Grantham Research Institute on Climate Change and the Environment

Resilient net zero

Exploring low-emission cooling solutions to extreme heat

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Research report

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Contents

List of abbreviations

AWHP: Adverse Weather and Health Plan [UK]

BAME: Black, Asian and Minority Ethnic

Defra: Department for Environment, Food and Rural Affairs [UK]

EEA: European Economic Area

EPA: Environmental Protection Agency [US]

ESMAP: Energy Sector Management Assistance Program

GLA: Greater London Authority

GPSC: Global Platform for Sustainable Cities

HHAP: Heat-Health Action Plan

HSE: Health and Safety Executive [UK]

IFRC: International Federation of Red Cross and Red Crescent Societies

IPCC: Intergovernmental Panel on Climate Change

LCRP: London Climate Ready Partnership

MHCLG: Ministry of Housing, Communities and Local Government [UK]

NHS: National Health Service [UK]

SWEP: Severe Weather Emergency Protocol

TfL: Transport for London

UHI: Urban heat island

UKHSA: UK Health Security Agency

USAID: United States Agency for International Development

WHO: World Health Organization

Summary recommendations for the UK

1. **Give higher prominence to low greenhouse gas emission approaches to enhance heat risk preparedness.** Siloed approaches to heat risk preparedness, prevention and protection fail to provide a full picture of the complexity of the issue. Low-emission responses are needed to ensure effective responses do not make the underlying issue worse, and that unintended consequences and complexities are fully considered.
2. **Implement fully-funded, year-round, complementary low-emission preparedness and responses to heat risk**. Efforts to tackle the impacts of extreme heat and better prepare the UK for these impacts without increasing emissions must be appropriately funded and bring together passive and active measures that are behavioural and/or cultural, institutional, infrastructural and/or technological, and ecosystem- or nature-based. These responses and general preparedness to heat need to be considered as a year-round issue, not just limited to summer periods.
3. **Reduce over-reliance on responsive measures**. Proactive responses to heat risk are needed to enhance low-emission approaches to improve heat risk preparedness and resilience. Behavioural and cultural measures must be rebalanced to enable more room for preparatory and preventative approaches that would reduce an over-reliance on reactive and protective responses.
4. **Identify and integrate 'non-negotiable' elements into measures**. Essential, 'non-negotiable' elements must be identified and carefully integrated into heat preparedness and responses to ensure the use of active responses (such as energy-intensive air conditioning systems) that may result in emissions are part of a broader solution for heat risk preparedness in which those most affected and vulnerable to heat are not put further at risk (e.g. in hospitals, prisons and those in domiciliary care, school and care settings).
5. **Learn from others**. Institutional approaches to low-emission heat preparedness and prevention in the UK must learn from international experience and carefully consider establishing appropriate mechanisms such as Heat Officers and localised Heat Health Action Plans to pre-empt the severity and urgency of heat risk the nation will face during and outside heatwave periods.
6. **Address heat inequalities and unintended consequences**. While effective low-emission cooling measures can be implemented, such as green spaces or urban water parks, if access to these facilities is not equal or fair, or unintended consequences are not properly considered, this can further enhance disparities between vulnerable groups.
7. **Approach heat vulnerability as a dynamic phenomenon**. The way in which vulnerability to heat is determined needs to be reviewed to better prioritise low-emission approaches. Those who are not considered vulnerable to heat could become vulnerable particularly during Level 4 Heat Health Alerts. Although groups most vulnerable to heat are known (and include children under the age of 5, adults over 65, those with underlying health conditions, pregnant women and outdoor workers), research suggests some of these groups (e.g. those over the age of 65) do not tend to identify as vulnerable, which may limit their awareness, knowledge and take-up of behavioural protective measures that can minimise their exposure to heat.
8. **Develop and implement Monitoring, Evaluation, Accountability and Learning (MEAL) standards and practices**. The implementation of heat adaptation and mitigation measures (e.g. behavioural and/or cultural, institutional, infrastructural and/or technological, and ecosystem- or nature-based) need to incorporate monitoring and reporting systems that provide reliable success measures and incorporate information related to emissions and emissions-saving alternatives.

Introduction

This report focuses on the exploration of existing low-emission cooling solutions to extreme heat through the review of international and UK evidence, with a particular focus on London.

- Section 1 focuses on existing active and passive measures for cooling down cities.
- Section 2 provides a snapshot of London, describing existing heat risk profiles, heat mapping exercises, the identification of heat vulnerability at the city level and current local responses to extreme heat from different actors.
- Section 3 addresses existing considerations regarding co-benefits, synergies, trade-offs and conflicts of heat adaptation actions.
- Section 4 presents conclusions and recommendations.
- Case studies of past and ongoing measures to address extreme heat in urban locations worldwide are provided in the Appendix.

1. Measures for cooling in cities: active and passive

The Intergovernmental Panel on Climate Change's (IPCC) *Sixth Assessment Report* (2023) indicates that it is virtually certain that temperature extremes, including heatwaves, have become more frequent and more intense across most regions of the globe. Europe is warming faster than other regions, with temperatures increasing by 2.2°C for the period 2018–2022 compared with 1850–1900; while the global temperature has increased by an average of 1.2°C (European Environment Agency, 2024). The increased frequency, magnitude and duration of heatwaves has been the object of global concern due to their multifaceted impacts on the environment, infrastructure, energy consumption, livelihoods and human health, among other areas.

Increases in global temperature are expected to influence heat exposure and increase cooling demand, which will exacerbate the need for immediate adaptation across different regions (Miranda et al., 2023). In the UK, extreme heat is expected to put additional burdens on the energy and transport sectors, infrastructure, health and care services, and lead to potential crop loss and reductions in air quality (UKHSA, 2023c). Given the significant implications, it is imperative to address and enhance mitigation and adaptation strategies to extreme heat at different levels of governance and across sectors (Zuo et al., 2015). This is a significant and growing challenge, given the complexity of delivering complementary and synergistic adaptation and mitigation actions, which are often influenced by implementation scale, spatial and temporal characteristics, the actors involved, and the range of implementation approaches (Watkiss et al., 2015).

In **temporal** terms, extreme heat adaptation and mitigation strategies broadly follow a disaster planning risk reduction cycle focusing on five interconnected phases (WHO, 2024): longer-term development and planning; preparation before the summer; prevention during the summer ; specific responses to heatwaves; monitoring and evaluation. For instance, this structure underpins the development of Heat Health Action Plans (HHAPs) adopted at the European level, including in the UK (Martinez et al., 2019). In the UK, high temperatures are recognised in the National Risk Register in which a heatwave with temperatures exceeding 35°C (or 40°C in parts of Southeastern, Eastern or Central England) over five consecutive days is considered as a reasonable worst-case scenario risk of natural and environmental hazard that could impact as much as 50–70% of the population (UK Government, 2023). Currently, while at the UK-level there is no unified guidance, responses to prolonged extreme heat are informed by the Third National Adaptation Programme (NAP3) (Defra, 2024), and the Adverse Weather and Health Plan (AWHP) (UKHSA, 2023a).

Such heat events, as established in UK legislation through the Civil Contingencies Act of 2004, are dealt with as an emergency and require the involvement of responders at different levels (Category 1 responders include county councils, district councils, London borough councils, NHS England, and the police; Category 2 responders include among others: utilities and transport sectors and the Health and Safety Executive). A set of Heat-Health Alerts (HHA) action cards (UKHSA, 2023d) and Hot Weather and Health Guidance and Advice (UKHSA, 2023e) identify suggested key actions and those responsible for implementing them. Relevant parties (including national government departments, local authorities, social and health care providers, third sector organisations) are responsible for ensuring appropriate response actions are deployed at the national and local levels to protect and support the public and those most vulnerable during extreme heat.

While health-centred approaches are predominant in high-income developed countries, globally, strategies differ by geographical location and countries' income levels. For example, heat adaptation and mitigation strategies in developing countries focus predominantly on agriculture and livelihoods, and are integrated as part of compounding hazards rather than focusing on extreme heat alone (Turek-Hankins et al., 2021).

Heat mitigation and adaptation: preparedness and response

In general terms, climate change mitigation refers to the act of making the effects of climate change less severe by preventing and reducing greenhouse gas emissions (EEA, 2024). Adaptation, on the other hand, focuses broadly on tackling the negative current and future impacts of climate change. Adaptation leverages anticipation and planning to prevent or minimise negative impacts while also maximising the benefits of potential opportunities (EEA, 2024).

Heat mitigation specifically refers to the action of reducing temperatures by implementing preventive measures, minimising impacts of high temperatures, fostering preparedness, managing response and recovery, and supporting rehabilitation (He et al., 2023). Heat mitigation "translates into overheating attenuation by reducing the number and magnitude of global and local sources of heat, by modulating the causes of heat entrapment (e.g. urban materials and anthropogenic heat), or by leveraging heat sinks and dispersion mechanisms" (Ulpiani et al., 2024, p. 24).

Heat adaptation refers to the alleviation of heat-related vulnerabilities, predominantly taking the form of "changes in behaviours, habits, responsiveness, and awareness to adjust to actual or expected climate conditions and their effects" (Ulpiani et al., 2024, p. 24). Heat adaptation measures look, for example, at increasing a system's (e.g. a city's) capacity to deal with high temperatures by enhancing people's awareness, strengthening heat governance and investing in disaster reduction (He et al., 2023). Heat adaptation measures can be 'hard' and 'soft'; the former refer to infrastructural interventions (upgrading buildings to withstand increased temperatures and protect occupants, setting up active cooling shelters, etc.), and the latter to social and institutional measures (heat awareness education, policies, insurance, etc.) (Rohat et al., 2021). Some heat adaptation measures can also include a mix of both 'hard' and 'soft' actions, such as heatwave early warning systems (Martinez-Juarez et al., 2019).

Many existing urban heat management measures are at the watershed between adaptation and mitigation, including measures aimed at increasing urban albedo or urban green surfaces (Ulpiani et al., 2024). A summary of existing urban heat management measures from the World Bank report Urban Overheating and Adaptation Measures (World Bank, 2024, p. 89) includes:

> "Adaptation measures:
>
> Heat Action Plans: Plans for response to extreme heat events
>
> Cooling Centres: Provide relief during heatwaves, particularly for vulnerable populations
>
> Energy-Efficient Building Standards: Minimize energy use for cooling systems
>
> Mitigation measures:
>
> Tree Planting and Urban Green Spaces: Absorb CO_2 and reduce heat through transpiration
>
> Expansion of Urban Wetlands: Cool areas through evaporation and increase biodiversity

Solar-Powered Street Vendors: Reduce heat generated by cooking with renewable energy

Measures that blend both adaptation and mitigation:

Cool Pavements: Reflect sunlight and reduce heat absorption, lowering local temperatures.

Cooling Microclimate Creation: Use water and vegetation to cool dense urban areas

Vertical Gardens on Freeways: Add greenery to absorb pollution and provide cooling."

Other forms of climate change adaptation and mitigation measures included in the World Bank report include utilising green spaces for increased mental health and wellbeing initiatives (adaptation in relation to natural resources); improving public lighting energy efficiency (adaptation in relation to the built environment and energy); municipal carbon footprint reporting, setting targets for emission reductions (mitigation in relation to the built environment and energy) or creating car free zones (mitigation in relation to the transport sector) (World Bank, 2024). All these examples relate to climate adaptation and mitigation measures, but they do not represent heat-specific adaptation and mitigation measures within the urban heat management domain.

Heat adaptation and mitigation are also used interchangeably in certain cases, which can be confusing. Within the World Bank report cited above, measures related to increasing the albedo of urban surfaces (such as painting roofs with light paint) are categorised as adaptation measures (World Bank, 2024, p. 4) and as mitigation measures and blended measures (World Bank, 2024, p. 89) within the same document.

Heat preparedness and response is considered a form of disaster risk reduction as it aims to put in place measures to reduce impact before, during and after an extreme heat event. Heat preparedness includes a combination of "primary (reducing hazard severity and limiting exposure), secondary (limiting disease development in exposed people), and tertiary (limiting disease progression and palliating symptoms) prevention activities" (Hess et al., 2023, p. 309). In the case of the UK, key actions to address heat-related preparedness and response include initiatives to elicit behaviour change, incorporating heatwave planning within organisations, developing targeted communications and messaging, and providing social support (Howarth et al., 2023a).

In **spatial** terms, extreme heat is exacerbated particularly in urban environments by the urban heat island (UHI) effect, which is characterised by higher temperatures in urban areas compared with less urbanised surrounding areas due to heat absorptive properties of buildings and roads (Oke, 1973, 1978). This, paired with the typically denser populations residing in cities, results in an enhanced risk of extreme heat exposure for urban residents. Over the period 1983–2016, there was an approximate 200% increase in population in cities worldwide, further exposing people to this hazard (Tuholske et al., 2021), resulting in a growing number of measures focusing on increasing urban heat resilience. Urban heat resilience can be understood as "the ability of an urban system and its constituent social, ecological and technical systems across temporal and spatial scales – to maintain or rapidly return to desired functions and improve quality of life in the face of chronic and acute heat risks, and to quickly transform systems that limit current or future capacity to adapt to extreme heat" (Keith and Meerow, 2022, p. 15).

While actions to tackle extreme heat vary, efforts to address the impacts of extreme heat can be grouped into four **categories** (Turek-Hankins et al., 2021):

- Behavioural or cultural
- Institutional
- Infrastructural or technological
- Ecosystem-based (or nature-based)

These actions are often implemented in the first instance by individuals or communities, secondly by governments (at different scales and through different implementing bodies), and finally by other actors including academics, third-sector organisations and the private sector. While the final goal of most measures is to protect human life, actions aim to achieve this by intervening at different **scales**: human (e.g. adopting protective behaviour, hydration), buildings and homes (e.g. shading, insulation), neighbourhoods (e.g. local heat action plans, shading in public places), cities (e.g. green corridors, cooling shelters networks), country (e.g. heat action plans), internationally (e.g. international guidance, communities of practice, information exchange platforms and consortia).

Extreme heat adaptation and mitigation measures are often broadly categorised into **passive** and **active:**

Active	Passive
• In broad terms, measures requiring a mechanical or electrical action that results in energy consumption and greenhouse gas emissions are considered active measures. • These can include: interventions relying on vapour compression cooling technologies, mechanical ventilation systems, absorption cooling systems, and high-pressure misters. • Active measures, such as air conditioners, have proven to be effective to save lives during extreme heat events(Barreca et al., 2012). However, they also lead to local ambient temperature increases which can contribute to higher nighttime temperatures, which is particularly problematic as the human body struggles to cool down at night (Salamanca et al., 2014).	• Passive measures comprise actions that do not require mechanical or electrical input to provide cooling. • They leverage design, materials' characteristics and natural systems' capacity to provide cooling solutions. • Examples of urban passive cooling solutions include urban trees, green roofs, shading and permeable paving (ESMAP, 2020).

Some of the measures presented in this report fall under the 'passive' umbrella while others fall clearly under active measures; however, some measures combine both passive and active solutions within the same action.

