk.

Staffordshire Moorlands ranks 76th and Cumberland 87th. Their relatively favourable overall position reflects much lower vulnerability across other aspects of the Index.

### 20 Local Authorities with the lowest average Extreme Heat Vulnerability

| Overall rank | Local Authority | Domains with highest relative vulnerability |
|---|---|---|
| 296 | Ribble Valley | Housing (178); Enhanced physical risk (229) |
| 295 | High Peak | Housing (128); Enhanced physical risk (150) |
| 294 | Staffordshire Moorlands | Enhanced physical risk (76); Access to cool spaces (225) |
| 293 | Westmorland and Furness | Enhanced physical risk (129); Housing (194) |
| 292 | Stroud | Enhanced physical risk (176); Outdoor environment (178) |
| 291 | Derbyshire Dales | Access to cool spaces (145); Enhanced physical risk (168) |
| 290 | South Ribble | Enhanced physical risk (125); Access to cool spaces (212) |
| 289 | Bromsgrove | Enhanced physical risk (119); Outdoor environment (168) |
| 288 | South Hams | Enhanced physical risk (120); Access to cool spaces (133) |
| 287 | North Yorkshire | Enhanced physical risk (162); Access to cool spaces (179) |
| 286 | Chorley | Enhanced physical risk (130); Housing (182) |
| 285 | Cumberland | Enhanced physical risk (87); Low ability to respond/prepare (195) |
| 284 | Warrington | Enhanced physical risk (185); Housing (187) |
| 283 | Rutland | Access to cool spaces (38); Outdoor environment (183) |
| 282 | Forest of Dean | Enhanced physical risk (79); Low ability to respond/prepare (189) |
| 281 | Cheshire East | Enhanced physical risk (148); Outdoor environment (214) |
| 280 | Cotswold | Access to cool spaces (93); Outdoor environment (194) |
| 279 | York | Housing (144); Access to cool spaces (187) |
| 278 | Malvern Hills | Enhanced physical risk (103); Low ability to respond/prepare (174) |
| 277 | West Devon | Enhanced physical risk (66); Low ability to respond/prepare (187) |

## Extreme Heat Vulnerability becomes even more concentrated in Inner London at neighbourhood level

The concentration in London becomes still clearer at neighbourhood level. Eighteen of the 20 LSOAs with the highest Extreme Heat Vulnerability are in Inner London. The two exceptions are Somers Town in Portsmouth and Church End in Brent, an Outer London borough. Finsbury Park West - Islington 005C is the neighbourhood with the highest overall Extreme Heat Vulnerability in England.

Unlike some neighbourhoods whose overall position is dominated by a single exceptionally high domain score, Finsbury Park West experiences relatively high vulnerability across several aspects of the Index. It ranks among the most vulnerable 1,000 neighbourhoods nationally for access to cool spaces, ability to respond and prepare, and housing. Its position therefore reflects an accumulation of different forms of vulnerability.

Camden is particularly prominent among the highest-vulnerability neighbourhoods. Three LSOAs in Kilburn East are among the ten most vulnerable nationally, ranked fourth, fifth and seventh. Kentish Town West is ranked third, while Chalk Farm also appears in the top 20. Housing and environmental pressures feature repeatedly as the strongest drivers. Brompton in Kensington and Chelsea, for example, has the third highest Housing vulnerability of any LSOA in England, while Northumberland Park in Haringey is ranked 14th.

Outdoor environment pressures are particularly prominent in Earl's Court, Brompton, Shepherd's Bush North and Ladbroke Grove.
Somers Town in Portsmouth stands out from the predominantly London pattern. Ranked second overall, its strongest drivers differ somewhat from those affecting many Inner London neighbourhoods: it ranks 46th nationally on Low ability to respond or prepare and 172nd on Enhanced physical risk. This suggests a greater role for population vulnerability and adaptive capacity alongside the pressures associated with a dense urban environment.

