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Extreme heat, health inequalities, and the net zero transition: future directions

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RAJAT GUPTA
ANNA MAVROGIANNI
CATHRYN BIRCH
CLARE HEAVISIDE
MIKE DAVIES
RUTH DOHERTY
SHAKOOR HAJAT
AMR HAMADA
ANDREW IBBETSON
ANDREW SCHURER
BHARGAV MACHA
CARLY REDDINGTON
CHENG CUI
CHENGYANG WU
DALE HOYLAND
EMER O'CONNELL
GESCHE HUEBNER
GIANDOMENICO VURRO
GIORGOS PETROU
HANNAH MARSHALL
HUGH WADDINGTON
JAMES MILNER
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LIZZY CURTIS
MADALENA VAZ MONTEIRO
MATT GREGG
PENINAH MURAGE
SAHAR ZAHIRI
SADIE BONIFACE
SARI KOVATS
SUSAN MICHIE
SUSIE VERNON
YUANHONG ZHAO

*Author affiliations can be found in the back matter of this article

CORRESPONDING AUTHOR:
Rajat Gupta
Oxford Brookes University, Oxford, UK
rgupta@brookes.ac.uk

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ABSTRACT

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As the UK progresses towards a net zero economy, rising temperatures and more frequent extreme heat events pose increasing risks to health and wellbeing, particularly for vulnerable populations. The 2022 heatwave, with temperatures over 40°C and more than 3,200 excess deaths, exposed limitations in current policy frameworks for addressing the interconnected challenges of climate mitigation, adaptation, and health equity. Despite projections indicating that up to 90% of homes may soon face overheating risk, building regulations and energy demand policies remain insufficiently aligned with emerging climate projections.

This paper introduces HEARTH, a newly established five-year, £7.4 million (€8.6 million) national research hub that examines the intersection of extreme heat, health inequalities, and the net zero transition. HEARTH adopts a stakeholder-led, whole-systems, mixed-methods approach to investigate how net zero interventions can deliver health co-benefits while reducing heat-related risks in vulnerable settings. The programme focuses on populations most at risk, including older adults, individuals with chronic conditions, and people living or working in confined or institutional environments.

The research integrates multi-scale climate modelling, from regional and urban climates to neighbourhood, building, and indoor environments, with empirical data on heat exposure, occupant behaviour, and physical and mental health outcomes across more than 200 monitored settings. HEARTH evaluates the health, equity, and economic impacts of interventions, including retrofit strategies, climate-resilient new construction, and nature-based solutions. The paper concludes by outlining research priorities and policy directions needed to ensure that the transition to net zero strengthens climate resilience and reduces health inequalities rather than exacerbating them.

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INTRODUCTION

The United Kingdom is entering a period of accelerating climate instability characterised by increasing frequency, intensity, and duration of extreme heat events. During the July 2022 heatwave, outdoor temperatures exceeded 40°C for the first time in recorded history, and more than 3,200 excess deaths were recorded across England and Wales (Office for National Statistics and UK Health Security Agency, 2022). Climate projections under both 2°C and 4°C global warming scenarios indicate that events of comparable magnitude are likely to become more frequent by the 2030s and 2050s (Bouhi et al., 2022).

Without effective adaptation measures, heat-related mortality is projected to increase sharply. Estimates suggest that annual heat-related deaths could rise by 257% to approximately 7,040 per year by the 2050s (Hajat et al., 2014). These health impacts are accompanied by substantial economic costs, with estimates suggesting that heat-related mortality could impose an annual burden of between £323 million and £9.9 billion by the 2050s (Climate Change Committee, 2019). These projections underline the urgency of integrating heat risk within climate mitigation, adaptation, and public health policy.

At the same time, the United Kingdom is progressing towards its legally binding target of achieving net zero greenhouse gas emissions by 2050. Decarbonisation strategies in the building sector emphasise fabric-first retrofitting, increased airtightness, electrification of heating systems, and low-carbon standards for new construction (Ministry of Housing, Communities and Local Government, 2025). While these strategies are essential for reducing emissions, they may unintentionally increase overheating risks if future climate conditions are not adequately incorporated into building design, retrofit programmes, and regulatory frameworks (Lomas, 2021).

This potential for maladaptation represents a critical challenge. Current building regulations and energy demand policies remain insufficiently aligned with mid-century climate projections. Consequently, mitigation measures designed to reduce emissions may inadvertently amplify climate-related health risks. Recent modelling suggests that up to 90% of homes in England may experience overheating risk by the mid-2030s under projected climate conditions (Bouhi et al., 2022). Addressing this challenge requires integrated approaches that align climate mitigation strategies with heat resilience and public health protection.

Extreme heat is not experienced equally across society. Heat-related risks are shaped by a combination of demographic, socioeconomic, environmental, and infrastructural factors. Socioeconomic inequalities further influence vulnerability through differences in housing quality, energy affordability, access to cooling, and the capacity to modify indoor environments (Wrotek et al., 2025; Climate Change Committee, 2022). Urban form and land cover also play a critical role, with dense urban areas and limited access to green space intensifying heat exposure through the urban heat island effect (Silva et al., 2026). These intersecting drivers of exposure and vulnerability highlight the need for systemic approaches that address the built environment, public health, and social inequality simultaneously.

This paper introduces HEARTH, a newly established five-year, £7.4 million (€8.6 million) national research hub. HEARTH is one of seven transdisciplinary research hubs funded by UK Research and Innovation (UKRI) and the National Institute for Health and Care Research (NIHR) as part of a £42 million initiative to ensure that the UK's transition to net zero protects and promotes physical and mental health. HEARTH focuses specifically on the intersection of extreme heat, health inequalities, and the net zero transition. The hub adopts a stakeholder-led, whole-systems, mixed-methods research framework that integrates expertise from climate science, building engineering, public health, social science, and economics.

HEARTH focuses on populations most at risk and those living or working in confined or institutional environments. The research programme integrates advanced climate modelling across multiple spatial scales, from regional and urban climate projections to neighbourhood, building, and indoor environments. These modelling approaches are combined with empirical monitoring of heat exposure, occupant behaviour, and physical and mental health outcomes. Through this integrated approach, HEARTH evaluates the health, equity, and economic impacts of a range of interventions, including building retrofit strategies, climate-resilient new construction, and nature-based cooling solutions.

VULNERABLE POPULATIONS AND HIGH-RISK SETTINGS

HEARTH focuses on populations disproportionately affected by extreme heat due to a combination of physiological susceptibility, social vulnerability, and environmental constraints. Indoor overheating represents a particularly significant health risk because the majority of heat exposure occurs indoors. Studies indicate that most heat-related fatalities occur within buildings (Quinn et al., 2014), where individuals spend more than 80% of their time, and older adults up to 90% (Almeida-Silva et al., 2014). As a result, indoor environments play a critical role in shaping population exposure to extreme heat and represent a key focus for intervention.

VULNERABLE POPULATION GROUPS

Evidence suggests that indoor overheating can become a potentially fatal hazard for the most heat-vulnerable groups, including older adults, individuals with chronic health conditions, and socioeconomically disadvantaged populations (Kenny et al., 2024). Understanding the specific vulnerabilities of these groups is therefore essential for designing effective adaptation strategies and informing equitable climate resilience policies.