Measures to mitigate and adapt to extreme heat in cities

Measures to address extreme heat and increase urban heat resilience in cities focus on actions at different scales, deployed across different temporal stages (long-term planning, pre-heat, during heat, post-heat), and addressing different thematic domains (behavioural or cultural, institutional, infrastructural or technological). Given the complex nature of extreme heat impacts on urban systems, adaptation and mitigation measures can in some instances work hand in hand (e.g. urban forests can contribute to adaptation by providing cooling and stormwater management benefits, while providing shading to buildings and reducing indoor temperatures at the same time as absorbing carbon emissions), or in other cases having contrasting effects (e.g. using air conditioning systems during extreme heat can provide cooling relief, but can also cause increase energy consumption and emissions as well as local ambient temperatures) (Watkiss et al., 2015).

Actions to adapt to and mitigate extreme heat and/or cooling measures are usually organised according to the four categories listed above (behavioural or cultural; institutional; infrastructural or technological; and ecosystem-based or nature-based). However, our assumption is that infrastructure and technological solutions will be an important part of the response to prepare the UK for heat and adapt to it, and hence this report focuses on those solutions that provide opportunities to adopt measures that produce the least amount of emissions.[1]

1.1. Behavioural and cultural measures

Despite the importance of measures addressing behavioural or cultural changes within heat adaptation and mitigation, they have received less attention than other interventions (e.g. infrastructural). This is potentially linked to the high volume of resources, including time, needed to change people's behaviour and the effect being perceived as less tangible (Zuo et al., 2015). Adaptation behaviours (such as self-protection, household and lifestyle changes) are not widespread, and tailored information and advice for individuals and organisations are needed in addition to upstream interventions (such as financial incentives and regulations) that can remove behavioural barriers (CAST, 2023). Nonetheless, behavioural adaptations are among the most effective and cost-effective ways that individuals have to consciously or unconsciously adapt to the surrounding environment; hence the importance of providing individuals with opportunities that facilitate behavioural adjustments (Shooshtarian et al., 2018).

The implementation of prevention strategies aimed at the promotion of lifestyle changes is likely to be more cost-effective than reactive measures while also requiring less energy and hence resulting in a smaller contribution in terms of emissions (Khoslaet al., 2021). Behavioural measures can include advice on food and drink intake, alcohol and recreational drug consumption, garment choices, use of accessories (such as sunglasses or hats), physical activities to avoid or perform, places to go to cool down or avoid overheating (e.g. green shaded spaces or air-conditioned public buildings or cooling shelters), showering/sponging, best practice at work, use of sunscreen, and what to do in case of heat-related illness.

While most behavioural measures focus on protective actions, the sphere of heat-related behavioural responses can include measures aimed at prevention of impacts and heat preparedness, seeking information, lobbying for political actions, addressing climate change, supporting others, and implementing best practice in institutional settings (McLoughlin et al., 2023). Within this, interventions could focus on increasing community members' awareness of extreme heat within vulnerable neighbourhoods, developing leadership to address complex climate issues, and increasing communities' agency to advocate for locally relevant potential heat adaptation solutions (Guardaro et al., 2020). Among the adaptive measures adopted by low-income neighbourhood residents as reported by Palinkas et al. (2022) are the activation of community and family networks to check on others' health and well-being, but also to request support during heatwaves. However, the authors also flagged limitations in the adoption of some behavioural measures due to limited resources at the personal level (e.g. not perceiving oneself to

[1] We provide a note on the study's limitations at the end of Section 4.

be at risk, lacking knowledge), household level (e.g. lacking A/C or considering it too expensive to turn on, inability to modify rented accommodation), and neighbourhood level (e.g. lack of green spaces). Limitations to the adoption of behavioural measures have also been associated with gender stereotypes within certain contexts (Yokoi, 2024). In the case of Japan, Yokoi's findings suggest that the association of umbrellas with women inhibits their use by men as a protective measure during hot weather, for example.

Behavioural measures can also focus on providing guidance on how to react during extreme heat events to cool down people's surroundings or to seek refuge in cool places if people are unable to do so. Measures such as turning off a heating system during warmer months, making sure that non-essential appliances are turned off, ensuring that fridges and freezers are fully functional and hence not using energy unnecessarily, and having access to cool drinks and properly stored food and medicines can ensure people stay cool and comfortable within their own homes (UKHSA, 2024a). For people unable to cool down at home, other suggested measures include seeking refuge in natural shaded places (such as parks or forests), cooler public buildings (e.g. shopping malls, public libraries) or designated cool spaces.

However, warnings have been raised about the risk of being more exposed to heat while trying to reach these places, highlighting the importance of identifying cool routes and optimising transport options for reaching cool spaces during periods of heat (Yoon et al., 2022). Furthermore, the need to adopt flexible procedures and processes during extreme heat allows people to have access to cooling facilities, support and adopt appropriate practices. These might include adopting flexible working patterns, extending operating hours of night-shelters for homeless individuals to allow them to rest and recover (Homeless Link, 2024), but also taking active measures to eliminate existing barriers that might be preventing people from attending cooling centres, for example facilitating access with pets (UKHSA, 2024c), the lack of which has prevented people from seeking support during extreme heat before (Moreno, 2022). As Khosla and colleagues (2020) argue, the creation of a 'culture of cooling' encompasses the systematic repetition of behaviours, choices and habits, all necessary conditions for the adoption of environmentally sustainable cooling practices.

Behavioural measures also include guidance to adopt extreme heat-adapted working practices. These include the adoption of flexible working schedules, allowing people to start working either earlier or later during the day to avoid the warmest hours, and allowing extended rest periods (World Economic Forum, 2023). Performing physically demanding work (e.g. farming, roadworks) during the coolest hours of the day, scheduling recurrent breaks and providing cooling opportunities to staff are encouraged (UKHSA, 2024c). Providing access to hydration and reminding people to drink and take a water bottle with them if they are moving around for work are also among recommended measures for managers. The identification of heat champions in the workplace who can act as an extreme-heat focal point has been suggested as potential good practice for heat-adapted workplaces. An additional behavioural measure suggests that managers should be aware of any individual who might be at higher risk of experiencing heat-related stress or illness and know how to identify symptoms and how to react in case of emergency (UKHSA, 2023d). Furthermore, evidence suggests that institutions, businesses and social services should incorporate mandatory risk assessments into their operations as a way to properly address heat risk (Howarth et al., 2024b).

Table 1.1. Behavioural and cultural measures

Long-term preparation and planning	Preparation for heat events	During a heat event	Post-heat event (monitoring and evaluation)
Identify vulnerable members of the family and/or community (UKHSA, 2024) Learn how to identify signs of heat stress and heat stroke (UKHSA, 2024) Increase extreme-heat-related knowledge and self-advocacy capacity among members of the community (Guardaro et al., 2020) Modify the environment to cool down (open windows, turn off appliances) (UKHSA, 2024) Increase heat knowledge and nature-based education (Kumar et al., 2023)	Look for weather forecast information (UKHSA, 2024) Register to receive alerts (UKHSA, 2024) Register for heat health-related services (telephone/apps) Secure supplies (e.g. bottled water, medicines) (UKHSA, 2024) Get in touch with people who might need help preparing before a heatwave (UKHSA, 2024)	Drink water (Palinkas et al., 2022) Protect yourself from the sun Use sunscreen (NHS England, 2022b) Go to a shaded area Go to a cooling centre (e.g. shopping mall, public library) Stay away from the sun during the hottest hours of the day (UKHSA, 2024) Close shutters or curtains during the day (Shade the UK and BRC, 2024) Do not use unnecessary appliances (Palinkas et al., 2022) Ventilate house during the night (Darmanis et al., 2020) Protect vulnerable individuals Make only necessary journeys to avoid heat (BRC, 2024a) Be mindful of alcohol intake (NHS Scotland, 2023) Be mindful of the impact of consuming recreational drugs (Groundswell, 2023) Take showers (Palinkas et al., 2022) Allow breaks to recover from heat (UKHSA, 2024)	Assess the impact of past heatwaves and prepare for the next (IFRC et al., 2022)

1.2. Institutional measures

Institutional measures related to extreme heat adaptation and responses include all those actions developed and deployed by institutional actors and designed to address cooling from an institutional perspective. These institutions broadly include international bodies, national governments, local authorities, third sector organisations, utilities and energy providers, but also smaller entities such as schools or social and health care providers, among others. Measures within this domain can include the development of early warning systems, heat adaptation and mitigation plans, statutory regulations at national and local levels, sectoral guidance at different scales, heat adaptation and mitigation stewardship, and knowledge and information sharing. Examples of these measures carried out in practice include the UN's international-level guidance Beating the Heat: A Sustainable Cooling Handbook for Cities (UNEP, 2021), national-level strategies such as the US's 2024-2030 National Heat Strategy (NIHHIS and IWG, 2024), and city-level heat plans like the Heat Resilience Solutions for Boston (City of Boston, 2022).

While institutional measures look at different aspects of heat adaptation and mitigation operationalisation (e.g. business continuity, organisational preparedness, communication cascading), at their core their ultimate goal is to preserve health, safeguard wellbeing and save people's lives. In line with this goal, work aimed at supporting institutional measures in the UK looked at the development of indicators that local public health organisations can employ to support their work in reducing the impacts of heat on populations' health (Murage et al., 2024). Work conducted by Martinez and colleagues (2019), aimed at assessing the impact of heat on population morbidity and mortality, found that a health-centred approach has become key to the development of heat adaptation measures across different European countries following the 2003 heatwaves in Europe.

An increased global awareness and concern regarding the impact of heat on people resulted in the development of the WHO 2008 Heat Health Action Plan Guidance (WHO, 2008). This guidance aimed to provide policymakers and health sector professionals across Europe with core elements and guiding principles to develop national and regional-level heat-health action plans. It suggests that measures should not only deal with emergency responses, but also focus on a long-term approach that considers different stages of heat adaptation and response, including: the identification of a leading body, accurate and timely early warnings, information plans, reductions in indoor heat exposure, particular attention for vulnerable groups, preparedness of the social care and health systems, long-term urban planning, and real-time surveillance and evaluation (WHO, 2008, p. 7). The WHO guidance was updated and complemented in 2011 to include public health and care, with detailed advice for different audiences within the sector (WHO, 2011). The core elements identified in this guidance led to the development of Heat Health Adaptation Plans (HHAPs) in different countries. While the thematic coverage and comprehensiveness of the plans vary across locations, there is evidence of the existence of HHAPs, or their equivalent, in at least 45 countries (Kotharkar and Ghosh, 2022) including Italy, New Zealand and India. The UK does not have a specific HHAP.

See Case Study 1 on Ahmedabad's Heat Action Plan (India)[2]

Heat adaptation and mitigation are complex and require targeted efforts and specialised expertise, resulting in the need to create **heat-related leadership and stewardship** roles. This is evidenced by the appointment of roles such as Chief Heat Officers promoted by the Adrienne Arsht-Rockefeller Foundation Resilience Center (Arsht-Rock Resilience Center, 2024a) in partnership with local authorities in different countries, but also as a global first-ever, with international agencies such as UN-HABITAT (UN Habitat and Arsht-Rock Resilience Center, 2022). To reinforce the importance of this approach, in the US the city of Los Angeles has a

[2] The case studies are contained in the Appendix.

dedicated operational budget for heat-specific adaptation and mitigation action stewarded by its heat officer and their extreme-heat dedicated staff (Purtill, 2024). In England, the Adverse Weather and Health Plan, which represents the highest national-level extreme weather framework (including both heat and cold), is under the responsibility of the UK Health Security Agency (UKHSA). While at this stage there no UK-dedicated role overseeing national-level heat adaptation and mitigation, there have been calls for a National Heat Risk Strategy (Howarth et al., 2024b) and for the national government to appoint a *Minister for Heat Resilience* to act as a focal point to steer coordinated action across departments and sectors (Environmental Audit Committee, 2024). To date, there is no evidence that any city in the UK has appointed a heat-dedicated role to oversee heat adaptation and mitigation.

See Case Study 14 on Chief Heat Officers

The Adverse Weather and Health Plan (AWHP) in the UK has been developed in parallel with the evolution of **Heat-Health Warning Systems**. Extreme heat early warning systems typically consist of a weather forecast, a weather-health link (that usually takes the form of a methodology to establish specific thresholds based on the adverse impacts of extreme heat on human health), a graded system of alert, and a communication protocol to disseminate such alerts (Casanueva et al., 2019). As highlighted by Casanueva and colleagues, different systems consider different climatic parameters and different thresholds; the latest are based mostly on methodologies linking temperature and recorded heat-related death rates. As populations vary in terms of their heat resistance and acclimatisation, there are no universally-agreed extreme heat thresholds; a similar issue arises in the definition of heatwaves within and across different countries (Chambers, 2020). The importance of identifying a meaningful and effective temperature limit triggers has been identified in several studies. For instance, McElroy et al. (2020) found that warnings issued for thresholds established at the county level in San Diego (US) had resulted in highly underestimated or overestimated hospitalisations in smaller local areas due to particular local climate conditions.

In addition to local climate differences, research indicates that thresholds should also consider that people are impacted differently by increases in temperature, suggesting that tailored warnings might be more effective compared with a one-size-fits-all approach (Li et al., 2017). Some individuals or groups are more vulnerable to increases in temperatures because of their health or physiological inability to respond to extreme heat, or due to their environments hindering their capacity to respond to it (Physiological Society, 2023). Despite limitations (e.g. not considering local climate temperature variations; using temperature thresholds that do not take into consideration particularly vulnerable groups), heat early warning systems have proven to be cost-effective tools for heat-related morbidity and mortality prevention (Williams et al., 2022). The systems, however, require high level coordination and planning efforts across different institutions at national level (Brimicombe et al., 2024). In the UK, particularly in England, heat early warnings are the joint responsibility of UKHSA and the Met Office, and comprise a four-level alert system (Green – Pre-summer readiness and summer, Yellow – Response, Amber – Enhanced response and Red – Emergency response) (UKHSA and Met Office, 2023). Once an alert is issued, the information is cascaded to different stakeholders based on the protocols set in the AWHP (UKHSA, 2023a). While a system for rapid dissemination of information is in place, there is limited collaboration and coordination across different government departments: this is a significant gap in the UK's extreme heat response (Howarth et al., 2023b).

Communication and information-sharing about extreme heat is a key component of adaptation and response. This can include pre-season awareness-raising, emergency preparedness measures such as cascading extreme heat early warnings, dissemination of guidance on how to adopt protective measures, and platforms for sharing best practice. At the international level, a 'Heat Action Day' initiated by the British Red Cross has been an important opportunity to raise awareness globally about the dangers of extreme heat, and to educate people about the actions that can be taken to mitigate and adapt to heat (IFRC, 2024). Similarly, trials conducted in Spain to explore the naming of heatwaves suggest this could "increase the perceived risk of extreme heat and increase residents' perceptions that their local government is responding effectively to heat events" (Metzger et al., 2024, p. 8). Cities such as Freetown, Sierra Leone, and Los Angeles and Miami, US have adopted extreme heat awareness raising campaigns that focus on heat during and outside summer periods (Arsht-Rock Resilience Center, 2024b). At a smaller scale, the US Environmental Protection Agency launched the 'Let's Talk About Heat Challenge' which provided grants to local institutions and organisations to develop community-relevant heat safety communications and ideas to support extreme heat-related capacity-building (EPA, 2024). This has demonstrated the important role of engaging with heat-impacted communities to work with them on identifying what works and what to communicate about heat risk effectively (Dunlap, 2024).