### 20 LSOAs with the highest Extreme Heat Vulnerability

| Rank | LSOA | Local Authority | Strongest domain pressures |
|---|---|---|---|
| 1 | Finsbury Park West - Islington 005C | Islington | Cool spaces (234); Ability to respond (578) |
| 2 | Somers Town - Portsmouth 018A | Portsmouth | Ability to respond (46); Physical risk (172) |
| 3 | Kentish Town West - Camden 007B | Camden | Cool spaces (497); Housing (909) |
| 4 | Kilburn East - Camden 020B | Camden | Housing (124); Outdoor environment (390) |
| 5 | Kilburn East - Camden 020D | Camden | Housing (175); Cool spaces (205) |

| Rank | LSOA | Local Authority | Strongest domain pressures |
|---|---|---|---|
| 6 | Shepherd's Bush North - Hammersmith and Fulham 004B | Hammersmith and Fulham | Housing (103); Outdoor environment (152) |
| 7 | Kilburn East - Camden 020E | Camden | Cool spaces (182); Housing (409) |
| 8 | Brompton - Kensington and Chelsea 014C | Kensington and Chelsea | Housing (3); Outdoor environment (57) |
| 9 | Earl's Court - Kensington and Chelsea 015D | Kensington and Chelsea | Outdoor environment (48); Cool spaces (94) |
| 10 | Northumberland Park - Haringey 002C | Haringey | Housing (14); Ability to respond (93) |
| 11 | Finsbury Park West - Islington 005E | Islington | Cool spaces (23); Outdoor environment (834) |
| 12 | Church Street - Westminster 009G | Westminster | Housing (76); Outdoor environment (653) |
| 13 | Shadwell North - Tower Hamlets 022A | Tower Hamlets | Housing (380); Cool spaces (882) |
| 14 | City of London - City of London 001E | City of London | Cool spaces (60); Housing (106) |
| 15 | White City - Hammersmith and Fulham 002C | Hammersmith and Fulham | Outdoor environment (176); Housing (218) |
| 16 | Queensway - Westminster 017D | Westminster | Outdoor environment (105); Housing (189) |
| 17 | Stockwell North - Lambeth 006E | Lambeth | Cool spaces (262); Outdoor environment (520) |
| 18 | Chalk Farm - Camden 012B | Camden | Housing (178); Cool spaces (498) |
| 19 | Ladbroke Grove - Kensington and Chelsea 002D | Kensington and Chelsea | Outdoor environment (95); Housing (277) |
| 20 | Church End - Brent 025B | Brent | Cool spaces (190); Ability to respond (213) |

## The least vulnerable neighbourhoods are concentrated in northern rural and semi-rural communities

The neighbourhoods with the lowest overall Extreme Heat Vulnerability are much more geographically dispersed than those at the top of the Index, but a clear northern and rural/semi-rural pattern is visible.

The least vulnerable neighbourhood is Chester-le-Street South & East - County Durham 013D, followed by Killinghall & Hampsthwaite in North Yorkshire and Ashington South in Northumberland. The bottom 20 also includes neighbourhoods in High Peak, Cumberland, Derbyshire Dales, Ribble Valley and Westmorland and Furness.

Several relatively affluent suburban neighbourhoods also appear, including parts of Appleton and Woolston in Warrington and Greasby, Hoylake and West Kirby on the Wirral.

As with the Local Authority results, some of these neighbourhoods have a more mixed profile than their overall position might initially suggest. Coastal neighbourhoods such as West Kirby, Whitley Bay Promenade, Hoylake and Thorpe Bay have Enhanced physical risk as their relatively weakest domain, consistent with the wider pattern of ageing populations and poorer health contributing more strongly to heat vulnerability in some coastal communities.

## 20 LSOAs with the lowest Extreme Heat Vulnerability

| Rank | LSOA | Local Authority | Strongest domain pressures |
|---|---|---|---|
| 33,755 | Chester-le-Street South & East - County Durham 013D | County Durham | Outdoor environment (30,086); Cool spaces (31,138) |
| 33,754 | Killinghall & Hampsthwaite - Harrogate 008A | North Yorkshire | Outdoor environment (27,873); Physical risk (32,199) |
| 33,753 | Ashington South - Northumberland 041G | Northumberland | Physical risk (28,533); Cool spaces (29,831) |
| 33,752 | Dinting, Simmondley & Charlesworth - High Peak 004D | High Peak | Outdoor environment (27,111); Housing (28,527) |
| 33,751 | West Kirby - Wirral 026B | Wirral | Physical risk (26,676); Cool spaces (29,688) |
| 33,750 | East Cockermouth & Buttermere - Allerdale 007A | Cumberland | Physical risk (27,035); Cool spaces (29,256) |
| 33,749 | Spofforth, Burn Bridge & Huby - Harrogate 021A | North Yorkshire | Physical risk (26,196); Outdoor environment (28,458) |
| 33,748 | Appleton - Warrington 025A | Warrington | Outdoor environment (24,889); Physical risk (28,713) |
| 33,747 | Hathersage, Bradwell & Tideswell - Derbyshire Dales 001B | Derbyshire Dales | Physical risk (27,071); Outdoor environment (28,595) |
| 33,746 | Whitley Bay Promenade - North Tyneside 006E | North Tyneside | Physical risk (24,150); Cool spaces (30,792) |
| 33,745 | North Gosforth - Newcastle upon Tyne 002F | Newcastle upon Tyne | Outdoor environment (28,125); Cool spaces (28,236) |