Older adults

Older adults are consistently identified as one of the population groups most vulnerable to extreme heat. Ageing is associated with physiological changes that reduce thermoregulatory capacity, including diminished sweating responses, impaired thirst perception, and reduced cardiovascular efficiency (Núñez-Rodríguez et al., 2025). These changes can limit the body's ability to dissipate heat and maintain thermal equilibrium during periods of high temperature.

Research has shown that the cardiovascular response to heat in older individuals involves a reduced ability to pump and redistribute blood to the skin, increasing strain on the heart (Hale, 1997). This can exacerbate existing cardiovascular or respiratory conditions and increase the risk of heat-related mortality (Kenney et al., 2014). In the United Kingdom, the growing proportion of older adults, particularly those living in care or nursing homes, represents a significant public health concern during heatwaves (Hajat et al., 2007). Evidence from previous heat events indicates that hospital admissions during heatwaves are disproportionately concentrated among individuals aged over 75 (Paterson and Godsmark, 2020). Furthermore, gender differences have been observed, with heat-related mortality risks found to be higher among women than men in older age groups (Hajat et al., 2007).

Individuals with chronic health conditions

Individuals living with chronic health conditions are also at increased risk during extreme heat events. Conditions such as hypertension, diabetes, cardiovascular disease, and respiratory illness can heighten physiological stress during heat exposure (Meade et al., 2023). Epidemiological studies have shown that mortality risks during heatwaves increase among individuals with cardiovascular and pulmonary disease, with reported increases in mortality of 2.48% and 1.61% respectively (Paterson and Godsmark, 2020). In addition, many medications used to treat chronic illnesses can interfere with thermoregulation, fluid balance and/or impair sweating, increasing the risk of dehydration (ibid). These physiological and pharmacological factors together increase susceptibility to heat stress.

Pregnant women and infants

Pregnant women and infants represent additional population groups with elevated vulnerability to extreme heat. Heat exposure during pregnancy has been associated with increased risks of preterm birth (Chersich et al., 2020), low birth weight, and a range of maternal health complications (Wyrwoll, 2023). These risks are likely to increase as extreme heat events become more frequent.

Infants are also particularly susceptible to heat-related illness due to immature thermoregulatory systems and limited capacity to regulate their own environmental conditions. Unlike adults, infants depend entirely on caregivers to maintain adequate hydration and manage their surrounding thermal environment (van de Kamp and Daanen, 2025). However, evidence on the specific environmental contexts in which infant heat vulnerability is greatest remains limited.

Socioeconomically disadvantaged households

Socioeconomic inequalities further shape vulnerability to extreme heat. Households experiencing energy poverty often lack the resources required to maintain safe indoor temperatures during periods of extreme heat. While fuel poverty has traditionally been associated with winter heating needs, there is increasing recognition that cooling requirements must also be considered within definitions of energy poverty in warming climates (Sanchez-Guevara et al., 2019).

Empirical research examining overheating risk in English dwellings indicates that certain housing types and tenure groups are particularly exposed. Analysis of more than 11,000 households suggests that privately or socially rented flats built between 1965 and the present, particularly those classified as non-decent homes and occupied by households in the lowest income quintile, are most likely to experience overheating (Zhang et al., 2025). These findings highlight the intersection between housing quality, socioeconomic disadvantage, and heat vulnerability.

Institutional and confined environments

Individuals living or working in institutional settings face additional risks due to limited control over their thermal environments. In such contexts, occupants often have restricted ability to modify indoor conditions, adapt behaviours, or access cooling strategies.

Prisons represent a particularly challenging environment. Security restrictions may limit access to natural ventilation, fans, thermostats, or other cooling measures. Prisoners typically spend extended periods in their cells—on average approximately 19 hours per day—which can result in prolonged exposure to elevated indoor temperatures (Dogbeh et al., 2015). Research suggests that prisoners may therefore have a lower upper thermal comfort limit than populations for whom conventional comfort standards were developed.

Similar constraints have been documented in care settings, where residents frequently have limited autonomy over their environment and depend on staff to manage thermal conditions (Brown and Walker, 2008). These structural limitations highlight the need for targeted interventions and building design strategies that prioritise heat resilience in institutional environments.

VULNERABLE SETTINGS UNDER INVESTIGATION

The intersecting physiological, social, and environmental vulnerabilities described above highlight the importance of understanding where and how heat exposure occurs in everyday environments. While population characteristics influence susceptibility to heat stress, the built environment largely determines the intensity and duration of exposure. Because individuals

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spend most of their time indoors, building characteristics, housing quality, urban context, and the degree of environmental control available to occupants strongly influence indoor thermal conditions during extreme heat events.

Certain building types and environments may therefore amplify or mitigate heat exposure, particularly for populations with limited capacity to modify their surroundings. Institutional settings, high-density housing, and poorly adapted buildings can act as critical nodes of heat risk within urban systems. Understanding the thermal performance of these environments, and how they interact with occupant vulnerability, is essential for identifying effective climate adaptation strategies.

To address these challenges, HEARTH examines more than 200 case study sites across four principal settings: homes, care settings, hospitals, and prisons (Figures 1–4). These environments represent locations where high heat exposure coincides with heightened health vulnerability and where the net zero transition may influence building performance and energy use. The research integrates multi-scale climate modelling, empirical indoor monitoring, and health outcome analysis to evaluate overheating risks and adaptation pathways across these settings.

Homes

Private homes represent the primary environment in which heat exposure occurs. During the 2022 heatwave, deaths in private homes were 11.6% above average, compared with 9.2% in care homes and 5.8% in hospitals, highlighting the central role of residential environments in heat-related mortality (Office for National Statistics and UK Health Security Agency, 2022).

HEARTH will evaluate the interaction between extreme heat, mitigation measures, and adaptation strategies across different housing tenures and typologies, including private rented housing, owner-occupied dwellings, and social housing. Building types will range from detached homes to high-rise flats, while neighbourhood-scale analysis will consider urban heat island effects.

Overheating risks in housing are influenced by several factors, including poor ventilation, excessive solar gains, inadequate shading, and limited opportunities for behavioural adaptation. Behavioural adaptation also plays a role in shaping thermal exposure. Qualitative research by Tweed et al. (2015) demonstrated that older residents actively seek microclimates within their homes by adjusting blinds, moving between rooms, or altering daily routines. However, some vulnerable residents may also be unable to modify their indoor environments through ventilation or shading or relocate to cooler spaces during heat events (Gupta and Gregg, 2013). These findings highlight that thermal comfort depends not only on building performance but also on occupant agency and environmental control, suggesting that adaptation strategies should address both physical and behavioural dimensions of overheating.

Figure 1 Examples of home archetypes.

Care settings

Care settings represent a particularly critical environment because they house some of the most physiologically vulnerable individuals in society. Residents of residential care homes, nursing homes, and extra-care housing are typically older adults with multimorbidity, reduced mobility, and increased sensitivity to heat stress.