Information-sharing is key both as a long-term measure to prepare for extreme heat and during a heatwave or high temperature event. In line with this, a joint initiative of the German and Vietnamese Red Crosses sought to share information about protective behaviours with highly exposed individuals in the streets of Hanoi, while also providing hydration and cooling opportunities through the use of mobile cooling shelters (Vietnamese Red Cross and German Red Cross, 2019). Internationally, initiatives such as the Global Extreme Heat Action Hub (USAID and IFRC, 2024), and extreme heat information repositories such as those hosted by the Global Platform for Sustainable Cities (GPSC, 2021), or the C40 Knowledge Hub (C40 Cities Climate Leadership Group and C40 Knowledge Hub, 2019), have also been successful at mobilising extreme heat mitigation and adaptation measures. In the UK, the government and other institutions have developed extreme heat-related guidelines (e.g. the Heat-Health Alerts [HHA] action cards [UKHSA, 2023d] and Hot Weather and Health Guidance and Advice [UKHSA, 2023e]), providing measures that should be adopted by institutions and the public. Additional advice on how to prepare and respond during extreme heat events is also available through the British Red Cross (BRC, 2024b), the National Health Service in England (NHS England, 2022a) and Scotland (NHS Scotland, 2023), and third-sector organisations (e.g. organisations supporting people experiencing homelessness [Homeless Link, 2024]). An additional information-sharing measure has been implemented in several countries (e.g. Spain, Australia, and Canada) to monitor **vulnerable** individuals during heatwaves through phone calls – for example, elderly people living alone – while also sharing tailored advice on the protective measures they can take during extreme heat events.

See Case Study 4 on telephone support programmes in Australia, Spain and Canada

Defining vulnerability in the context of heat

We present here the definition of 'vulnerability' as defined in the IPCC Working Group II glossary and also used in the Climate Change Committee's third Climate Change Risk Assessment Evidence Report (UK Climate Risk, 2021):

> *The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.* (IPCC AR5, 2014)

Vulnerability is a key concept in the climate adaptation discourse, yet is highly contested and lacks a commonly agreed definition. This poses challenges given the importance that vulnerability plays in the development of climate adaptation policies and the direction these policies take. "Protecting the vulnerable" or "focusing on vulnerable" areas or populations are recurrent milestones within extreme heat-related policy development and implementation. As highlighted by Virokannas et al. (2020), the reasons behind the vulnerability or the motives that lead certain individuals or groups to be labelled as vulnerable, and the consequences of this, are often not carefully reflected on. Brown (2015) argues that, "increasingly, the term [vulnerability] seems to be used less in its relational sense (where someone is vulnerable to something specific, such as illness or violence) and more as a stand-alone term" (Brown, 2015, pp. 1–26). Brown identifies different instances of "vulnerability" within the heat adaptation policy discourse in the UK:

"**Natural or innate vulnerability**": associated for example with different life stages – e.g. the very young or very old been more vulnerable to heat stress – or certain conditions (e.g. those using certain medications or having an impairment or condition are more likely to be impacted by heat). Within the UK context this is also referred to as physiological vulnerability (Physiological Society, 2023).

"**Situational vulnerability**": for example, linked to the limited capacities of a certain individual to control their environments within care settings, or those living incarcerated within the prisons system.

"**Social disadvantage-related vulnerability**": for example, linked to socioeconomic deprivation, education level, language proficiency, among other factors used to assess social vulnerability in the context of extreme heat.

Both situational and social disadvantage-related vulnerability have also been referred to by the bucket term 'environmental vulnerability' within the UK context (ibid.).

As Mayrhofer (2024) acknowledges, attaching concepts of vulnerability to specific groups and individuals influences how these are addressed, categorised and perceived, and the assumptions made about them. This not only fails to identify and question the underlying structures that have generated vulnerability in the first place, but also prevents the achievement of adequate responses and can perpetuate stigmatising and patronising narratives.

Additional challenges can also result from a mismatch between 'assumed' and 'self-perceived' vulnerability. Indications of this can, for example, be associated with the results of a study conducted in the UK in 2019/20 (Turner et al., 2024), which show that among the older adults surveyed (a population frequently considered vulnerable within extreme heat studies), less than half considered that their own health was at risk in the event of hot weather. The authors argue that effective targeted communications should be developed to address this self-identification gap. In other instances, discrepancies between vulnerability expectations and perceived vulnerability have been found in the context of care workers in relation to themselves and the people they care for. For instance, participants in this UKHSA research reported that the "impacts of the extreme heat were felt by the population more generally, and some didn't spontaneously mention the specific risks related to their clients" (UKHSA, 2024).

While these cases might not be fully representative, they do exemplify some of the challenges associated with framing heat adaptation from a 'vulnerable group' approach. As Mayrhofer (2024) cautions, certain approaches to vulnerability might be perpetuating othering, victimising and patronising dynamics, which might be faced with resistance by the same individuals or groups the policies aspire to support. A potential approach that moves from targeting vulnerable groups towards an understanding of vulnerability as a dynamic concept that can apply to anyone under certain circumstances could provide the inputs to shape effective heat adaptation measures.

Institutional measures also look at the reduction of indoor heat exposure as indoor temperatures can be higher than outdoor temperatures, particularly at night (Zuurbier et al., 2021). As people tend to spend most of their time indoors (Duffield and Bunn, 2023) and many buildings in the UK are prone to overheating, even outside the summer season indoor temperatures must also be taken into consideration (Howarth et al., 2024b). Measures addressing this often focus on advice to reduce temperatures at home by promoting behavioural change (e.g. opening windows when it is safe to do so; turning off appliances), and providing guidance on how and when to use active cooling (e.g. air conditioning or fans). Other measures include the adoption of infrastructural modifications (e.g. blinds installation, shading) or nature-based solutions (e.g. increasing vegetation and green surfaces) to decrease heat gains and promote natural ventilation and shading.

Heat in the context of occupational health is also gaining increasing attention in the UK, with calls to introduce maximum indoor temperature thresholds for working spaces (Sacares, 2023; Howarth et al., 2024b). While maximum working temperature thresholds are in place in other countries (European Environment Agency, 2022), there is currently no maximum indoor temperature limit for working spaces in the UK. While employers are required to ensure 'reasonable' temperatures for workers (HSE, 2024), there is no agreed value to define what 'reasonable' represents in terms of heat. Similar limitations also apply elsewhere; for example, the Urban Design Forum has called for the establishment of mandatory indoor building temperature reporting and maximum limits to safeguard the health and safety of building occupants in New York City (Urban Design Forum, 2020).

Table 1.2. Institutional measures

Long-term preparation and planning	Preparation for heat events	During a heat event	Post-heat event (monitoring and evaluation)
Heat Health Action Planning (WHO, 2008) Provide training to key staff (UKHSA, 2024) Train caregivers in social facilities (nursing homes, children's homes) on protection measures, detection of relevant symptoms and management of cases (IFRC et al., 2022) Identify heat champions in the workplace (UKHSA , 2024) Account for heat risk within institutional operations (UKHSA, 2024) Adaptive social protection schemes	Heat Health early warning systems Name heatwaves (Metzger et al., 2024) Develop community-relevant heat safety communications and ideas to support extreme heat-related capacity-building (EPA, 2024) Set up community cooling centres (German Red Cross, 2024)	Provide hydration to staff (UKHSA, 2024) Cascade information to different stakeholders based on established protocols (UKHSA, 2023a) Share information about protective behaviours while providing emergency heat relief (Vietnamese Red Cross and German Red Cross, 2019) Disseminate guidance on how to protect from heat and how to keep your surroundings cool (UKHSA, 2024) Reach vulnerable individuals to check on them while sharing advice on	Assess action plan efficiency (what worked, what could be improved?) (Arrighi et al., 2020) Update action plans for next year (ibid.)

focused on extreme heat (IFRC et al., 2022). Anticipatory action (ibid.) Heat action days (IFRC, 2024) Extreme heat off-season period awareness campaign (Arsht-Rock Resilience Center, 2024b)		what they can do to protect themselves (IFRC, 2021)	

1.3. Infrastructural and technological measures

Infrastructural and technological measures have received wide coverage in the academic literature. These measures focus mostly on the built environment, both at the wider urban and the building scale; in very limited instances they also focus on the human body. For instance, to a limited extent technological measures have focused on the development of cooling garments (Ren, Han and Fang, 2022; Rahimi et al., 2024) and wearable devices (Lou et al., 2022), although these are mostly confined to experiments and prototypes and/or have limited commercial diffusion. Of much wider diffusion are the use of mechanical cooling systems (such as air conditioners) and electric fans, which account for as much as 20% of the total electricity consumption in buildings at a global level. Demand for energy to fuel air conditioning is set to triple by 2050 (IEA, 2018). With the cooling services industry (which includes spaces cooling) already accounting for over 10% of global greenhouse gas emissions, alternative refrigerants, improved energy efficiency and lower-carbon electricity grid have been identified as suitable alternatives to reduce emissions (Dong et al., 2021).

While air-conditioning contributes towards increased emissions and exacerbates the urban heat island effect through local heat waste, it has been identified as an effective way to reduce heatwave morbidity and mortality (Kravchenko et al., 2013; Lane et al., 2014). Wide application of this measure can be seen in the cooling shelters network and cooling mobile services activated by certain cities during extreme heat events. Additionally, infrastructural measures can focus on modifications to existing houses to limit overheating by, for example, installing external shades or verandas, adding solar reflective films on windows, installing windows that can be easily opened to maximise ventilation, and increase walls' and roofs' thermal mass (Shade the UK and BRC, 2024).

See Case Study 3 on mobile cooling buses and tents in Hanoi (Vietnam) and Phoenix (US)

Other forms of infrastructural or technological measures include **passive solutions**. Some of these, such as cool roofs and cool streets, are aimed at increasing urban surfaces' albedo. Both these solutions contribute to reducing heat by reflecting radiation, hence reducing the amount of heat stored in buildings and street surfaces. While their implementation entails some level of industrialisation and infrastructural works that generate emissions, once they are in place these measures are passive. In the case of cool roofs, the application of a reflective coating can lead to up to 6°C heat reduction of the indoor temperature of dwellings and an average roof surface temperature of 25°C cooler for treated roofs compared with those without treatment (MEER, 2023), based on results collected in Freetown (Sierra Leone). In the case of cool streets, while effective in reducing surface temperatures by a number of degrees, cool pavements can result in increased radiation at the height of the body when reflective coating is applied over surfaces with high daytime pedestrian use such as playgrounds, recreational areas and courtyards, suggesting that they should be avoided in areas with high pedestrian traffic (Schneider et al., 2023). Other types of infrastructural measures seek to increase shading using devices such as screens and sun sails. In the case of Cordoba (Spain) the latter has led to up to 16°C decreases in surface temperatures compared with non-shaded surfaces, while also helping reduce façades' temperatures (Garcia-Nevado et al., 2020). While not addressed in depth in this report, it is worth mentioning that other forms of infrastructural and technological measures can include wind towers (Sadeghi et al., 2020), seawater district chillers (Schibuola and Tambani, 2020), solar control windows films (Sun et al., 2021), the installation of shutters and blinds and insulation (Porritt et al., 2012), and the use of misters (Vanos et al., 2022).

See Case Studies 6 on cool pavements and streets (Los Angeles and Phoenix, US); 9 on shading devices (Cordoba, Spain); and 13 on 'Cool Down Freetown' (Sierra Leone)

Table 1.3. Infrastructural and technological measures

Long-term preparation and planning	Preparation for heat events	During a heat event
Insulation in buildings (Kumar et al., 2022) Passive ventilation mechanism-wind towers (Sadeghi et al., 2020) Shading structures (Garcia-Nevado et al., 2020; Middel et al., 2021) Cool pavements (Black-Ingersoll et al., 2022) Cool streets (Ko et al., 2022; Schneider et al., 2023) Cool roofs (Black-Ingersoll et al., 2022) Solar-control window films (Sun et al., 2021) Shutters and blinds (Porritt et al., 2012)	Maintenance and check of cooling equipment (UKHSA)	Use misters to reduce temperature (Vanos et al., 2022) Cooling shelters (Lee and Han, 2024) Mobile cooling (e.g. Vietnamese and German Red Cross) Use A/C (Lane et al., 2014)

Note: There are no post-heat event (monitoring and evaluation) measures in this category.

1.4. Nature-based measures

Nature-, ecosystem-based or blue-green infrastructure measures are effective, low-regret measures for adaptation and disaster risk reduction, given their capacity to provide multiple benefits including reducing temperature extremes, sequestering carbon, mitigating the impacts of flooding, or preventing drought (IPCC, 2022). Blue-green solutions have led to decreased air temperatures, ranging from 3.5°C to 5°C reductions in botanical gardens, between 3.2°C and 4.9°C in wetlands, and between 3.1°C and 3.8°C in relation to street trees, for example (Kumar et al., 2024). In addition to their heat mitigation effect, Kumar and colleagues (2024) have identified **five co-benefits of green-blue infrastructure measures**, including increased biodiversity, water and air quality improvements, reductions in ambient noise, flood and drought mitigation and enhanced opportunities for outdoor recreation. Despite their direct heat mitigation effects and the associated co-benefits, nature-based measures correspond globally to less than 15% of the overall extreme heat-related responses (Turek-Hankins et al., 2021). Constructing a wider evidence base to assess efficacy, understanding of trade-offs, long-term impacts and management implications, and to broaden understanding of potential unintended consequences, could supporting the scale-up of nature-based measures in the urban environment (Frantzeskaki et al., 2019). Despite their benefits, nature-based measures should be complemented with technological, behavioural, cultural and other type of measures (ibid).

Existing nature-based measures provide cooling through different mechanisms:

- Firstly, nature-based measures incorporating vegetation facilitate further evapotranspiration. This is a combination of the effect of water transpired by plants in addition to the moisture that evaporates from soil and vegetation, which in combination with other factors – such as climatic conditions, seasonality, wind velocity, type of vegetation, substrate, and water content – has a cooling effect on the surrounding environment (Cascone et al., 2019). Evapotranspiration is essential in solutions applied at the building scale, such as green roofs, but also for larger scale green infrastructure such as urban forests and parks.
- Secondly, nature-based measures provide cooling benefits through thermal insulation. In solutions such as green façades (but also green roofs), vegetation cover shading is a main source of thermal insulation of the building (Dede et al., 2021). Green façade insulation can lead to reduced indoor wall temperature during daytime; however, at night it can also help retain heat indoors, which might be a disadvantage if not properly addressed through façade design (Hoelscher et al., 2016) or the use of natural ventilation (Olivieri et al., 2017).
- Thirdly, nature based-measures can provide shading from vegetated areas, which reduces the solar radiation hitting urban surfaces, diminishing the heat stored during the day and consequently released at night, effectively contributing to the reduction of the urban heat island effect (Imran et al., 2019).