| Rank | LSOA | Local Authority | Strongest domain pressures |
|---|---|---|---|
| 33,744 | Menston & Burley Moor - Bradford 005A | Bradford | Cool spaces (26,446); Housing (29,686) |
| 33,743 | Waddington, Gisburn & Slaidburn - Ribble Valley 001E | Ribble Valley | Housing (28,569); Ability to respond (29,457) |
| 33,742 | Appleton - Warrington 025B | Warrington | Outdoor environment (25,889); Cool spaces (25,963) |
| 33,741 | Hoylake - Wirral 014C | Wirral | Physical risk (23,960); Cool spaces (26,967) |
| 33,740 | Thorpe Bay - Southend-on-Sea 016D | Southend-on-Sea | Physical risk (26,440); Ability to respond (28,165) |
| 33,739 | Woolston - Warrington 014C | Warrington | Outdoor environment (25,004); Housing (28,000) |
| 33,738 | Dinting, Simmondley & Charlesworth - High Peak 004B | High Peak | Physical risk (25,724); Outdoor environment (27,638) |
| 33,737 | Langwathby, Kirkoswald & Alston Moor - Eden 001B | Westmorland and Furness | Ability to respond (25,926); Physical risk (28,158) |
| 33,736 | Greasby - Wirral 023D | Wirral | Physical risk (20,863); Outdoor environment (30,905) |

## Different places experience different forms of vulnerability

Looking beneath the overall Index highlights several distinct geographies of Extreme Heat Vulnerability.

Housing and the urban environment are central to London’s vulnerability. London boroughs account for 19 of the 20 Local Authorities with the highest average Housing vulnerability, with Slough the only non-London authority in this group. The City of London, Tower Hamlets, Westminster and Kensington and Chelsea have the four highest Housing vulnerability scores nationally. London also dominates the Outdoor Environment domain, with Kensington and Chelsea, Hammersmith and Fulham, Westminster and City of London occupying four of the five highest-vulnerability positions.

The ability to prepare for and respond to heat is particularly challenging in diverse and disadvantaged urban communities. Newham, Brent and Tower Hamlets occupy the top three positions nationally on this domain, while Leicester, Barking and Dagenham, Boston, Hackney and Slough also feature among the highest-ranking authorities. This reflects the interaction of income deprivation, rented housing, language barriers and access to healthcare rather than any single characteristic.

Enhanced physical risk has a very different geography. Tendring has the highest average vulnerability on this domain, followed by Blackpool and East Lindsey. Thanet, Torbay, Rother, Great Yarmouth, North Norfolk, Wirral, Wyre, South Tyneside and the Isle of Wight also feature among the most vulnerable authorities. The prominence of coastal and seaside communities reflects the greater concentration in many of these areas of older residents and people living with long-term health conditions or disabilities.

The Index therefore identifies more than a simple urban-rural divide. Dense inner-city neighbourhoods tend to experience the greatest overall accumulation of heat vulnerability, particularly through housing, access to cooling, the outdoor environment and barriers to adaptation. Coastal communities are more strongly affected by the physiological vulnerability of their populations, while many rural and semi-rural areas record comparatively low overall vulnerability despite sometimes experiencing challenges on individual domains.

This variation is important for adaptation planning. The actions required to reduce vulnerability in Inner London - such as improving the thermal performance of housing, increasing shade and tree cover and expanding access to cooling spaces - may differ considerably from the interventions required in ageing coastal communities, where identifying and supporting residents at enhanced physical risk may be a greater priority.