HEARTH will assess how building design, operational practices, and adaptation measures influence overheating risk and health outcomes across these settings. The research will

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evaluate the impacts of extreme heat and the net zero transition on resident wellbeing, staff working conditions, and building performance.

Early evaluations of extra-care housing in England identified several environmental shortcomings. Barnes et al. (2011) found that overheating was particularly problematic for residents with limited mobility who were unable to move to cooler areas. Further operational challenges in managing indoor temperatures include conflicting thermal comfort preferences between staff and residents, limited access to environmental controls, and lack of awareness among staff regarding overheating risks or heatwave response procedures (Gupta et al., 2016; Gupta and Howard, 2020). Monitoring in these studies have also reported persistent overheating, with indoor temperatures frequently exceeding 30°C and night-time bedroom temperatures remaining above daytime levels.

Building design features can further exacerbate these risks. Limited cross-ventilation, sealed windows, and safety practices such as keeping bedroom doors closed overnight restrict nocturnal cooling. Thermal modelling suggests that by the 2080s, indoor temperatures during heatwaves in some care homes could reach 32–36°C, posing serious health risks for frail residents (Gupta et al., 2021).

Figure 2 Examples of care settings.

Hospitals

Hospitals represent complex environments in which climate resilience must be balanced with strict clinical and operational requirements. HEARTH will investigate overheating risks across acute hospitals, community hospitals, and mental health facilities, examining how extreme heat interacts with patient vulnerability and building performance.

Hospitals face dual challenges during heat events. Patients may be highly susceptible to heat stress due to illness, age, or medical treatment, while healthcare facilities must maintain controlled indoor conditions for infection prevention and clinical safety. Retrofitting ageing hospital estates without compromising these requirements presents a significant challenge.

Evidence indicates that overheating risks are already widespread across the National Health Service estate. Approximately 90% of UK hospitals are considered at risk of overheating (Betts and Brown, 2021; Climate Change Committee, 2022). In 2021–2022, NHS England recorded 5,554 overheating incidents, representing a substantial increase over previous years (HM Government, 2022).

Extreme heat also affects healthcare delivery. In England, in-patient mortality rates have been shown to increase by 6–26% during heatwave periods (Thompson et al., 2022). In addition, operational disruptions have been reported, with nearly one in five UK doctors reporting cancellation of elective procedures during the 2022 heatwave due to overheating or staff shortages (GreenSurg Collaborative, 2023).

Figure 3 Examples of hospital settings (aerial photo (centre) from Google maps 2026).

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Prisons

Prisons represent another high-risk institutional environment due to a combination of structural constraints, high occupancy densities, and limited occupant autonomy. HEARTH will examine overheating risks across multiple prison typologies, including closed prisons, ageing Victorian-era facilities, and overcrowded wings. Thermal conditions in prisons are often shaped by restricted ventilation, security requirements, and limited opportunities for behavioural adaptation. Prisoners typically have little control over their thermal environment, including access to windows, fans, or temperature controls.

Prisoners are also more likely than the general population to experience chronic physical and mental health conditions that increase sensitivity to temperature extremes (Holt, 2015). Approximately 70% of prisoners meet diagnostic criteria for two or more mental health conditions (House of Commons Justice Committee, 2021). Many prisoners experience multiple overlapping vulnerabilities. A high prevalence of complex physical and mental health comorbidities and the medications used to treat these conditions put prisoners at heightened risk.

The ageing prison population further compounds this risk. In the United Kingdom, the number of prisoners aged over 50 has increased by more than 150% over the past two decades (Sturge, 2021). Older prisoners are more likely to experience chronic illness, reduced thermoregulatory capacity, mobility limitations and increased sensitivity to heat exposure, which may heighten vulnerability during extreme heat events. Women in prison may face additional vulnerabilities, including higher rates of chronic illness, trauma histories, and mental health conditions (Swavola et al., 2016). Extreme environmental conditions may therefore exacerbate both physical and psychological health risks in incarcerated populations.

Figure 4 Examples of prison settings (all aerial photos from Google maps 2026).

Cross-setting synthesis

Across the four environments examined by HEARTH several common mechanisms influence heat exposure and vulnerability as shown in Figure 5. First, many occupants experience limited control over their thermal environment, whether due to physical frailty, institutional rules, or building design constraints. Second, these environments frequently combine high occupancy densities with limited ventilation, increasing internal heat gains. Third, many occupants exhibit elevated physiological vulnerability, including older age, chronic illness, or medication use that affects thermoregulation.

At the same time, each setting presents distinct adaptation challenges. Housing requires scalable retrofit strategies across diverse building types and tenures. Care homes must balance thermal comfort with resident safety and staffing constraints. Hospitals must maintain strict environmental control while ensuring patient safety. Prisons represent highly constrained environments where security and infrastructure limitations restrict adaptation options.

HEARTH addresses these challenges through an integrated research approach combining multi-scale climate modelling, empirical indoor environmental monitoring, behavioural studies, and health outcome analysis. This approach enables comparative analysis of overheating risk across building types and supports the development of evidence-based adaptation strategies aligned with the net zero transition.

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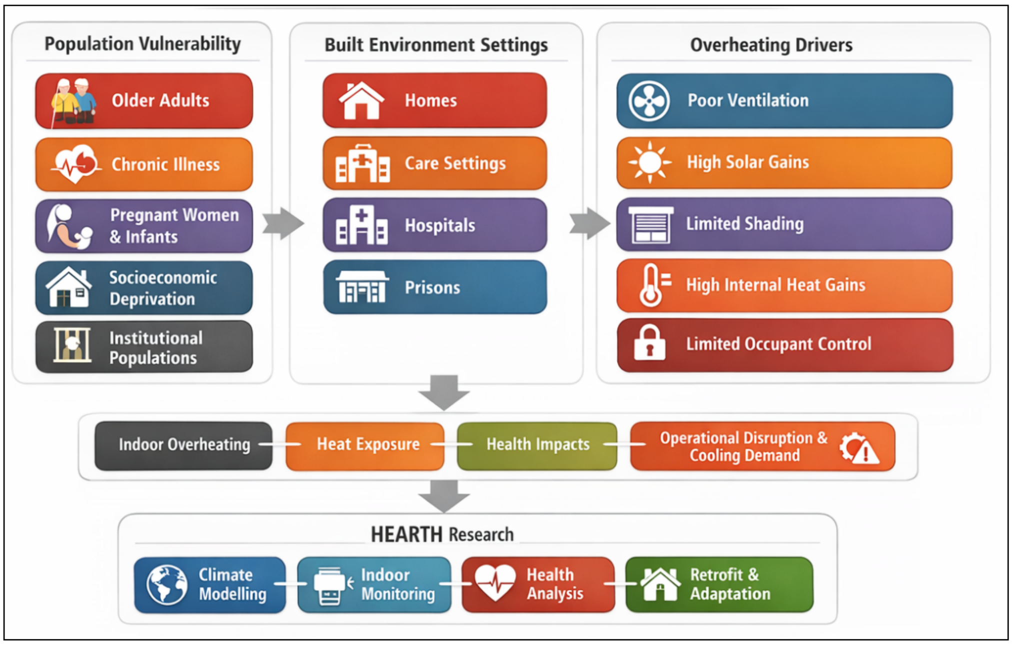

Figure 5 Heat vulnerability across settings investigated by HEARTH.