Blue spaces such as rivers, lakes, ponds, canals, coastal environments and urban water bodies can also contribute to heat mitigation through different mechanisms. Blue spaces can absorb heat during the day as they usually have a lower albedo than land, leading to an accumulation of heat within these water bodies that contributes towards cooling the immediate surroundings. However, evidence shows that this heat can also exacerbate the urban heat island effect when it is released at night (Ampatzidis and Kershaw, 2020). Large water bodies such as seas (and lakes) can generate breezes that significantly decrease temperatures in outdoor coastal environments (He et al., 2020). Furthermore, the high evaporation level from surface of water bodies, in combination with other factors (e.g. the shape and width of water bodies and their depth and orientation), can result in an average temperature reduction of around 2.5°C in urban areas (Lin et al., 2020). In addition to their cooling benefits on the environment, immersion in water bodies can be an effective way for people to cool down during periods of extreme heat but can pose an increased risk of drowning (UKHSA, 2024b). However, many such accidents could be prevented or minimised by sharing water safety and drowning prevention messages ahead of expected heat periods (Peden et al., 2024). Both green and blue measures can thus lead to heat mitigation and can provide synergistic cooling benefits in addition to increase environmental capital (Gunawardena et al., 2017).

See Case Study 8 on urban gardening and farming in Chennai (India)

Nature-based measures have the capacity to reduce temperatures at the building scale. Green roofs, for example, can reduce indoor temperatures by up to 15°C without generating any solid waste or emitting any organic pollutants during their life time, and have the added benefit of not involving polluting energy-intensive industrial processes, unlike other insulation materials commonly used in the built environment (Mihalakakou et al., 2023). If coupled with urban farming and gardening, in addition to mitigating heat, green roofs can also contribute to food security and livelihoods, as exemplified by the work of the Chennai Resilience Center (CRC) where vulnerable communities have been provided with an opportunity to grow food for their own consumption and for sale (Ayyangar et al., 2023). Furthermore, increasing green roof coverage at the city scale could lead to a significant reduction in the urban heat island effect and a consequent reduction in buildings' energy consumption (Razzaghmanesh et al., 2016). Anecdotal evidence suggests that changes to local councils' approaches to maintaining green spaces (parks, verges, hedgerows, etc.) such as adopting 'relaxed mowing' can also be helpful for adaptation. At street level, urban vegetation can contribute towards reductions of up to 75% in surface temperatures within urban hotspots compared with non-vegetated areas, with trees having the most impactful reductions in terms of temperature (Ananyeva and Emmanuel, 2023). When street vegetation and tree planting interventions are scaled-up at the city level, they can lead to reductions in urban temperatures of up to 3°C and significant CO_2 sequestration, while also contributing to urban renovation and the enhancement of active mobility networks like in the case of Medellin's green corridors (Ashden, 2019).

See Case Study 12 on green corridors in Medellin, Colombia

Urban blue-green spaces can also act as natural cooling shelters during periods of extreme heat, and urban spray and water parks can provide cooling opportunities for adults, children and teenagers while also consuming less water than some other solutions (Singh et al., 2020). Spray parks also have the advantage of been more accessible and less risky in terms of drowning compared with other water-based cooling options such as pools or open water swimming. While urban parks and forests are effective nature-based cooling measures, access to these spaces is not always equal across all groups within society. Proximity, attractiveness, travel distance, different users' perceptions about green-blue spaces, and the lack of accessibility are among the factors influencing people's likelihood to visit that should be considered for the achievement of more equitable nature-based urban cooling services (Vasconcelos et al., 2024; Yang et al., 2024).

In the UK, initiatives such as the Nextdoor Nature programme (The Wildlife Trusts, 2024) aim to address access gaps that might prevent certain people from accessing nature and green spaces (such as people facing poverty, adults with a long-term illness or condition and minoritised ethnic groups). As a way of addressing the gap in access to nature-based cooling opportunities, initiatives such as the OASIS project in Paris aim to increase access by working in existing school playgrounds. The interventions have contributed to day temperature reductions ranging between 2°C and 1°C at the microscale (Karam et al., 2023), achieved through tree and shrub planting, removal of impermeable surfaces, and adding shading. Additionally, the project has increased citizen participation and governance related to climate resilience and nature-based solution design, nature-centred education for children and social cohesion.

See Case Study 7 on the OASIS Project, Paris

Table 1.4. Nature-based measures

Long-term preparing and planning	During a heat event
Green roofs (Razzaghmanesh et al., 2016; Ayyangar et al., 2023; Mihalakakou et al., 2023) Green walls (Hoelscher et al., 2016; Olivieri et al., 2017; Dede et al., 2021) Street trees (Ananyeva and Emmanuel, 2023) Urban forests (Livesley et al., 2016) Urban parks (Yang et al., 2024) Green corridors (Ashden, 2019) School playground greening (Karam et al., 2023)	Gren spaces as cooling shelters (Vasconcelos et al., 2024) Swimming as a cooling mechanism (UKHSA, 2024b)

Note: There are no preparation for heat event or post-heat event (monitoring and evaluation) measures in this category.

2. A focus on London

London's heat vulnerability and exposure profile

Global temperature increases in the past decade have resulted in higher mean annual temperatures recorded compared with the pre-industrial average. Hot weather and periods of extreme heat, including heatwaves, are increasing in frequency and duration across most regions worldwide (IPCC, 2022). For the UK, projections based on different radiative forcing targets for 2100 (set at 2.6, 4.5, 6.0, and 8.5 watts per square metre) indicate that hot summers are expected to become more frequent and drier (Met Office, 2019). With the projected increases in global temperatures (based on different Representative Concentration Pathways/RCP scenarios), by 2070 the highest emission scenario (RCP 8.5) could translate to UK summer (June to August) mean temperatures increasing by between 0.9°C and 5.4°C. Warmer and drier summers are expected to become more likely, which can lead to an increase in heat-health-related concerns, and potentially disruptive impacts to livelihoods and infrastructure.

In London, projections from the London Climate Pack (Met Office, 2022) indicate that average summer temperatures in the city are expected to increase by between 1.1°C and 7.3°C under different scenarios for the 2030s, 2050s and 2080s. Maximum summer temperatures could potentially reach higher values within the same timeframes, with an expectation of up to +8.5°C by 2080 under the RCP 8.5 high emissions scenario (expected to be likely if emissions targets are not met) at the 90th percentile. These projections are based on average temperatures and do not include extreme weather conditions such as prolonged heatwaves, during which temperatures are expected to be higher. In addition to national and regional weather, urban climate is also impacted by the urban heat island (UHI), which increases temperatures in cities compared with surrounding rural areas (Oke, 1973, 1978). This is usually a result of factors including the urban form and density, vegetation coverage, the presence of water bodies, the characteristics of impervious surfaces, building and roofing materials and predominant wind patterns, which influence the distribution and intensity of the urban heat island. In London, this phenomenon can lead to an increase in temperature of up to 10°C in certain locations compared with neighbouring areas (Doick et al., 2014).

Extreme heat is recognised as one of the main climate-related risks, with potentially negative impacts for London across different sectors (Mott MacDonald, 2018). Based on a 2018 impact assessment, extreme heat in the city could lead to: electricity transmission and distribution challenges, reduced employee productivity and potential disruption to businesses, increased risk of buildings overheating and an associated increase in cooling demand, IT hardware component stress and reduced lifecycle, and disruptions to the natural environment (including loss of urban vegetation due to heat stress) (ibid.). Furthermore, extreme heat has the potential to negatively impact human health, causing heat stress, heat strokes and death. A study covering 35 countries in the European region, including the UK, shows that extreme high temperatures were associated with over 47,000 heat-related deaths in 2023 alone (Gallo et al., 2024). Over the period covered by the study (2015–2023) this mortality level was only surpassed by 2022, which was the hottest year on record in the UK at the time of the study (Met Office, 2023). Based on the UKHSA Heat mortality monitoring report this was also the year in which the highest number of heat-related mortalities was observed (UKHSA, 2024d).

The summer of 2022 in the UK saw close to 3,000 heat-related deaths (Howarth et al., 2024b) and an estimated 387 all-cause excess mortality cases were recorded in London alone, associated with five heatwave periods recorded during that summer (UKHSA, 2024d). Significant levels of excess deaths were observed among the age groups 45-65 years and over 65 years old; heat-vulnerable populations also include babies and young children, people with health conditions and disabled people, pregnant women, people on certain medications, people who are ill and dehydrated, people who experience alcohol or drug dependence, people living alone and unable to take care of themselves, people physically active and spending a lot of time outdoors, people working outside, and rough sleepers (UKHSA, 2023a). As flagged by Cheng et al. (2021), the identification of heat-vulnerable populations and locations remains challenging and inconsistent across locations. The differences in available data, geographical variations, heat acclimatisation and differing cultural approaches to heat all contribute to this heterogeneity. There is not currently a commonly agreed definition of heat vulnerability (as explained in Section 1), and its conceptualisation remains complex and multi-faceted (Lagelouze et al., 2024). The groups identified by the UKHSA, however, are consistent with those identified in existing studies at the London level (see for example Wolf and McGregor, 2013), the UK level (see for example Arbuthnott and Hajat, 2017), and internationally (see for example Li et al., 2022).

Key recommendations from the London Climate Resilience Review have identified the need for a London-wide strategic action plan on heat risk to address the threats that heat poses to London residents and systems (including transport, water supply, and health and care services) (Howard Boyd et al., 2024). The Greater London Authority (GLA) has developed London Climate Risk Maps to analyse climate exposure and vulnerability across the city (GLA and Bloomberg Associates, 2022). Climate vulnerability in this study is presented as the result of exposure to climate impacts (including heat) and personal or social factors that influence people's capacity to cope with and respond to an extreme event (Bloomberg Associates, 2022). The map was produced by combining exposure metrics (land surface temperature, fine particular matter or $PM_{2.5}$, nitrogen dioxide, tree canopy cover, areas of deficiency in access to public open space) and vulnerability metrics (people aged under 5 and over 75, English language proficiency, income deprivation, social renters, people from BAME backgrounds). The results provide an overview of heat risk for the whole Greater London area at the neighbourhood or Lower Layer Super Output Area (LSOA) scale. As highlighted by the authors, the map lacks the detail to identify heat risk at a granular scale, for which other types of analysis would be necessary. An additional study commissioned by the GLA and published at the beginning of 2024 partially addresses this by identifying key properties vulnerable to heat (GLA, 2024a).

A pilot study conducted in the London Borough of Islington identified that the borough's building stock is not ready to withstand the increasing risk of excessive heat while also evidencing a gap in the identification of overheating risk at the neighbourhood level. The study focused on building archetypes' vulnerabilities and called for the implementation of a standardised way to understand a heat metric certificate (which could for example support tenants or buyers in making informed decision about properties, but also facilitate the communication of complex overheating information to a wider audience) (Love Design Studio et al., 2024).

A separate study developed by ARUP focuses on identifying neighbourhoods with a higher density of properties prone to overheating, those with a higher temperature due to the urban heat island effect, and residential settings with vulnerable occupants (GLA, 2024a). The study is centred on key building typologies including schools, hospitals, care homes and residential properties, all of which are considered to be settings more likely to host heat-vulnerable individuals at higher risk of suffering from the adverse effect of extreme heat. The heat risk maps were produced combining three sets of variables, representatives of: a) *property vulnerability* (which contains variables employed to measure buildings' vulnerability to heat, such as building form, solar gain, building fabric), b) *socioeconomic vulnerability* (which relates to the building occupants and includes age, deprivation and social isolation), and c) *heat hazard* (which includes environmental and climate data such as land cover classification, tree canopy cover and surface albedo).

The residential buildings heat risk map locates a concentration of properties at higher risk towards the city centre including in the boroughs of Hackney, Islington, Tower Hamlets and Camden. However, areas considered to be at heat risk have been identified within every London borough. Regarding school buildings, the most vulnerable facilities overlap with the higher heat hazard area located towards the city centre. This is related to a higher urban heat island intensity and increased socioeconomic vulnerability. Islington, Hackney and Tower Hamlets are the boroughs hosting the most at heat-risk schools. Additionally, the outer London Borough of Enfield, located to the north, also shows high heat risk levels. This is related to a combination of high values of property and socioeconomic vulnerability. High-risk hospitals have also been identified towards the city centre (due to the greater urban heat island effect). According to the study, these are in Southwark, Tower Hamlets, Hackney, Islington, and Kensington and Chelsea. Pockets of high-risk facilities associated with higher socioeconomic vulnerability have been identified in central and east London. These includes the Barts Health NHS Trust, Barking, Havering and Redbridge University Hospitals NHS Trust, Homerton University Hospital NHS Foundation Trust, Whittington Health NHS Trust, and University College London Hospitals NHS Foundation Trust.

Finally, care home facilities have been associated with the highest heat risk out of all other properties across London (GLA, 2024a). Socioeconomic vulnerability data was not included in care homes risk mapping. This is because care homes host particularly vulnerable individuals who are at higher physiological risk and/or have limited access to independently control their environment. Care homes in the boroughs in and around central London are identified as at higher risk due to the higher heat hazard level in this area.

While this study provides an overall indication of at heat risk properties, more detailed assessments are needed to gather information for an effective operationalisation of adaptation and mitigation measures at property scale. Initiatives that have moved in this direction include the Care Home Overheating Audit Pilot Project (GLA, 2020a) and the Climate Adaptation Plans for schools (GLA, 2023c), of which Tiverton Primary School's climate adaptation plan constitutes a comprehensive example (GLA, 2023a).

How London currently responds to heat risk

Delivering responses to heat risk in London involves a range of actors; at this stage, measures implemented are not unified under a comprehensive strategy but rather represent a collection of initiatives addressing heat risk from different angles. At the highest level, existing responses are implemented and coordinated by the GLA and its institutional partners; others come from local government at the borough level and involve local groups and other entities such as faith-based organisations. Additionally, measures are deployed by third-sector organisations and academics. Existing initiatives include direct implementation and policy guidance (e.g. for the 'London cooling hierarchy' – see below), but also research aimed at identifying potential future interventions at the building and city scale. While some initiatives focus primarily on addressing heat risk, others incorporate this as one of multiple components that also tackle other issues such as flood risk reduction, curbing energy demand, improving health and wellbeing, reducing social inequalities and minimising emissions.