CONCEPTUAL FRAMEWORK

HEARTH adopts a whole-systems climate–health framework that conceptualises extreme heat risk as the interaction between climate hazards, environmental exposure, population vulnerability, health outcomes, and intervention responses. The framework integrates multiple spatial scales, linking climate projections to indoor heat exposure, human health impacts, and policy-relevant adaptation strategies. It is structured around five interconnected domains: compound heat risk, environmental exposure, population vulnerability, health outcomes, and intervention and solution evaluation. The HEARTH framework diagram (Figure 6) illustrates this pathway from climate projections through environmental exposure and population vulnerability to health outcomes and adaptation solutions.

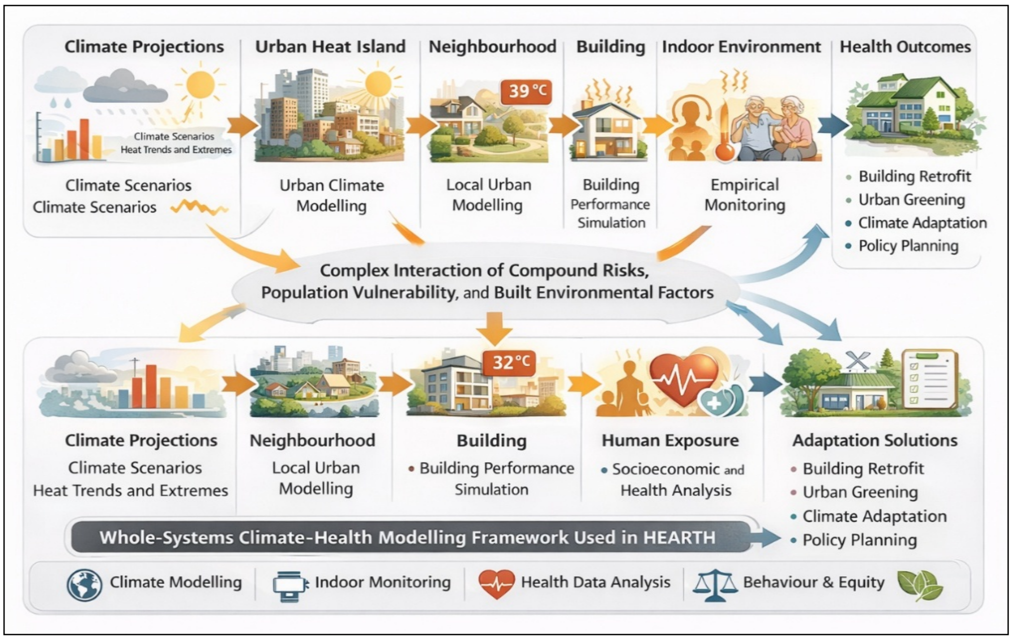

Figure 6 HEARTH whole systems climate–health framework.

Compound heat risk refers to the interaction of extreme heat with other environmental and systemic stressors. Heat events rarely occur in isolation and can generate cascading impacts across infrastructure systems and environmental resources. For example, during the 2022 UK heatwave, drought conditions placed additional pressure on water resources precisely when public demand increased significantly (Mehryar et al., 2025). Such compound interactions illustrate how climate hazards can simultaneously affect multiple sectors, including water supply, energy systems, and public health.

Environmental exposure includes both outdoor and indoor heat environments. Outdoor exposure is influenced by urban heat island effects, land cover, and urban morphology, which can significantly amplify local temperatures (Heaviside et al., 2015). At neighbourhood scale, factors such as building density, vegetation cover, and urban configuration shape microclimatic conditions. Indoor exposure is further determined by building design, materials, ventilation, and operational practices. Poorly adapted buildings may experience prolonged overheating, increasing heat exposure for occupants who spend the majority of their time indoors.

Population vulnerability reflects the social, demographic, and health characteristics that influence susceptibility to heat exposure. These include age, chronic illness, socioeconomic deprivation, and housing conditions. Certain health conditions further increase vulnerability. For instance, individuals with chronic psychiatric conditions—including psychoses, dementia, and substance misuse disorders—are particularly susceptible to heat-related harm (Arbuthnott and Hajat, 2017).

These interacting factors ultimately manifest in physiological and mental health outcomes, including cardiovascular strain, respiratory illness, renal complications, mental health deterioration, and increased mortality. Understanding these pathways is essential for identifying populations and environments at greatest risk.

The final domain concerns intervention and solution evaluation that reduce heat-health risk and reduce or avoid increased emissions (e.g. air conditioning), including building retrofit strategies, climate-resilient urban design, nature-based cooling interventions, and behavioural adaptation measures. The framework also considers interactions between mitigation and adaptation strategies, recognising that poorly designed net zero interventions may inadvertently increase overheating risks if future climate conditions are not adequately considered.

This conceptual structure aligns with established climate–health risk assessment frameworks, including the UK Climate Change Risk Assessment (CCRA3), UKHSA's Weather–Health Alerting System, and NHS Climate Change Risk Assessment tools. By linking climate drivers, environmental exposures, social vulnerability, and health outcomes, the framework supports causal clarity and the development of evidence-based policy responses.

RESEARCH DESIGN

To operationalise the heat-health framework, the HEARTH programme adopts a mixed-methods, multi-scalar research design integrating climate science, building performance analysis, public health research, and social science approaches.

The programme combines:

- Climate modelling to assess future heat risks under different warming scenarios.
- Urban climate and building physics modelling to evaluate overheating risks at neighbourhood and building scales.
- Empirical indoor environmental monitoring across more than 200 sites.
- Health data linkage and epidemiological analysis to examine associations between heat exposure and health outcomes.
- Behavioural and qualitative research to understand occupant responses and institutional practices.
- Economic and equity analysis to evaluate the costs, benefits, and distributional impacts of adaptation strategies.

This integrated approach enables analysis across multiple spatial scales, linking regional climate projections and urban heat island dynamics with building-level exposure and individual health outcomes. By combining modelling, empirical monitoring, and health data analysis, HEARTH provides a comprehensive evidence base for understanding how extreme heat interacts with the built environment and social vulnerability within the context of the net zero transition.

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HEARTH THEORY OF CHANGE

HEARTH's Theory of Change (Figure 7) provides the causal architecture linking scientific evidence generation to improved climate resilience and health equity in the United Kingdom. The framework explains how transdisciplinary research, stakeholder engagement, and integrated data analysis generate evidence that informs policy and practice, ultimately reducing heat-related health risks while supporting the transition to net zero. The approach connects climate hazards, environmental exposure, population vulnerability, health outcomes, and intervention strategies within a single analytical pathway, enabling a comprehensive understanding of how extreme heat affects human health across different environments.

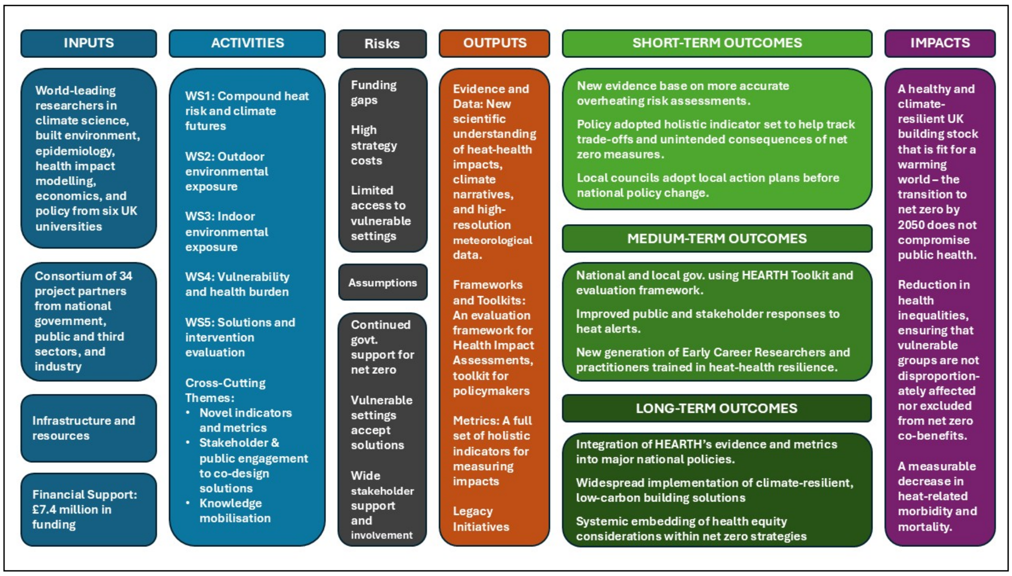

Figure 7 HEARTH Hub Theory of Change diagram.

INPUTS: TRANSDISCIPLINARY CAPACITY AND INFRASTRUCTURE

The HEARTH programme is built upon a transdisciplinary consortium that integrates expertise in climate science, building physics, epidemiology, public health, economics, and social science. Partnerships extend across universities, government agencies, the NHS, housing providers, care organisations, and community groups. These collaborations are supported by access to advanced climate and building modelling infrastructure, environmental monitoring technologies, environmental chambers, and linked health datasets.

Together, these resources provide the capacity to investigate compound heat risks, environmental exposure pathways, population vulnerability, and intervention effectiveness. The programme focuses on five geographically diverse study areas—Brighton, London, Oxfordshire, Leeds–Bradford, and Edinburgh—which collectively represent a latitudinal transect of the United Kingdom's climate as well as a diversity of urban, suburban, rural, coastal, and inland environments.

ACTIVITIES: INTEGRATED CLIMATE–HEALTH RESEARCH

Compound heat risk and climate futures

The programme first establishes the hazard context within which exposure and vulnerability occur. High-resolution weather and climate scenarios are developed to characterise extreme heat events and co-occurring hazards under different climate mitigation pathways, including net-zero futures. The analysis integrates downscaled regional climate projections, urban heat island modelling, socio-spatial risk mapping, and future energy demand modelling. Multi-scalar climate modelling across regional, urban, and neighbourhood scales enables the assessment of compound heat risks under both 2°C and 4°C warming scenarios, thereby defining the macro-climatic and systemic conditions shaping subsequent exposure and health impacts. Metrics for temperature extremes will be evaluated through stakeholder workshops.

Key outputs include new climate scenarios, datasets describing co-occurring climate extremes, and methodological advances for heat-health monitoring and early warning systems. The work

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also generates stakeholder-informed metrics for extreme heat and cold events and humidity indicators tailored to vulnerable indoor settings. Together, these outputs contribute to the development of a holistic indicator framework linking climate, health, and economic data to assess the trade-offs and unintended consequences of net-zero policies.

Outdoor environmental exposure

The programme then quantifies spatial variation in outdoor heat exposure from city to neighbourhood scales to understand interactions between climate processes and the built environment. Urban heat exposure is influenced by urban morphology, surface materials and albedo, building density, and the distribution of green and blue infrastructure. Microclimate modelling, remote sensing, and empirical environmental measurements are used to quantify variation in heat intensity, duration, and cumulative exposure across diverse urban typologies.

Outputs include meteorological datasets derived from urban environmental models for the five case-study cities; analysis of the cooling impacts of urban greening and building design interventions; nationally aggregated data from citizen weather stations addressing urban monitoring gaps; spatial maps of green infrastructure characteristics and associated health benefits; and integrated maps combining heat exposure with social and demographic vulnerability. These outputs provide the evidence base required for HEARTH decision-support tools and evaluation frameworks designed to assist national and local governments in prioritising equitable and effective climate adaptation strategies.

Indoor environmental exposure

Because individuals spend most of their time indoors, indoor environments represent the primary locus of heat-health risk. The programme therefore characterises indoor exposure pathways by empirically measuring physical and mental health impacts associated with indoor heat exposure among high-risk populations living or working in residential and institutional environments.

This analysis combines building energy simulation, dynamic thermal modelling of retrofit and new-build archetypes under future climate scenarios, continuous monitoring of temperature, humidity and carbon dioxide, and wearable exposure sensors. In addition, questionnaires and focus groups with occupants, and semi-structured interviews and workshops will be performed to capture behavioural analysis of occupant practices such as window opening, shading use and occupancy patterns, staff and operational practices and constraints. A mixed-methods approach, including quantitative and qualitative fieldwork questionnaires and interviews, to understand occupants' thermal comfort experience and habits in their living environment has precedent (Attia, 2020; Gupta et al., 2016).

By linking regional climate projections with building-level modelling and empirical monitoring, the programme demonstrates how macro-scale warming translates into lived indoor heat exposure across homes, care homes, hospitals and prisons. Outputs include longitudinal datasets of indoor environmental conditions, physiological data capturing core body temperature, skin temperature and cardiovascular strain via non-invasive wearables, and qualitative insights from semi-structured interviews with residents, patients, and operational staff. These datasets establish a robust empirical evidence base on overheating risks and inform heat-stress prevention guidance for vulnerable groups.

Vulnerability and health burden

Environmental exposure data are subsequently integrated with health indicators to quantify differential vulnerability and heat-related health burden. Linked health datasets—including hospital admissions, primary care records, mental health indicators, and wellbeing surveys—are analysed to examine relationships between heat exposure and cardiovascular, respiratory, renal, metabolic, and mental health outcomes. Workshops will be held to identify theories of systemic and behaviour change used in policy/practice and evidence of effectiveness along multiple dimensions including cost and equity, identify enablers of and barriers to implementation, including evidence on implementation processes, public acceptability and cost-effectiveness.

Equity-sensitive analyses assess how heat risks are distributed across socioeconomic groups and vulnerable settings, enabling identification of populations and environments where intervention is most urgent. Outputs include health impact assessment frameworks for evaluating climate interventions, economic analyses incorporating Disability-Adjusted Life Years (DALYs) and NHS cost estimates, and integrated health-risk metrics capturing multi-sectoral policy impacts on specific population groups. These outputs support evidence-based recommendations for reducing health inequalities within climate adaptation policies.