At the institutional level, London's response to extreme heat comprises measures such as those included in The London Plan 2021 (GLA, 2021), which incorporates a sustainable infrastructure policy directly addressing heat risk management. This policy addresses heat risk from a planning perspective and contains the London cooling hierarchy, a strategy that addresses overheating for new developments, prioritising the reduction of indoor heat through passive measures and design, leaving mechanical ventilation and active cooling as a last resort. The dual objective is to manage overheating risk while addressing cooling energy demands and emissions reduction. Other institutional actions, such as the 'Heat Risk in London' working group, part of the London Climate Ready Partnership, act as a knowledge exchange platform for organisations working on heatwave prevention and response, and long-term heat risk planning (LCRP, 2024b). The working group also functions as a repository for existing heat risk-related resources such as the report on London's overheating thresholds (LCRP et al., 2018) and its sector impacts review (Mott MacDonald, 2018). While the working group does not have a delivery budget, it has supported initiatives such as the London Climate Resilience Review (Howard Boyd et al., 2024) and Future Buildings Standard Consultation on changes to part L (MHCLG, 2021) and has provided evidence to the Environmental Audit Committee (LCRP, 2024a) as part of its overheating and sustainable cooling enquiry.

The London Climate Resilience Review (Howard Boyd et al., 2024), commissioned by the GLA, contains key advice addressing heat risk, among other climate resilience-related recommendations. The review highlights the importance of producing a strategic heat risk action plan for the city, incorporating a governance framework with detailed roles and responsibilities, as heat risk emerged as being insufficiently addressed across multiple sectors and organisations. Among other things, the review highlighted the importance of engaging in long-term heat adaptation that considers those most impacted, focuses on bridging existing gaps, and allocates resources for implementation, management and skill development for those in charge of delivery. The document also evidences the importance of conducting an extreme heat exercise to test the city's preparedness and identify potential cascading effects and concurrent risk in the event of a prolonged heat event.

In response to the latter recommendation, in June 2024, the GLA's London Resilience Unit brought together representatives of local government, emergency responder organisations, public health, environment agencies, transport services, business and utilities, voluntary groups and the faith sector to test London's extreme heat response. The exercise, named 'Operation Helios', explored different scenarios and response mechanisms, considering the impact on individuals, communities and services to better prepare the city to respond during periods of prolonged heatwaves (GLA, 2024g). Recommendations that emerged from the exercise included the development of a London-wide strategy for managing extreme heat (including adaptation and risk mitigation, response and recovery), improving the evidence base and learning opportunities related to heat planning and heatwave response (particularly from contexts similar to London), developing regional and local heatwave response plans, improving public messaging, and addressing inequity in heat risk and risk management.

In terms of nature-based measures, the Trees for London initiative is a good example (GLA, 2024h). With existing trees in the city already removing an estimated 2,241 tonnes of pollution every year (including PM_{10} particulate matter and NO_2 emissions) and contributing to flood risk reduction and carbon storage, this measure also addresses heat reduction (GLA, 2022) with the aim of increasing London's tree canopy from covering 21% of the city surface to 23.1% by 2050 (GLA, 2024h). The initiative is being implemented through projects such as the Grow Back Greener Fund community grant scheme, street tree planting schemes, tree planting packs for community groups and schools, and the creation of woodland and tree planting projects in high heat risk zones. The Grow Back Greener Fund has awarded £2 million to 56 community projects to create or enhance green spaces and waterways, plant trees and increase climate resilience across different London boroughs (GLA, n.d.). Some of the funded projects, such as one in Southall in the Borough of Ealing, address the removal of pervious surfaces and their replacement with green planting to create pocket parks (*Borough of Hounslow Herald*, 2023). The Cold Schools project in Bexley focuses on using trees and hedge planting in combination with rainwater harvesting and meadows to mitigate flood risk and increase natural habitat availability. Other projects include extending green roofs, such as the case of Hanover School's Rooftop in Islington, and enhancing walking and cycling routes in Enfield (GLA, n.d.). While all projects address aspects of climate resilience, evidence for the level to which they directly contribute towards heat resilience, by reducing temperatures, raising awareness about heat risk or educating about potential protective behaviours for example, has not been identified.

London's extreme heat-related measures directed at protecting citizens include an initiative developed by the GLA in partnership with Refill that is installing drinking fountains and identifying bottle refill points to provide London residents and visitors with hydration opportunities while promoting the reduction of single-use containers (Refill, 2020; GLA, 2024f). Another measure is the cool spaces map that goes live every year during the period 1 June to 30 September. The map displays locations across London put forward by the Boroughs, where people can seek refuge from the sun and cool down. This network of cool places includes locations such as air-conditioned and other buildings expected to be cooler than outside during hot weather, parks, vegetated areas, and areas that are likely to have a cooler land surface temperature compared with other locations in the city (GLA, 2024c). The cool spaces' selection takes into account aspects such as sitting space capacity, water availability, operating hours, toilets and wheelchair access availability (GLA, 2024d); however, information on specific operative temperature threshold criteria was not identified. It must be noted that, as reported by GLA, these spaces are not specifically designed to support vulnerable individuals during extreme heat and should not be considered substitutes for medical assistance if someone experiences heat-related illness (GLA, 2024c).

Evidence indicates that vulnerable individuals such as homeless people are more likely than others to experience hospitalisation due to high temperatures (Hajat et al., 2023), and the lack of access to appropriate shelters and support can pose challenges for these individuals (Eurocities, 2023). Examples of measures addressing these challenges at the London level include the activation of the Severe Weather Emergency Protocol (SWEP) during extreme heat. This has led to collaborative responses implemented by local authorities and organisations as reported in the Hot Weather SWEP case studies of local responses document published by Homeless Link (Homeless Link, 2023). Measures implemented included the extension of operating hours in community facilities, temporary installation of gazebos to provide shade, the provision of sun cream, water, and hats, welfare checks by outreach teams, and relaxed eligibility criteria to access shelters. Evidence of additional measures addressing individuals belonging to other vulnerable groups can be found in the Care Home Overheating Audit Pilot Project developed by the GLA in partnership with University College London (UCL) and Oxford Brookes University. Looking at five London care homes for the elderly, the project has identified recommendations for indoor and outdoor interventions and activities to reduce indoor overheating, priority areas for intervention, and an overheating checklist that can be used by care homes for older residents to implement actions to reduce the indoor overheating exposure of vulnerable residents (GLA, 2020b).

Children sweat less than adults and have a higher metabolism, which translates into them getting hot faster; they are also generally more physically active and less likely to rehydrate than adults, which puts them at a higher risk of experiencing heat exposure or illness (UNICEF, 2022). In London, 98% of schools have reported overheating as an issue, and during the 2022 summer heatwave alone, 47 out of 60 schools surveyed reported having experienced significant overheating impacts resulting in disruption to pupils' education and a total of 33 closure days (GLA, 2023c). The Climate Resilient Schools initiative, a joint programme between the GLA, the Department for Education and Thames Water (GLA, 2024b), looks at addressing heat risk in schools. While the initiative aims to improve schools' resilience by addressing different climate impacts and risks through four thematic streams, heat risk is among the most pressing. Within its climate adaptation plan stream, the programme has developed tailored advice that London schools can incorporate to manage and reduce heat risk by:

- Adapting school grounds and buildings
- Adapting operations to reduce common contributors to heat risk
- Adopting behavioural change
- Implementing learning and awareness-raising activities with children
- Conducting monitoring and performance evaluations.

These measures have been summarised in a GLA report (GLA, 2020b) and a compendium (GLA et al., 2023) of adaptation and resilience measures published by the programme's partners. The initiative has also created a network of weather stations in 24 schools that collect data such as air temperature, humidity and solar radiation. Learning resources incorporating data from the stations are used to teach students about topics such as local weather, weather extremes and climate resilience (FreeStation, 2024).

A package of information on how to cope with hot weather in London from the GLA (GLA, 2024e) covers aspects of staying safe in hot weather, working and travelling in the city, enjoying water, accessing weather forecasts and monitoring heat alerts, among other factors. This resource incorporates general guidance and information produced by UKHSA, the Met Office, NHS England, the Health and Safety Executive and the Royal Life Saving Society among others. In addition to GLA guidance, other forms of advice are issued on an ad hoc basis during extreme heat periods. These include, for example, customer advice notices issued by Transport for London (TfL) recommending travelling only if it is essential and informing people about potential disruption to services (TfL, 2022). To reduce the impact of heat on its customers, TfL has covered 40% of the Underground network with air conditioning, improved tunnel ventilation systems, and incorporated energy savings and passive solutions such as installing solar reflective roof covers on trains and using window film to keep carriages cool (TfL, 2024).

3. Complexities, interdependencies and interlinkages in adopting complementary adaptation–mitigation approaches to heat risk

Integration between heat adaptation and mitigation is essential; however, thorough consideration of the interlinkages between adaptation and mitigation measures is needed to avoid unintended consequences, maladaptation and mal-mitigation (Howarth, 2024).

Policy aimed at reducing the risks of climate change should consider the existing inter-relationships among adaptation and mitigation measures, as actions in one area can have consequences on another and vice versa. Mitigation and adaptation measures can involve co-benefits, synergies, trade-offs and conflicts (Sharifi, 2022), and there might be instances in which processes can have consequences for both adaptation and mitigation (Klein et al., 2007). Sharifi (2022) identifies the following:

- Co-benefits: e.g. an increase in green spaces in urban areas can lead to decreases in temperatures but also increases in biodiversity and opportunities to spend time outdoors.
- Synergies: e.g. the combined effect of different types of interventions, such as increasing green areas, implementing cool roofs, and installing shading devices, can lead to greater benefits.
- Trade-offs: e.g. a wider adoption of A/C can contribute to reduced heat mortality, but might increase the nocturnal urban heat island effect and increase emissions in the long run.
- Conflicts: e.g. increasing density in urban areas to reduce transport-related emissions might result in a lack of space to develop green infrastructure such as parks and urban forests.

Below, examples are provided of the complexities, interdependencies and inter-linkages in adopting complementary adaptation and mitigation approaches to heat risk, categorised by behavioural and cultural, institutional, infrastructural and technological, and nature-based measures, as introduced in Section 1.

Behavioural and cultural measures: complexities and linkages

Behavioural maladaptation, meaning adopting an inappropriate response to a situation, in the context of extreme heat can result in increased vulnerability and lead to long-term health consequences (Thiamwong et al., 2024). While most people in the UK recognise that heatwaves can have negative impacts on health and wellbeing, they tend to perceive themselves as able to cope and consider that others are more likely to be impacted than themselves (Howarth et al., 2024a). Research suggests that people aged over 65 are less likely than other age groups to self-identify as vulnerable (ibid.), and in fact fewer than half of older adults consider themselves to be at risk during extreme weather events. The adoption of protective behaviours is more common among those who identify themselves as being at risk (Turner et al., 2024). This is consistent with findings that 35% of over 75-year-olds, 33% of people living in top-floor flats and 34% of those working outdoors do not self-identify as being at risk during heatwaves (BRC, 2023a).

Not considering extreme heat as a serious risk for health can deter people from taking proactive measures to prepare for summers, and this is especially true regarding investment in adaptation and mitigation to extreme high temperatures among social care practitioners in the UK (UKHSA, 2024e). Despite being aware of measures such as keeping out of the sun between 11am and 3pm, only half of UK respondents to a survey stated they always or often kept out of the sun during those hours (Khare et al., 2015).

Manifestations of behavioural maladaptation to extreme heat (in Australia) have been found to potentially lead to negative long-term health effects by reducing the amount of outdoor activities performed and leading to increases in the consumption of fizzy drinks and alcoholic beverages (Zander et al., 2024). Other forms of behavioural maladaptation might be linked to the use of air conditioning, which, while it can help protect from heat stress, increases greenhouse gas emissions, exacerbates the urban heat island effect, and may not be reliable in situations of power outages (Tong et al., 2021). Other complexities associated with behavioural measures during extreme heat include the increased risk of fatal drowning among beachgoers during heatwave days, which emphasises the importance of disseminating water safety education ahead of the warm season (Peden et al., 2024).

From the perspective of behavioural adaptation and mitigation measures, researchers suggest that communication on such measures might primarily be reaching those already engaged with the topic while missing those less familiar, unaware or unconcerned with it, thus minimising the efficacy (Kondo et al., 2021). Furthermore, Kondo and colleagues suggest that there might be a gap between the awareness people might have about measures, and their understanding and capacity to effectively deploy them, suggesting that communications should include practical information about implementation options (e.g. about behavioural measures). Additionally, the effective adoption of behavioural measures might be impacted by the way policies are delivered; behavioural change policies that require people to opt in, and those with high implementation costs can lead to selective uptake and might not be effective in reducing health inequalities (Public Health Scotland, 2023). For example, there is a growing link between fuel poverty and access to mechanical cooling where "policies or actions to address climate impacts may not equally benefit everyone in the community" (ibid., 2023, p. 11).

Researchers argue that 'cooling poverty' is a systemic issue, unequally impacting people and linked to inadequate infrastructure, be it physical infrastructure (buildings, cooling systems, etc.), social infrastructure (networks of support, social resources, etc.), or intangible infrastructure (such as knowledge or behavioural adaptive mechanisms) (Mazzone et al., 2023). In the UK, the need for equity in relation to overheating and cooling has been raised, particularly among persons with low income who have expressed that active cooling, but also minor passive adaptations to their houses, are sources of concern (Hoggett et al., 2024). The energy costs associated with a growing demand for cooling linked to increases in temperatures can lead households into summertime energy poverty, exacerbating climate-related inequalities and leading to potential health implications for those unable to afford cooling (UKHSA, 2023b).

The adoption of behavioural and cultural measures is further complicated by the fact that people at higher risk might not necessarily consider themselves vulnerable, which can in turn limit their awareness, knowledge and take-up of behavioural protective measures (Wolf et al., 2010; Erens et al., 2021; BRC, 2023a; Howarth et al., 2024a). Challenges related to people's perceptions of hot weather, the different impacts of heat on different vulnerable individuals, and other misconceptions about extreme heat further complicate communications and impede wider diffusion of the adoption of extreme heat mitigation and adaptation behavioural measures (Ravishankar and Howarth, 2024). For instance, in the UK people are less likely to avoid drinking excess alcohol, spend time in cooling places or wear wet clothing, despite many people believing that these and other such protective measures would be effective (BRC, 2023b).

Wider socioeconomic factors can also influence people's capacity to have access to resources and information and hence leave some individuals without options to properly manage their heat risk. This can significantly impact groups that are already in situations of vulnerability such as older individuals or people in socioeconomically marginalised situations (Climate Resilience Dialogue, 2024).

Institutional measures: complexities and linkages

From an institutional perspective, evidence from the UK suggests that heat adaptation and mitigation policies that seek to minimise emissions do not receive enough political attention and lack sufficient funding. This makes implementation harder, complicating decision-making processes and prioritisation (Howarth et al., 2024b, 2025). Additionally, short- and long-term management of heat risk has been found to be negatively impacted by the absence of clear strategic direction and leadership, as well as adequate institutional structures able to deliver the necessary coordination and collaboration across agencies to achieve effective actions (Ravishankar and Howarth, 2024). These issues are not limited to the UK, with evidence of similar challenges impacting institutional heat adaptation and mitigation responses recognised in other countries. For instance, Kearl and Vogel (2023) discuss this in the context of the US, suggesting that the fragmentation of policy, authority and control over heat adaptation and mitigation pose a major governance issue, impacting institutions' capacity to deliver effective heat response strategies.