Solutions and intervention evaluation

The programme evaluates both existing and future net-zero interventions to determine whether they reduce overheating risk while delivering health and carbon co-benefits. Interventions assessed include building fabric retrofit strategies, passive cooling and solar shading measures, ventilation optimisation, nature-based cooling solutions, and climate-resilient new-build standards. To inform the development of evidence-based recommendations for policymakers, estate managers and practitioners, stakeholder engagement and practice-based workshops will be undertaken throughout the programme. Each intervention is evaluated using a multidimensional framework incorporating reductions in overheating hours, implications for winter energy demand, carbon emissions performance, health co-benefits, distributional equity, and cost-effectiveness. Outputs include evidence on the effectiveness and limitations of current heat mitigation measures, simulation results for retrofit strategies under future climate scenarios, and a comprehensive database of intervention impacts on temperature exposure, thermal comfort, energy consumption, and greenhouse gas emissions. These findings inform guidelines for climate-resilient, low-carbon buildings and support evidence-based decision making by policymakers and practitioners.

OUTPUTS: INTEGRATED EVIDENCE GENERATION

Refer to the activities above for key outputs. Together, these outputs provide policymakers, practitioners, and other stakeholders with robust evidence to support risk assessment, intervention prioritisation, and climate-resilient planning.

Dissemination activities will include policy briefs, primary datasets and other published work. Fully anonymised data and associated metadata will be made openly accessible via the UK Data Service no later than the publication of the main findings of the project. Furthermore, an open-access online platform will be created to share study results, methodologies, summary datasets, and digital outputs.

OUTCOMES: POLICY AND PRACTICE TRANSLATION

In the short term, the programme will establish a robust empirical evidence base on overheating risks and heat-health impacts across vulnerable environments, including homes, care settings, hospitals, and prisons. Integrated datasets linking climate, environmental, and health indicators will support improved risk assessment and contribute to the development of heat-health monitoring and early-warning systems.

In the medium term, the evidence generated through the programme is expected to support the adoption of HEARTH decision-support tools and evaluation frameworks by national and local governments. These tools will assist policymakers in identifying effective and equitable climate adaptation strategies, improving responses to heat alerts, and strengthening professional capacity in climate–health resilience.

IMPACTS

In the long term, the HEARTH programme aims to influence national climate and health policy frameworks, including future Climate Change Risk Assessments and National Adaptation Programmes. The programme will support the widespread implementation of climate-resilient, low-carbon building solutions while embedding health equity considerations within net zero strategies.

The ultimate impact of the HEARTH Theory of Change is the creation of a climate-resilient built environment and a health system better equipped to manage the risks of extreme heat. By reducing heat-related morbidity and mortality and addressing underlying social inequalities, HEARTH contributes to a net zero transition that safeguards the health of populations most vulnerable to climate change.

DISCUSSION

A central contribution of HEARTH lies in its explicit integration across spatial, disciplinary, and policy scales. The programme links regional climate projections, urban and neighbourhood microclimates, building archetypes and indoor thermal environments, individual-level exposure and behaviour, clinical outcomes and health service utilisation, and the modelling and evaluation of real-world adaptation solutions. This multi-scalar integration is essential for understanding how global climate trajectories translate into indoor overheating risk and, ultimately, into differential health outcomes. By combining climate modelling, building physics simulation, empirical environmental monitoring, and epidemiological analysis, HEARTH moves beyond siloed assessments of overheating to establish causal pathways from compound climate hazards to measurable health burdens.

Future research should further refine compound risk modelling to incorporate interacting environmental and infrastructural stressors, including air pollution, humidity, power outages, water scarcity, and concurrent extreme events. Integrating modelling of energy system resilience and healthcare system capacity would improve understanding of cascading risks during prolonged heatwaves. There is also a need to develop probabilistic, scenario-based modelling approaches that capture uncertainty across climate trajectories, behavioural responses, and socioeconomic change. Embedding these approaches within policy-relevant decision frameworks will strengthen anticipatory adaptation planning.

Although significant progress has been made in modelling overheating risk, several knowledge gaps remain. Future research should establish exposure thresholds that better reflect health-relevant indoor conditions; examine behavioural adaptation limits among vulnerable populations; investigate interactions between indoor heat, humidity, and indoor air quality; and assess thermal risk in high-occupancy institutional settings. Longitudinal monitoring across multiple heat seasons will be particularly important for capturing behavioural change, adaptation fatigue, and cumulative health impacts.

As building decarbonisation accelerates, additional research priorities include evaluating long-term retrofit performance under extreme heat conditions, analysing the interaction between electrification of heating systems and summer peak electricity demand, and examining trade-offs between airtightness, ventilation, and overheating risk. There is also a need to explore the scalability and effectiveness of nature-based cooling strategies in dense urban environments.

Future work should also strengthen equity-sensitive heat–health analysis by integrating granular socioeconomic data, assessing medication-related heat sensitivity, examining mental health impacts in confined environments, and analysing differential exposure across tenure types and housing quality. Economic evaluation frameworks should increasingly incorporate avoided healthcare costs and distributional impacts, thereby strengthening the evidence base for climate–health co-benefits. Integrating qualitative lived-experience research with quantitative health datasets will also improve understanding of behavioural responses, coping strategies, and structural constraints.

Finally, a critical future direction lies in the institutional embedding of integrated heat–health indicators within building regulation frameworks, NHS estate strategies, local authority adaptation planning, and national adaptation programmes. The standardisation of resilience metrics and their alignment with statutory monitoring and reporting systems will be essential to ensure sustained policy impact beyond the lifetime of individual research initiatives.

CONCLUSION

Extreme heat is emerging as a defining public health challenge of the net zero transition. The excess mortality observed during the 2022 UK heatwave highlighted misalignments between climate mitigation policies, building regulations, infrastructure resilience, and health protection systems. As the building sector accelerates fabric-first retrofits, increased airtightness, electrification of heating systems, and low-carbon construction, failure to incorporate future climate projections and health equity considerations risks intensifying indoor overheating and widening existing health inequalities.

HEARTH addresses this challenge through a whole-systems research framework that integrates compound climate risk, environmental exposure, population vulnerability, health outcomes, and intervention evaluation. By combining climate modelling, building physics simulation, empirical monitoring, epidemiological analysis, behavioural research, and economic evaluation, the programme establishes causal pathways linking macro-scale climate change to individual-level heat exposure and health impacts.

The programme places particular emphasis on populations most vulnerable to extreme heat, including socioeconomically disadvantaged households, and people living or working in institutional environments such as care homes, hospitals, and prisons. In doing so, HEARTH reframes overheating not simply as a building performance issue but as a driver of health inequality embedded within broader socio-ecological systems.

Through the development of integrated heat–health indicators, equity-sensitive evaluation frameworks, and co-produced decision-support tools, HEARTH aims to ensure that scientific evidence informs policy and practice. As part of the wider UKRI–NIHR programme placing health at the centre of net zero strategies, the hub contributes to aligning climate action with population wellbeing. As we are addressing some of the most vulnerable people in society, we propose that the approach presented here could be applied to almost any other social group or region. However, the approach is likely limited to the building sector regarding the intersection of climate risk, mitigation and adaptation.