A study conducted in Greater Kuala Lumpur, Malaysia (Ramakreshnan et al., 2019) concluded that a combination of resistance to scientific knowledge, poor dissemination of evidence about the urban heat island effect among policymakers, and policy negligence (e.g. local authority departments' siloed working) was leading to an underestimation of extreme heat and impacting the way it was managed at the urban scale. In contrast, members of the academic community, practitioners, urban developers and the non-governmental organisation (NGO) sector involved in the study displayed a high level of awareness and concern about the need to address extreme heat in local urban policies. This example outlines the need for holistic and synergistic policy and governance approaches to address extreme heat that foster interdepartmental and intersectoral cooperation among different political spheres and actors (ibid.).

Due to the multifaceted nature and impact of extreme heat, significant challenges in the identification of those responsible for the implementation of adaptation and mitigation measures exist across the world, and this is further complicated in instances where national and city-level governments are led by entities with diverging political views (Farhan et al., 2024). In the US, for example, there is a great divide in the way climate-related discussions are carried out and perceived by people with different political affiliations which has repercussions for the levels of trust and perceived credibility of the scientific community working on climate issues (Funk and Kennedy, 2016). For instance, results of a survey conducted by the Pew Research Centre showed that "72% of conservative Republicans say the media exaggerates the threat of climate change, while 64% of liberal Democrats say the media does not take the threat of climate change seriously enough" (ibid.), which provides an indication of the level of polarisation around climate change debate in the country. These results are in line with research findings about extreme heat and global climate change risk that suggest that people with liberal political beliefs are more likely to support policies addressing extreme weather compared with individuals who consider themselves conservatives or moderate (Yazar et al., 2022).

To add to the complexity, Mees and colleagues (2015) suggest that extreme heat responses require joint multi-stakeholder responsibility and leadership. For example, extreme heat response often involves state actors such as local authorities, the health system and fire department, non-governmental civil society groups such as the Red Cross, private sector, service providers and faith-based groups – particularly when it comes to protecting those most vulnerable. From an economic standpoint, the International Labour Organization (ILO) estimates that US$2.4 trillion and an equivalent of 80 million full-time job losses associated with occupational heat impacts are expected by 2030 (ILO, 2019). The intensification of extreme heat constitutes an occupational health hazard for all workers, which requires the re-evaluation of existing occupational health and safety legislation (ILO, 2024). While changes to safeguarding measures for workers are necessary, the implementation of measures aimed at changing working patterns and practices, and putting in place maximum temperature thresholds (Sacares, 2023) could also significantly impact productivity, workers' earnings and labour costs for employers (Tigchelaar et al., 2020). Humphrys (2024) argues that seeking a solution to a, thus far, narrow and fragmented approach to occupational health in the context of a changing climate will require solutions that go beyond the usual consultations between government, industry and labour and address the redistribution of risks, burdens and benefits across all the parties concerned. This further emphasises the need for collaboration and agreement across actors from different sectors to tackle extreme heat risk.

Infrastructural and technological measures: complexities and linkages

With an estimated 30% of global energy consumption and 26% of global energy-related emissions directly linked to building operations (IEA, 2023), extreme heat adaptation and mitigation within this sector can potentially lead to significant contributions towards resilient net-zero. However, retrofitting existing buildings and replacing energy-intensive and outdated technologies can be complex, slow and expensive (Miu et al., 2018; DLUHC et al., 2024). Built environment interventions may also increase emissions due to extensive physical reconfigurations and increased energy demand related to construction and maintenance (Sharifi, 2020). Additionally, some infrastructural and technological measures can lead to unintended consequences. In regions with cold winters, such as northern Europe, including the UK, solutions such as cool roofs can lead to potential problems during the cooler seasons, by impeding the absorption of solar radiation (Tian et al., 2023), prompting greater use of heating which in turn can increase heating-related emissions.

In the case of the UK, where existing buildings are predominantly built for winter conditions (e.g. with insulation and double glazed windows), during the summer months (but also at other times of the year) households are at high risk of overheating (Howarth et al., 2024b). Furthermore, the fact that British buildings are not particularly suited for extreme temperatures can result in increased energy demand during both extreme heat in summer and extreme cold in winter (ibid.). Measures targeting outdoor spaces can also be problematic. The implementation of solutions such as cool streets (e.g. using light-coloured coating pavements) can lead to reductions in surface temperatures but can also increase the amount of heat directed to the bodies of people standing right on top of such surfaces (Schneider et al., 2023). The use of misters can be effective to cool down the air temperature, helping cafes and restaurants to continue serving during hot days, for example; however, they can also waste precious water resources if not properly deployed (Vanos et al., 2022).

Nature-based measures: complexities and linkages

While nature-based solutions can provide effective contributions to heat adaptation and mitigation, these measures present a range of complexities across different areas. As a starting point, nature-based solutions can be applied widely to different contexts and sectors, but a one-size-fits-all approach is not viable. Such measures can help protect against heatwaves, e.g. by reducing temperatures through evapotranspiration and shade in vegetated areas. They can also help protect against flooding (e.g. by increasing permeable surfaces to limit storm water runoff and using vegetation to stabilise slopes and reduce the risks of landslides), drought and water scarcity (e.g. by employing vegetation and waterbodies to retain water and allowing aquifers to recharge), and sea level rise and coastal flooding (e.g. by restoring and protecting vegetation on wetlands, mangroves and dune ecosystems) (C40 Knowledge Hub, 2021). However, to maximise their benefits, co-benefits, and mitigate potential disbenefits when managing heat risk, these type of solutions require tailored approaches that take into consideration the local climate and existing environmental, cultural and economic contexts, all of which can affect the uptake and long-term sustainability of options (Curt et al., 2022).

For instance, in cities with historic buildings, nature-based interventions need to consider existing built environment characteristics such as building styles and typologies. While poorly developed nature-based interventions could lead to potentially negative impacts on buildings, such as the building material's biodeterioration (e.g. plants' roots can create cracks or loosen mortar; microbes and animals can damage materials' surfaces), loss of value, or obstruct maintenance operations, properly developed measures can protect heritage (e.g. reducing temperature-related weathering processes and the impact of rain on materials) while also reducing the urban heat island effect, maximising the mutual gains that can be obtained in terms of heat adaptation and mitigation and heritage conservation (Coombes and Viles, 2021). Urban greening initiatives such as tree planting require strategic planning to ensure that optimal cooling benefits are created. For instance, research conducted in the Greater Sydney area in Australia found that high trees with dense canopies can lead to reductions in day-time temperatures, due to shading and evapotranspiration, but they can trap warm air under their canopies at night (Wujeska-Klause and Pfautsch, 2020). Similarly, in the case of trees located near blue spaces, humid air can become trapped under the canopies in wind-sheltered areas, resulting in a reduction of evapotranspiration that can produce increases in temperature and uncomfortable environmental conditions (Gunawardena et al., 2017).

The distribution and size of green areas across the city can also impact the cooling benefits achieved through nature-based measures. Results from a study developed for the city of Phoenix, Arizona indicate that clustered green spaces can enhance local cooling, but their cooling benefits at the regional level are lower compared with increasing green spaces in a spatially dispersed pattern (Zhang et al., 2017). The cooling effect of green spaces also varies from day to day. Measurements conducted in Kensington Gardens (London), indicate a variability in the cooling boundary (the extent to which the park has a cooling effect on its surroundings) ranging from 20m to 400m, and changes in the cooling magnitude varying between 4.0°C and 0.4°C on different days (Doick et al., 2014). In addition to the distribution and size of green spaces, their cooling effects are also influenced by differences in factors including plant types, foliage colour and density, canopy and soil characteristics, and water availability (Rahman et al., 2020). Also, while trees have been found to have a higher cooling intensity than shrubs (1.35°C higher) (Wang et al., 2023), a combination of both can decrease particulate matter inflow from roadways to pavements (Jeong et al., 2022), providing a joint protective effect from heat and air pollution. This emphasises the importance of promoting nature-based measures that provide multiple benefits, including by choosing the right plants, while also promoting diversity of solutions to maintain public acceptance and long-term support (Cameron and Blanuša, 2016).

To add to the technical complexity, increasing vegetation and tree canopy coverage in urban areas can be costly. As pointed out by Kearl and Vogel (2023), tree planting only constitutes a portion of the lifecycle costs of green infrastructure-based measures: to maximise the cooling benefits trees need to grow and reach maturity and they require regular attention, maintenance and care. Additionally, the presence of trees can lead to property damage, impacting homes due to land subsidence, for example (O'Callaghan, 2005), or damaging pavements and road infrastructure (Mullaney et al., 2015), resulting in further potential costs for repairs and compensation. For instance, costs associated with conflicts between root growth and pavements [sidewalks] reported across 18 cities in California included several millions of dollars in annual expenditure linked to pavements, kerbs and gutter repairs, and over US$10 million for trip and fall payments and associated legal staff's time (McPherson, 2000).

In addition to these economic implications (e.g. unintended damage to existing infrastructure, implementation costs), the creation and maintenance of certain nature-based measures (such as green roofs and façades, but also extensive urban forests) can lead to considerable amounts of carbon dioxide emissions. For example, in the case of urban forests, emissions can derive from dead trees and the decomposition of organic matter, and from the use of machinery such as woodchippers, chainsaws, backhoes and the vehicles needed for maintenance (Nowak et al., 2002). However, with appropriate design (e.g. prioritising species that require minimum maintenance) and management practices (e.g. limiting the use of energy-intensive maintenance practices), the magnitude of emissions can be significantly lower than the emissions' sequestration capacities of urban forests (Strohbach et al., 2012).

Additional concerns related to the implementation of nature-based solutions can arise from the use of pesticides in urban green spaces, which can lead to contamination, with negative effects on human and ecological health (Meftaul et al., 2020). For example, pesticides can infiltrate groundwater systems, impacting water quality, causing acute levels of toxicity among beneficial insects (such as bees) and water invertebrates (such as shrimps), and they have also been associated with birth defects, cancer and hormone disorders among other negative effects on human health (ibid.).

Finally, the implementation of nature-based heat adaptation and mitigation measures can impact urban socioeconomic dynamics or lead to conflict with other urban adaptation strategies. This complicates decision-making as multiple competing priorities require a thorough understanding of the trade-offs and co-benefits that different strategies entail. In this context it is important to identify solutions that address multiple socioeconomic, environmental and health-related co-benefits and can maximise buy-in from all those involved in the processes (Sharifi et al., 2021). For example, studies have shown that people value their involvement in designing and delivering interventions in green spaces, which can also lead to an increase in environmental awareness (Dobson et al., 2019). Instances of conflicting policies include development and enhancement of green infrastructure that leads to population displacement in the communities of vulnerable individuals the interventions were aiming to support, due to unintended increases in real estate value and gentrification (Anguelovski et al., 2019). In other cases, nature-based measures can conflict with emissions reduction strategies linked to urban densification, that can, for example, have a positive impact on transport-related emission reductions but in turn can result in increased urban heat island exposure and limited land availability to develop nature-based measures (Sharifi, 2020).

4. Conclusions and recommendations

This report has focused on the exploration of existing low-emission cooling solutions to extreme heat through a review of international, UK- and London-focused evidence.

With temperature extremes and heatwaves increasing in magnitude and frequency worldwide, extreme heat has become a global concern, particularly for urban areas, where the problem is exacerbated by the urban heat island effect. Extreme heat has a range of impacts across multiple sectors and scales, including significant concerns for the environment, infrastructure, energy consumption, livelihoods and human health. There is growing consensus that heat risk is not confined to the summer months only and management and preparedness require behavioural and cultural, institutional, infrastructural and technological, and ecosystem- or nature-based measures.

In London, extreme heat is not distributed evenly across the city, with some boroughs, building typologies and residents at higher risk than others. Settings such as health and social care facilities, schools, prisons and residential buildings are at higher risk due to overheating and the higher level of vulnerability of their occupants. Heat responses in the city are fragmented across different areas and do not follow a strategic action plan; they require multi-stakeholder collaboration across different sectors and scales. The London Climate Resilience Review and the extreme heat exercise 'Operation Helios' highlighted the city's need for a heat management strategy, a larger evidence base and learning opportunities related to heat planning and heatwave response, regional and local heat response plans, improved public messaging, and addressing inequalities in heat risk. Furthermore, a clear and robust heat governance framework with detailed roles and responsibilities is needed to bridge existing governance gaps across multiple sectors and organisations.

The development of robust strategic low-emission heat action planning is needed as the inter-relationships between heat risk management measures can influence the outcomes of implementation in the short and long term (both positively and negatively). Maladaptation and mal-mitigation remain serious threats in relation to heat risk management due to existing gaps in awareness, vulnerability perception and implementation at different levels (institutional and individual) and across different sectors. Siloed-working, limited cross-sectoral collaboration, political polarisation and the lack of clear heat risk management governance structures and funding are hindering progress in terms of heat adaptation and mitigation. Blind spots in different areas (e.g. heat occupational hazard, heat vulnerability and heat governance) can increase heat risk for individuals already considered vulnerable (such as outdoor workers, incarcerated people and people with disabilities) or lead to unintended greater emissions. The cost and difficulties associated with some measures, but also their unintended consequences, can further increase the heat inequality divide, which reinforces the need for upstream and midstream policy that addresses the removal of barriers. Finally, the implementation of some measures might lead to increased emissions, further exacerbating warming in the long run; careful consideration for emission reductions needs to be made when choosing the portfolio of measures to be implemented.

Summary of recommendations for the UK

1. **Give higher prominence to low greenhouse gas emission approaches to enhance heat risk preparedness.** Siloed approaches to heat risk preparedness, prevention and protection fail to provide a full picture of the complexity of the issue. Low-emission responses are needed to ensure effective responses do not make the underlying issue worse, and that unintended consequences and complexities are fully considered.
2. **Implement fully-funded, year-round, complementary low-emission preparedness and responses to heat risk.** Efforts to tackle the impacts of extreme heat and better prepare the UK for these impacts without increasing emissions must be appropriately funded and bring

together passive and active measures that are behavioural and/or cultural, institutional, infrastructural and/or technological, and ecosystem- or nature-based. These responses and general preparedness to heat need to be considered as a year-round issue, not just limited to summer periods.

3. **Reduce over-reliance on responsive measures**. Proactive responses to heat risk are needed to enhance low-emission approaches to improve heat risk preparedness and resilience. Behavioural and cultural measures must be rebalanced to enable more room for preparatory and preventative approaches that would reduce an over-reliance on reactive and protective responses.
4. **Identify and integrate 'non-negotiable' elements into measures**. Essential, 'non-negotiable' elements must be identified and carefully integrated into heat preparedness and responses to ensure the use of active responses (such as energy-intensive air conditioning systems) that may result in emissions are part of a broader solution for heat risk preparedness in which those most affected and vulnerable to heat are not put further at risk (e.g. in hospitals, prisons and those in domiciliary care, school and care settings).
5. **Learn from others**. Institutional approaches to low-emission heat preparedness and prevention in the UK must learn from international experience and carefully consider establishing appropriate mechanisms such as Heat Officers and localised Heat Health Action Plans to pre-empt the severity and urgency of heat risk the nation will face during and outside heatwave periods.
6. **Address heat inequalities and unintended consequences**. While effective low-emission cooling measures can be implemented, such as green spaces or urban water parks, if access to these facilities is not equal or fair, or unintended consequences are not properly considered, this can further enhance disparities between vulnerable groups.
7. **Approach heat vulnerability as a dynamic phenomenon**. The way in which vulnerability to heat is determined needs to be reviewed to better prioritise low-emission approaches. Those who are not considered vulnerable to heat could become vulnerable particularly during Level 4 Heat Health Alerts. Although groups most vulnerable to heat are known (and include children under the age of 5, adults over 65, those with underlying health conditions, pregnant women and outdoor workers), research suggests some of these groups (e.g. those over the age of 65) do not tend to identify as vulnerable, which may limit their awareness, knowledge and take-up of behavioural protective measures that can minimise their exposure to heat.
8. **Develop and implement Monitoring, Evaluation, Accountability and Learning (MEAL) standards and practices**. The implementation of heat adaptation and mitigation measures (e.g. behavioural and/or cultural, institutional, infrastructural and/or technological, and ecosystem- or nature-based) need to incorporate monitoring and reporting systems that provide reliable success measures and incorporate information related to emissions and emissions-saving alternatives.

Limitations

This report has focused primarily on measures within the behavioural and/or cultural, institutional and ecosystem- nature- based domains, covering only partially infrastructural and/or technological measures. This is a result of our assumption being that infrastructure and/or technological solutions will be an important part of the response to prepare and adapt the UK to heat, and hence this report has focused on those solutions that provide opportunities to adopt measures that produce the least amount of emissions. While the report has aimed to cover evidence of emissions and emissions-saving considerations in the field of heat adaptation actions, the limited availability of evidence has restricted our capacity to provide more comprehensive accounts in this area. Furthermore, contrary to our initial ambition, the heterogeneity of metrics and reporting practices employed in heat adaptation measures implemented across different fields have limited this review’s capacity to provide more in-depth accounts on cooling magnitude and heat risk management success measures.

Finally, the report, in line with heat risk management practices common in the UK and Europe, has focused largely on measures linked to human health. However, we acknowledge that extreme heat has important implications beyond human health and wellbeing (such as the impact on animals and plants, livelihood systems and the water cycle), that were not covered in this review.

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Appendix: Measures for cooling in cities – case studies

The case studies identified in this Appendix are part of past and ongoing measures to address extreme heat in cities worldwide. They comprise initiatives by national and local governments, international and national third-sector organisations, academics and private stakeholders, among others. These actions are representative of extreme heat adaptation and mitigation measures deployed at different stages (long-term development and planning, pre-heat, during heat events, post-heat). Furthermore, they address individual, community, organisational/institutional and nature-based actions to bring in cooling across a range of scales: body-human, households/buildings, neighbourhoods-cities, regional, national and international. The measures to address extreme heat in cites presented comprise active and passive measures linked to four main thematic families (as per Section 1 above):

1. Behavioural or cultural
2. Institutional
3. Infrastructural or technological
4. Nature-/ ecosystem-based

It is important to clarify that some measures might fall completely within one of the thematic groups or scales, while others might combine actions across the thematic spectrum, work at different scales or involve diverse stakeholders. Finally, this selection does not include large-scale active infrastructural/technological solutions such as cooling districts, as these did not fit within the scope of the review.

Case Study 1. Ahmedabad Heat action plan (India)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? The project is the result of the development of an international partnership aimed at developing climate change adaptations focused on public health in India. It started as part of a 'Joint Indo-U.S. Climate Change and Public Health Workshop' held in 2009 in Goa, India. Ahmedabad Municipal Corporation (AMC) partnered with the Natural Resources Defense Council (NRDC) and the Indian Institute of Public Health Gandhinagar (IIPH-G) to develop an Ahmedabad Heat Action Plan (HAP). In the initial stages the project saw the involvement of other partners. For more details on the HAP development see Knowlton et al. (2014).

What problem(s) did the action address? The initiative started in response to the May 2010 severe heatwave that led to multiple deaths in the region of Ahmedabad.

Cost of implementing the action? Not disclosed.

Cost of maintaining the action? Not disclosed.

Description of initiative (including 'pre, during, post' dimensions) The heat action plan considers actions across four main areas:

- Early warning system: formal communication channels have been created to reach key stakeholders such as government agencies, health officials, first responders, community organisations and media outlets. Extreme temperature forecasts are issued by the Indian Meteorological Department's (IMD) Meteorological Centre located in Ahmedabad.
- Public awareness and community outreach: Reaching people to communicate messages about heatwaves, how to protect themselves, and how to avoid heat stress.
- Capacity-building of key actors: Training of medical staff in different position so that they can effectively recognise, prevent and manage heat-related illness.

- Reducing heat exposure and promoting adaptive measures: These include launching a city-wide cool roof programme.

During the post-heat season, the AMC nodal office organises a yearly evaluation meeting with all the relevant stakeholders.

How did it increase resilience? A study estimated 1,190 yearly deaths avoided following the implementation of the HAP (Hess et al., 2018).

Potential for replication? Due to its success, lessons learned from Ahmedabad have been used to develop a seven-step process to support other cities in developing their action plans that comprise:

1. City engagement

2. Vulnerability assessment and establishing heat-health threshold temperatures

3. Developing a heat action plan

4. Team preparation and coordination

5. Implementation and monitoring

6. Evaluating and updating the plan

7. Strategies for reducing extreme heat and adapting to climate change. (City of Ahmedabad, et al., 2015)

Any follow up evaluation and monitoring? An evaluation of the system suggests that the Heat Action Plan warnings were associated with summertime all-cause mortality rate reductions and that the plan could serve as a guide for other cities aiming to implement similar extreme heat-related initiatives (Hess et al., 2018). Worldwide, heat action plans have been developed in many countries. Their distribution, however, is uneven across continents, with the majority of plans developed within European countries (Kotharkar and Ghosh, 2022). A set of heat action plans from different countries is available through the Global Heat Health Information Network.

An updated version of the HAP was developed in 2019.

Further information:

www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2018.pdf
https://assets.publishing.service.gov.uk/media/57a08984e5274a27b2000105/CDKN-Ahmedabad-Paper.pdf

https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2019-update.pdf

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Case Study 2. Spray parks in Cape Town (South Africa) and El Paso (US)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? Spray parks have been developed on the initiative of the city local authorities in both cities to provide cooling alternatives specifically targeting children.

What problem(s) did the action address? The lack of cooling spaces within vulnerable neighbourhoods.

Description of initiative (including 'pre, during, post' dimensions) The city of Cape Town has developed a network of spray parks designed to keep children cool and active during hot weather. The facilities, embedded within urban parks, provide shaded areas for adults in addition to the water spray games targeting mainly children – from toddlers to teenagers (City of Cape Town, 2024). This solution provides a safe environment for children to cool down, while also using less water than a swimming pool that gets filtered and recirculated through the system (15-20% less compared to a medium size municipal pool (Singh et al., 2020) (Arrighi et al., 2020). These facilities are available at six different locations in low-income areas in the city, providing free, disabled-friendly access to the spray areas during the summer months. This solution constitutes a water-based cooling alternative for those who don't know how to swim or are afraid to (CapeTownMagazine.com, 2016).

Similar interventions have been developed by the city of El Paso, in Texas, with 11 spray parks active across the city (City of El Paso, 2024b). As part of the city's Department of Public Health 'Be Climate Ready' campaign, sunscreen is available for residents for free across several locations, including the spay parks (City of El Paso, 2024a).

How did it increase resilience? By providing cooling facilities in urban parks within heat vulnerable neighbourhoods.

Co-benefits? Water savings compared with municipal pools, increased accessibility, and an incentive for active playing while staying outdoors during warm weather.

Did any maladaptation or unintended consequences emerge? Spray parks have been the object of vandalism which has hindered their operations: see https://kisselpaso.com/why-havent-the-city-of-el-paso-spray-parks-opened/

Some of the parks have not worked as expected: see https://cbs4local.com/news/local/people-share-frustration-due-to-spray-park-in-northeast-el-paso-not-working

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Case Study 3. Mobile cooling, buses and tents – Hanoi (Vietnam) and Phoenix (US)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? In Hanoi the action was identified and developed by a partnership between the Vietnamese and German Red Crosses. In Phoenix (Arizona) the initiative was identified and developed by the city.

What problem(s) did the action address? Providing cooling opportunities for vulnerable individuals during heatwaves. In Hanoi vulnerable individuals included street vendors and motorists. In Phoenix, it included rough sleepers.

Description of initiative (including 'pre, during, post' dimensions) As part of a wider heat emergency preparedness and response initiatives, a partnership between the Vietnamese and German Red Crosses has led to the deployment of mobile cooling centres in the city of Hanoi. The use of air-conditioned buses, paired with cooling tents, was used to provide relief to vulnerable people. The buses drove around the city disseminating heat awareness and protection messages and stopping in strategic locations to provide cooling opportunities for street vendors and motorcycle riders (Arrighi et al., 2020). The focus on these particularly vulnerable groups was part of the project strategy based on forecasting and anticipatory actions which had previously collected information on vulnerability and protective behaviours among outdoor workers (Lohrey et al., 2021). In addition to encouraging the adoption of protective behaviours, volunteers were trained to recognise the symptoms of heat exhaustion and provide first aid assistance through in case of need (Vietnamese Red Cross and German Red Cross, 2019).

The use of cooling buses and mobile cooling centres (tents) during heatwaves has also been adopted by the city of Phoenix, Arizona as part of its heat response actions. Cooling tents have been installed in proximity to encampments and a mobile drinking water unit was planned to deliver cool water in strategic locations across the city (City of Phoenix, 2023). In the past, buses have been deployed to locations where numerous emergency calls related to heat issues have been reported, for instance, where there is a concentration of unhoused individuals (ABC15 Arizona, 2023).

How did it increase resilience? By providing people with resources and information to protect themselves during heatwaves. In the case of Hanoi, the initiative also included heat-health management and response training of volunteers. In the case of Phoenix, by providing unhoused people with opportunities to increase their adaptive capacity by recuperating in a cool place during extreme heat.

Case Study 4. Telephone support programmes – Australia, Spain and Canada

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? In Australia the action was identified and developed by the Australian Red Cross in partnership with the South Australian Department of Human Services. In Spain the action was identified and develop by the Spanish Red Cross. In Canada, the system was developed and tested by a group of academics in Montreal.

What problem(s) did the action address? The action focuses on reaching vulnerable individuals with information about heatwaves and reminders about protective behaviours that can be adopted. In the case of Spain and Australia the system also worked as a way to monitor vulnerable people and deploy emergency services in case of need.

Description of initiative (including 'pre, during, post' dimensions) Remaining in contact with vulnerable individuals during periods of hot weather can serve the dual purpose of awareness raising and monitoring, which are both relevant for the progressive improvement of Heat Health Adaptation Plans (WHO, 2021). Telecross REDI, a programme run by the Australian Red Cross and funded by the South Australian Department of Human Services, calls pre-registered individuals to remind them about the protective measures they can follow once an extreme heat event is declared. In case of consecutive missed responses or manifested emergencies, at-home checks or emergency services are deployed. This service (among other parts of the South Australian Heat Health Warning System) has been evaluated as a cost-effective 'no regret' heat response measure (Williams et al., 2022).

An analogue service, run with the support of volunteers, has been deployed by the Spanish Red Cross to share heat-related information with vulnerable individuals from July to September (Arrighi et al., 2020). The service is structured around fortnight scheduled calls during which individuals are asked about the protective behaviours they have been adopting and are reminded about personalised protective measures they can take to protect themselves. An alternative system has tested automated calls in Montreal, to raise awareness and reduce the use of health emergency services among at-risk individuals. Results of the test suggested that messages disseminated to specific groups at tailored extreme heat thresholds could support individuals, particularly those who are more vulnerable (Mehiriz et al., 2018).

How did it increase resilience? By providing elderly individuals with information about ongoing heatwaves and what they can do to protect themselves and remote monitoring to promptly deploy emergency services in case of distress.

Case Study 5. Individual-household adaptation – Hong-Kong

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? Action identified and developed by the Hong Kong Red Cross during its 2021-2022 operation year.

What problem(s) did the action address? Increasing the resilience of vulnerable individuals living in inadequate housing.

Description of initiative (including 'pre, during, post' dimensions) Within the framework of its effort to strengthen the extreme weather resilience of vulnerable individuals living in inadequate housing, the Hong Kong Red Cross has provided home improvements and disaster preparedness supplies to a total of 90 households during the period covered by its 2021-2022 annual report (Hong Kong Red Cross, 2022a). The initiative consisted of identifying vulnerable individuals/households, assessing their homes in relation to the risks posed by extreme events, and providing tailored adaptation interventions and supplies.

Among the heatwave response items provided, electric fans were distributed to those in need; for example, to those individuals living in accommodation without windows (Hong Kong Red Cross, 2022b). Fans have been found to be effective during heatwaves under certain conditions (Jay et al., 2015); however, evidence suggests that above certain thresholds and for individuals with reduced physiological heat response capacity they can become dangerous (Meade et al., 2024). For instance, available advice issued by the UK Health Security Agency discourages the use of electric fans when the temperature is above 35°C (UK Health Security Agency, 2024).

How did it increase resilience? By providing house adaptation to vulnerable individuals.

Case Study 6. Cool pavements and streets – Los Angeles and Phoenix (US)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? The initiatives were identified and developed by the City Los Angeles (California) and the City of Phoenix (Arizona).

What problem(s) did the action address? The action addresses the urban heat island effect.

Cost of implementing the action? US$11 million between fiscal year 2020 and 2023 in Los Angeles (see https://www.nbclosangeles.com/news/local/how-effective-is-cool-pavement-in-la/3248308/)

US$3 million US dollars for the pilot project in Phoenix (see https://azbigmedia.com/business/heres-how-cool-pavement-pilot-program-is-impacting-phoenix/)

Description of initiative (including 'pre, during, post' dimensions) In 2019, the City of Los Angeles launched the project 'Cool Streets LA'. The initiative was aimed at confronting the impact of climate change at the neighbourhood level by combining tree planting, shaded bus benches, hydration stations and cool pavements (City of Los Angeles, 2019). Cool pavement interventions focused on coating existing streets with a light-coloured coating to increase surface albedo. A study conducted by Ko et al. (2022), confirmed that these interventions can generally reduce air temperature, but reported uncertainty on cool pavements' capacity to provide a viable solution in terms of human health and wellbeing. Another study conducted on similar interventions in the city of Phoenix concluded that while cool pavements can reduce temperature under certain metrics, they can result in increased body-height radiation under certain conditions, hence suggesting that "these solutions should not be used on surfaces with high daytime pedestrian use as it will increase heat load on the body" (Schneider et al., 2023, p. 7).

How did it increase resilience? By reducing temperature in the neighbourhoods as part of the programme.

Known cooling impact(s) Los Angeles: Up to 5.56°F surface temperature reduction in street surface with coating compared to older road surface (see https://scag.ca.gov/sites/main/files/file-attachments/tt022019_coolpavement.pdf?1605822043).