Ultimately, achieving net zero must be assessed not only by reductions in greenhouse gas emissions but also by its capacity to reduce avoidable morbidity and mortality, protect vulnerable populations, and strengthen health system resilience. HEARTH provides an evidence-based pathway for embedding health equity within climate mitigation and adaptation strategies, supporting a climate-resilient net zero transition in a warming UK.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **PowerPoint Slides.** PowerPoint Slides relating to this article. URI: https://eceeeproceedings.org/articles/110/files/6a6340e3ebd36.pdf

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The authors have no competing interests to declare.

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AUTHOR AFFILIATIONS

Rajat Gupta orcid.org/0000-0001-8959-0251
Oxford Brookes University, Oxford, UK

Anna Mavrogianni orcid.org/0000-0002-5104-1238
University College London, London, UK

Cathryn Birch orcid.org/0000-0001-9384-2810
University of Leeds, Leeds, UK

Clare Heaviside orcid.org/0000-0002-0263-4985
University College London, London, UK

Mike Davies orcid.org/0000-0003-2173-7063
University College London, London, UK

Ruth Doherty orcid.org/0000-0001-7601-2209
University of Edinburgh, Edinburgh, UK

Shakoor Hajat orcid.org/0000-0002-3086-362X
London School of Hygiene & Tropical Medicine, London, UK

Amr Hamada orcid.org/0000-0002-2564-3809
University College London, London, UK

Andrew Ibbetson orcid.org/0000-0001-6238-3455
University College London, London, UK

Andrew Schurer orcid.org/0000-0002-9176-3622
University of Edinburgh, Edinburgh, UK

Bhargav Macha orcid.org/0009-0005-0411-5985
University College London, London, UK

Carly Reddington orcid.org/0000-0002-5990-4966
University of Leeds, Leeds, UK

Cheng Cui orcid.org/0000-0002-4230-4753
University College London, London, UK

Chengyang Wu orcid.org/0009-0007-0786-7968
University College London, London, UK

Dale Hoyland
Oxfordshire County Council, UK

Emer O'Connell orcid.org/0000-0002-9887-5731
Greater London Authority, UK

Gesche Huebner orcid.org/0000-0002-1304-4366
University of Exeter, Exeter, UK

Giandomenico Vurro orcid.org/0000-0002-1909-8787
University College London, London, UK

Giorgos Petrou orcid.org/0000-0002-1524-2681
University College London, London, UK

Hannah Marshall orcid.org/0009-0009-3345-6841
London School of Hygiene & Tropical Medicine, London, UK

Hugh Waddington orcid.org/0000-0003-3859-3342
London School of Hygiene & Tropical Medicine, London, UK

James Milner orcid.org/0000-0003-0304-639X
London School of Hygiene & Tropical Medicine, London, UK

Lauren Davis orcid.org/0000-0001-6504-4416
Sussex Community NHS Foundation Trust, UK

Lizzy Curtis
Oxfordshire County Council, UK

Madalena Vaz Monteiro
Forest Research, UK

Matt Gregg orcid.org/0000-0001-6009-991X
Oxford Brookes University, Oxford, UK

Peninah Murage orcid.org/0000-0002-4506-0897
London School of Hygiene & Tropical Medicine, London, UK

Sahar Zahiri orcid.org/0000-0001-7618-860X
Oxford Brookes University, Oxford, UK

Sadie Boniface orcid.org/0000-0003-3492-6402
University College London, London, UK

Sari Kovats orcid.org/0000-0002-4823-8099
London School of Hygiene & Tropical Medicine, London, UK

Susan Michie orcid.org/0000-0003-0063-6378
University College London, London, UK

Susie Vernon orcid.org/0009-0004-2674-1103
Sussex Community NHS Foundation Trust, UK

Yuanhong Zhao orcid.org/0000-0002-8099-4652
Oxford Brookes University, Oxford, UK

REFERENCES

Almeida-Silva, M, Wolterbeek, HT and **Almeida, S.** 2014. 'Elderly exposure to indoor air pollutants'. *Atmospheric Environment*, 85: 54–63. DOI: https://doi.org/10.1016/j.atmosenv.2013.11.061

Arbuthnott, KG and **Hajat, S.** 2017. 'The health effects of hotter summers and heat waves in the population of the United Kingdom: a review of the evidence'. *Environmental health*, 16: 119. DOI: https://doi.org/10.1186/s12940-017-0322-5

Attia, S. 2020. 'Spatial and behavioral thermal adaptation in net zero energy buildings: An exploratory investigation'. *Sustainability*, 12(19): 7961. DOI: https://doi.org/10.3390/su12197961

Barnes, S, Torrington, J, Darton, R, Holder, J, Lewis, A, McKee, K, Netten, ANN and **Orrell, A.** 2011. 'Does the design of extra-care housing meet the needs of the residents? A focus group study'. *Ageing and Society*, 32: 1193–1214. DOI: https://doi.org/10.1017/S0144686X11000791

Betts, RA and **Brown, K.** 2021. *Third UK Climate Change Risk Assessment Technical Report*.

Bouhi, N, Canta, A, Chikte, S, Edwards, M, Fielding, V and **Reynolds, J.** 2022. *Addressing overheating risk in existing UK homes*. London, UK: Climate Change Committee (CCC).

Brown, S and **Walker, G.** 2008. 'Understanding heat wave vulnerability in nursing and residential homes'. *Building Research & Information*, 36: 363–372. DOI: https://doi.org/10.1080/09613210802076427

Chersich, MF, Pham, MD, Areal, A, Haghighi, MM, Manyuchi, A, Swift, CP, Wernecke, B, Robinson, M, Hetem, R, Boeckmann, M, Hajat, S, Climate, C and **Heat-Health Study, G.** 2020. 'Associations between high temperatures in pregnancy and risk of preterm birth, low birth weight, and stillbirths: systematic review and meta-analysis'. *BMJ*, 371: m3811. DOI: https://doi.org/10.1136/bmj.m3811

Climate Change Committee. 2019. *Heat and Preventable Deaths in the Health and Social Care System*. London: Climate Change Committee (CCC).

Climate Change Committee. 2022. *Risks to health, wellbeing and productivity from overheating in buildings*. London: Climate Change Committee (CCC).

Dogbeh, A, Jomaas, G, Bjarløv, SP and **Toftum, J.** 2015. 'Field study of the indoor environment in a Danish prison'. *Building and Environment*, 88: 20–26. DOI: https://doi.org/10.1016/j.buildenv.2014.10.025

GreenSurg Collaborative. 2023. 'Elective surgical services need to start planning for summer pressures'. *Br J Surg*, 110: 508–510. DOI: https://doi.org/10.1093/bjs/znad033

Gupta, R and **Gregg, M.** 2013. 'Preventing the overheating of English suburban homes in a warming climate'. *Building Research & Information*, 41: 281–300. DOI: https://doi.org/10.1080/09613218.2013.772043

Gupta, R and **Howard, A.** 2020. *ClimaCare report: Five London care homes*. Oxford: Oxford Brookes University.

Gupta, R, Howard, A, Davies, M, Mavrogianni, A, Tsoulou, I, Jain, N, Oikonomou, E and **Wilkinson, P.** 2021. 'Monitoring and modelling the risk of summertime overheating and passive solutions to avoid active cooling in London care homes'. *Energy and Buildings*, 252. DOI: https://doi.org/10.1016/j.enbuild.2021.111418

Gupta, R, Walker, G, Lewis, A, Barnfield, L, Gregg, M and **Neven, L.** 2016. *Care provision fit for a future climate*. York: Joseph Rowntree Foundation.

Hajat, S, Kovats, RS and **Lachowycz, K.** 2007. 'Heat-related and cold-related deaths in England and Wales: who is at risk?' *Occupational and environmental medicine*, 64: 93–100. DOI: https://doi.org/10.1136/oem.2006.029017

Hajat, S, Vardoulakis, S, Heaviside, C and **Eggen, B.** 2014. 'Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s'. *J Epidemiol Community Health*, 68: 641–648. DOI: https://doi.org/10.1136/jech-2013-202449

Hale, B. 1997. 'Heat stress: the impact on seniors'. *Pennsylvania State University College of Health and Human Development News*. State College.

Heaviside, C, Cai, XM and **Vardoulakis, S.** 2015. 'The effects of horizontal advection on the urban heat island in Birmingham and the West Midlands, United Kingdom during a heatwave'. *Quarterly Journal of the Royal Meteorological Society*, 141: 1429–1441. DOI: https://doi.org/10.1002/qj.2452

HM Government. 2022. *UK Climate Change Risk Assessment 2022*.

HoC Justice Committee. 2021. *Mental health in prison: Fifth Report of Session 2021–22*. London.

Holt, DW. 2015. *Heat in US Prisons and Jails: Corrections and the Challenge of Climate Change*. New York, NY, USA: Sabin Center for Climate Change Law, Columbia Law School. DOI: https://doi.org/10.2139/ssrn.2667260

Kenny, GP, Tetzlaff, EJ, Journeay, WS, Henderson, SB and **O'Connor, FK.** 2024. 'Indoor overheating: A review of vulnerabilities, causes, and strategies to prevent adverse human health outcomes during extreme heat events'. *Temperature (Austin)*, 11: 203–246. DOI: https://doi.org/10.1080/23328940.2024.2361223

Kenney, WL, Craighead, DH and **Alexander, LM.** 2014. 'Heat waves, aging, and human cardiovascular health'. *Medicine and science in sports and exercise*, 46: 1891. DOI: https://doi.org/10.1249/MSS.0000000000000325

Lomas, KJ. 2021. 'Summertime overheating in dwellings in temperate climates'. *Buildings & Cities*, 2. DOI: https://doi.org/10.5334/bc.128

Meade, RD, Notley, SR, Akerman, AP, McGarr, GW, Richards, BJ, McCourt, ER, King, KE, McCormick, JJ, Boulay, P, Sigal, RJ and **Kenny, GP.** 2023. 'Physiological responses to 9 hours of heat exposure in young and older adults. Part I: Body temperature and hemodynamic regulation'. *J Appl Physiol (1985)*, 135: 673–687. DOI: https://doi.org/10.1152/japplphysiol.00227.2023

Mehryar, S, Howarth, C and **Conway, D.** 2025. 'Heat risk interdependencies in the UK: Implications for adaptation'. *Earth's Future*, 13: e2024EF005797. DOI: https://doi.org/10.1029/2024EF005797

Ministry of Housing Communities and Local Government. 2025. *The Future Homes and Buildings Standards: 2023 consultation*. London: Ministry of Housing, Communities and Local Government.

Núñez-Rodríguez, S, Collazo-Riobó, C, Sedano, J, Sánchez-Iglesias, AI and **González-Santos, J.** 2025. 'Heat tolerance in older adults: a systematic review of thermoregulation, vulnerability, environmental change, and health outcomes'. *Healthcare*, MDPI, 2785. DOI: https://doi.org/10.3390/healthcare13212785

Office for National Statistics and UK Health Security Agency. 2022. *Excess mortality during heat-periods: 1 June to 31 August 2022*. London: Office for National Statistics (ONS).

Paterson, SK and **Godsmark, CN.** 2020. 'Heat-health vulnerability in temperate climates: lessons and response options from Ireland'. *Globalization and health*, 16: 1–17. DOI: https://doi.org/10.1186/s12992-020-00554-7

Quinn, A, Tamerius, JD, Perzanowski, M, Jacobson, JS, Goldstein, I, Acosta, L and **Shaman, J.** 2014. 'Predicting indoor heat exposure risk during extreme heat events'. *Science of the total environment*, 490: 686–693. DOI: https://doi.org/10.1016/j.scitotenv.2014.05.039

Sanchez-Guevara, C, Peiró, MN, Taylor, J, Mavrogianni, A and **González, JN.** 2019. 'Assessing population vulnerability towards summer energy poverty: Case studies of Madrid and London'. *Energy and Buildings*, 190: 132–143. DOI: https://doi.org/10.1016/j.enbuild.2019.02.024

Silva, MB, Bressane, A, Almendra, R, Lyra, AM and **Machado, VM.** 2026. 'Urban heat riskscape and green injustice: a scoping review of health and environmental impacts'. *Urban Forestry & Urban Greening*, 129305. DOI: https://doi.org/10.1016/j.ufug.2026.129305

Sturge, G. 2021. *UK Prison Population*. In: Commons, HO (ed.). London: UK Government.

Swavola, E, Riley, K and **Subramanian, R.** 2016. *Overlooked: Women and jails in an era of reform*.

Thompson, R, Landeg, O, Kar-Purkayastha, I, Hajat, S, Kovats, S and **O'Connell, E.** 2022. 'Heatwave Mortality in Summer 2020 in England: An Observational Study'. *Int J Environ Res Public Health*, 19. DOI: https://doi.org/10.3390/ijerph19106123

Tweed, C, Humes, N and **Zapata-Lancaster, G.** 2015. 'The changing landscape of thermal experience and warmth in older people's dwellings'. *Energy Policy*, 84: 223–232. DOI: https://doi.org/10.1016/j.enpol.2015.03.011

van de Kamp, E and **Daanen, H.** 2025. 'Narrative Review on Infants' Thermoregulatory Response to Heat'. *International Journal of Environmental Research and Public Health*, 22: 1265. DOI: https://doi.org/10.3390/ijerph22081265

Wrotek, M, Marginean, I, Boni, Z, Chwałczyk, F, Vicedo-Cabrera, AM, Salvador, C and **Jancewicz, B.** 2025. 'From inequalities to vulnerability paradoxes: juxtaposing older adults' heat mortality risk and heat experiences'. *Environmental Health*, 24: 24. DOI: https://doi.org/10.1186/s12940-025-01179-2

Wyrwoll, CS. 2023. 'RISING STARS: The heat is on: how does heat exposure cause pregnancy complications?' *Journal of Endocrinology*, 259. DOI: https://doi.org/10.1530/JOE-23-0030

Zhang, L, Robinson, C and **Hasova, L.** 2025. 'Housing and household vulnerabilities to summer overheating: A Latent Classification for England'. *Energy Research & Social Science*, 125: 104126. DOI: https://doi.org/10.1016/j.erss.2025.104126

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