Phoenix: Cool pavement (CP) surface temperature was, on average, 12.0°F and 10.5°F lower than the asphalt concrete at noon and during afternoon hours (ranging from 9–16°F lower), and 2.4°F lower, on average, at sunrise. At 6 feet high, the temperature was lower above the CP than the non-treated surface in the evening by approximately 0.5°F (ranging from 0.9°F lower to 0.1°F higher), which may help reduce the nighttime urban heat island effect. Daytime differences averaged 0.3°F lower above the CP (ranging from 1.2°F lower to 0.2°F higher). Mean radiant temperature, representing a human's total radiant heat exposure walking on the surfaces, was increased at noon and during afternoon hours by approximately 5.5°F on average (ranging from 2.6 to 9.2°F higher), due to higher surface reflectivity.

Did any maladaptation or unintended consequences emerge? Cool pavements can reduce temperature under certain metrics; they can result in increased body-height radiation under certain conditions (see above). Divergent opinions were expressed among residents during the Phoenix pilot, concerning visual appeal and aesthetics, impacts on property values, the longevity of the coating, and surface friction.

Further reading: Full Phoenix evaluation report: https://sustainability-innovation.asu.edu/sustainabilitysolutions/wp-content/uploads/sites/15/2021/09/COPE-Report_FULLFINAL.pdf

Case Study 7. Urban cooling OASIS – Paris (France)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? This action is part of the City of Paris Climate Adaptation Plan and resilience strategy (2018 – ongoing). The pilot initiative was funded by the European Regional Development Fund (ERDF) in the context of Urban Innovative Actions.

What problem(s) did the action address? Climate adaptation project that focuses on addressing the heat island effect.

Cost of implementing the action? 10-school pilot (2018-2022)-EUR 4,995,793.16 (ERDF-UIA funding); subsequent phases EUR 9m per/year for 25 schools (approximate estimate).

Description of initiative (including 'pre, during, post' dimensions) The OASIS project's aim is to create cool islands within densely populated neighbourhoods by transforming existing school playgrounds (yards). Schools were selected as they are widely available across the city of Paris (every resident lives within a 250m radius of a school), they are community hubs (people's children study in those schools, elections and other community activities are held there), and they have the space (schoolyards) to implement changes within the urban fabric. The interventions were co-designed with the community (including pupils, parents and teachers) with the objective of raising awareness around the project objectives, to promote behaviour change, build ownership and foster social interaction and inclusiveness. The schoolyard renovations incorporated biodiversity strengthening (including tree planting, wet swales and rain gardens), soil revitalisation and natural material surface covering, valuing and reusing water, installing shading devices, and developing activities and practices related to the use, valorisation and maintenance of the schoolyards (Ferrer et al., 2022).

More information on cooling schools initiatives developed in other cities has been made available by the C40 Cities network. These include the guidance for climate change adaptation developed for London Schools in 2020. An open-access observatory with completed interventions and recommendations for schoolyard transformations are available to the public.

How did it increase resilience? Providing cooling islands in areas of the city that suffered from heat island effect.

Known cooling impact(s) Preliminary findings on the evaluation of the microclimatic performance of cool island schoolyard restoration conducted on one of the OASIS school sites suggest that these interventions have a cooling effect at the micro-scale (Karam et al., 2023). This study identified potential temperatures offsets in schoolyards of between 2°C and 1°C in daytime temperatures. However, the magnitude of the effect remains limited, although this might be influenced by methodological factors as well as a temporal aspect related to the full development of the vegetation planted (see https://www.sciencespo.fr/liepp/fr/actualites/evaluation-de-limpact-thermique-des-cours-decole-oasis/ and https://cdn.paris.fr/paris/2024/04/08/roc-22-08-etude-cours-oasis-avril-2023-efET.pdf).

Co-benefits? Community involvement in schoolyard design, increased biodiversity within the courts and increased water retention from changes in pavement materials.

Did any maladaptation or unintended consequences emerge? Reductions in temperatures were limited.

Any follow up evaluation and monitoring? (state if there wasn't) Follow up thermal evaluation: https://www.sciencespo.fr/liepp/fr/actualites/evaluation-de-limpact-thermique-des-cours-decole-oasis/. Evaluation on the materials used in the courts: https://hal.science/hal-03778874/document. Additional information: https://uia-initiative.eu/en/operational-challenges/paris-oasis-0

Case Study 8. Urban gardening and farming – Chennai (India)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? Initiative identified and developed by the Chennai Resilience Center (CRC)

What problem(s) did the action address? Urban heat, food insecurity and limited green areas within informal shelters and densely populated areas.

Description of initiative (including 'pre, during, post' dimensions) The Chennai Urban Farming Initiative (CUFI) is a project developed by the Chennai Resilience Center (CRC) to build local resilience to extreme heat while improving food security. The project focuses on transforming roof tops, terraces, paved courts, and other similar urban spaces to increase community resilience. The initiative tackles simultaneously heat preparedness, food security and under/unemployment, by supporting urban farming in vulnerable communities, including homeless shelters, child development services centres, special education schools, and households in informal settlements. As part of their monitoring activities, CRC has set up a temperature monitoring station in one of their terrace gardens.

How did it increase resilience? By supporting vulnerable households to plant and take care of their own urban gardens and farms.

Known cooling impact(s) Findings indicate that during daylight time (6:00am–6:00pm), the spaces directly located under the roof garden are 2-3°C cooler than other rooms directly exposed to sunlight (Ayyangar et al., 2023).

Co-benefits? Supports food security.

Case Study 9. Shading devices – Cordoba (Spain) and Freetown (Sierra Leone)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? The action in Cordoba (Spain) was identified and developed by a group of academics Garcia-Nevado, Beckers and Coch in 2020.The action in Freetown City (Sierra Leone) was identified and developed by a partnership between Adrienne Arsht-Rockefeller Foundation Resilience Centre and the City.

What problem(s) did the action address? Extreme heat exposure in urban areas.

Description of initiative (including 'pre, during, post' dimensions) The provision of shade in the urban environment is a critical component of extreme heat mitigation. As not all shade is equal in terms of heat reduction – buildings' shade provides the highest temperature reductions, followed by trees and canopies – it is important to deliver the "right shade in the right place" (Middel et al., 2021). With building renewal in the urban fabric happening at a slow pace and tree growth taking several years, engineered-artificial shading can provide relatively rapid implementation cooling solutions. The installation of sun sails in the city of Cordoba (Spain) has led to reductions in up to 16°C in surface temperatures, while also helping reduce façade temperatures. This solution achieves similar benefits to those provided by cool coating interventions while entailing only minor modifications to the built environment (Garcia-Nevado et al., 2020).

Freetown City Council, in partnership with Adrienne Arsht-Rockefeller Foundation Resilience Centre and the Atlantic Council, has installed 669 square metres of shade structures, equipped with 40 solar lights, across three major street markets in Freetown. The project's core theme 'Protecting women and girls from extreme heat', aims to provide protection from solar radiation to over 2,300 women working in the city's markets (UNFCCC, 2023). The initiative creates cooler markets for the benefit of shoppers, vendors and their products. While the structure provides shade and protection from the sun, it also provides repair during the rainy season (Adrienne Arsht-Rockefeller Foundation Resilience Center, 2023).

How did it increase resilience? By shading street vendors in Freetown and by cooling street canyons and reducing building façade temperatures in Cordoba.

Known cooling impact(s) In Freetown, the initiative provide protection from solar radiation to over 2,300 women working in the city markets (UNFCCC, 2023). Sun sails in Cordoba led to reductions in up to 16°C in surface temperatures, while also helping reduce façade temperatures.

Case Study 10. Neighbourhood-scale community-built heat action planning – Greater Phoenix (US)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? Joint initiative of The Nature Conservancy, Maricopa County Department of Public Health, Central Arizona Conservation Alliance, Urban Resilience to Extremes Sustainability Research Network, Arizona State University's Urban Climate Research Center, and Center for Whole Communities, Phoenix (USA) – 2018.

What problem(s) did the action address? Extreme heat at the neighbourhood scale.

Description of initiative (including 'pre, during, post' dimensions) The Nature's Cooling Systems project is a joint initiative of The Nature Conservancy, Maricopa County Department of Public Health, Central Arizona Conservation Alliance, Urban Resilience to Extremes Sustainability Research Network, Arizona State University's Urban Climate Research Center, and Center for Whole Communities. One of the project aims was to develop local neighbourhood-scale action plans across three high-priority neighbourhoods. Four key overarching themes were identified: advocate and educate; improve comfort/ability to cope; improve safety; build capacity. While overlapping themes emerged from the workshop organised in the three neighbourhoods, the actions suggested by communities varied across locations. Residents identified different solutions based on the priorities they have identified in their areas. In addition to the definition of the community action plans, the projected aimed at building capacity among citizens to advocate for their heat adaptation and mitigation measures as a way of raising awareness and empowering communities (Nature's Cooling Systems Project, 2019). According to the researchers involved in the project, the initiative was also successful in contributing to leadership development, developing participants' capacity to understand and communicate about complex climate science issues and the associated impacts (Guardaro et al., 2020).

How did it increase resilience? By identifying neighbourhood-scale heat adaptation and mitigation interventions based on community-based action plans. The action also increased community capacity to advocate for heat adaptation.

Co-benefits? Social cohesion, increased awareness.

Additional information: https://issuu.com/crummey/docs/ncsbooklet_tnc_az_highres_2018_offi

Case Study 11. Extreme heat app – Athens (Greece)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? The action was developed within the context of an EU-funded project led by National Observatory of Athens (NOA) in partnership with academic, public and private actors (2017).

What problem(s) did the action address? Increasing population awareness about the risks of extreme temperatures and inducing self-protecting behaviours.

Cost of implementing the action? EUR 572,307

Description of initiative (including 'pre, during, post' dimensions) EXTReme tEMperature Alerts for Europe (EXTREMA) is an app developed by the National Observatory of Athens (NOA) in collaboration with academic and private institutions within the framework of an EU-funded project in 2017. Athens, Paris, Rotterdam, Lisbon, Milan and Mallorca are locations that have adopted 'Extrema'. The platform uses real-time satellite data, models and city-specific data to estimate temperature, humidity and thermal comfort indexes at 1km-squared resolution. The app service can support users in finding the nearest cooling space, nearest water points and the coolest route to get there. It can be personalised to provide user-specific notifications with heat stress risk for the current location and recommendations on measures to reduce risk (EXTREMA, 2018). The app, which was first introduced as part of Athens' extreme heat mitigation and adaptation initiatives, has now evolved into a global platform.

How did it increase resilience? By providing real time updates during extreme heat events and alerting users about protective measures they can take and where they can go to cool down or hydrate.

Additional information: https://extrema.space/

Case Study 12. Green corridors, Medellin (Colombia)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? The project 'Corredores Verdes', or Green Corridors, is an initiative developed by the municipality of Medellin (Colombia).

What problem(s) did the action address? Increasing urban temperatures in Medellin.

Cost of implementing the action? The project had an initial cost of US$16.3 million.

Cost of maintaining the action? US$625,000 per year.

Description of initiative (including 'pre, during, post' dimensions) The initiative is a long-term intervention aimed at increasing and improving green areas in the city of Medellin, providing active travel routes, areas for leisure and sport, and addressing under-developed neighbourhoods in the city. By 2019, 65 hectares of planting had been improved or created across the city waterways and 6.2 hectares along road infrastructure. Up to 2 hectares of impervious surfaces have been converted to planted areas (Ashden, 2019).

How did it increase resilience? The project contributed to the reduction of urban temperatures, while also providing opportunities for active transportation.

Known cooling impact(s) The intervention has already contributed to the reduction of up to 3°C in certain areas of the city.

Co-benefits? It is estimated that one corridor (of the 30 already activated) can absorb 160,787 kg of CO_2 per year and contribute to capturing particulate matter (C40 Cities, 2019). As part of the project, 75 citizens from disadvantaged backgrounds were trained to be city gardeners and planting technicians.

Did any maladaptation or unintended consequences emerge? Unintended consequences: researchers have highlighted that the project might be leading to the displacement or relocation of middle- and low-income families living within the green corridors area of influence which favours the permanence of higher-class citizens who are not threatened by the complex socioeconomic changes the project has put in action (Anguelovski et al., 2019).

Case Study 13. MEER project – reflective roofs, Freetown (Sierra Leone)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? Private/public partnership between MEER (Mirrors for Earth's Energy Rebalancing) and Freetown local authority (2024 – ongoing).

What problem(s) did the action address? Households living in densely populated informal settlements in Freetown experience extremely high temperatures. The project aims to reduce temperatures within urban dwellings in such areas.

Description of initiative (including 'pre, during, post' dimensions) The 'Cool down Freetown!' MEER research program in Sierra Leone, is an experimental project focused on cooling at the single dwelling scale in underdeveloped settlements. The project, which started in February 2023, was developed in partnership with Freetown City Council's Heat Offices and involves graduates from the Fourah Bay College. The area of Kroo Bay, characterised by tightly packed informal settlement houses with roofs close to each other, was selected for this pilot project.

The initiative involved the local community in informative sessions and has consulted them on the impact experienced from extreme heat. Furthermore, MEER has installed a reflective film developed by the firm on dwellings' roofs with the aim of reflecting sunlight and reduce heat absorption in the rooms below.

How did it increase resilience? By reducing the indoor temperature of households in densely populated informal settlements.

Known cooling impact(s) Houses in the neighbourhood where the reflective film has been installed show up to 6°C indoor heat temperature reductions. Roofs with the coating were on average 25°C cooler than those without treatment.

Co-benefits? Knowledge sharing with local academics and workers.

Case Study 14. Chief Heat Officers (CHO) – Adrienne Arsht-Rockefeller Foundation Resilience Center (Arsht-Rock)

How was/were the action(s) (i) identified and (ii) developed (e.g. community led, council led etc.)? The action was identified by the Adrienne Arsht-Rockefeller Foundation Resilience Centre and started in 2021. The action seeks the involvement and financial contribution of the local authorities where the Chief Health Officers are appointed.

What problem(s) did the action address? The action seeks to unify extreme heat responses within local authorities within one responsible officer.

Description of initiative (including 'pre, during, post' dimensions) The Chief Heat Officers (CHOs) cover a role embedded in a selected number of local authorities across the world. The initiative, promoted by the Adrienne Arsht-Rockefeller Foundation Resilience Centre started in 2021. CHO is responsible for unifying extreme heat responses in its cities. The main aim of the CHO is to identify, develop and implement strategies and priority initiatives to tackle heat resilience in the short, medium and long term. Thus far CHO is actively working in the cities of Miami (US), Freetown (Sierra Leone), Santiago (Chile), Athens (Greece), Melbourne (Australia), North Dhaka (Bangladesh), and a global CHO embedded within UN Habitat. CHOs are appointed by local officials who have made heat action a priority for their government, and they work in conjunction with other stakeholders.

How did it increase resilience? By appointing within city local authorities a single person responsible for identifying, developing and implementing strategies and priority initiatives to tackle heat resilience in the short, medium and long term.

Appendix – references

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