Written evidence from the Institution of Mechanical Engineers to the UK House of Commons Environmental Audit Committee inquiry on Heat Resilience and Sustainable Cooling.

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About the Institution of Mechanical Engineers

The Institution of Mechanical Engineers (IMechE) represents 112,000 engineering professionals and students in the UK and across the world. The Engineering Policy unity (EPU) of the IMechE informs and responds to UK policy developments by drawing on the expertise of our members and partners.

This response has been prepared by the EPU with input from the IMechE's Process Industries Division, Construction and Building Services Division and Energy, Environment and Sustainability Group. It has been informed by the Institutions recent report that looks at adapting industry to rising temperatures and future heatwaves, and the supporting blog posts.

What evidence exists on the relationship between heat and human health (mortality and morbidity), and which communities are worst affected?

1. Increased temperatures and heat are closely linked to several health impacts, particularly impacting already vulnerable groups. The body reacts to heat by increasing blood flow to the surface of the skin and by sweating, then as the sweat evaporates the surface cools. However, heat stress can occur when this mechanism of controlling internal body temperature fails and the body cannot shed excess heat. Under such conditions, the body's heart rate increases, and its core temperature rises, the person begins to find it difficult to concentrate, feels unwell, and may experience fainting. Direct consequences include dehydration, heat stroke and heat exhaustion. Ultimately death can result if the body is not cooled down.

2. Between the 30th May and 4th September 2022 several heatwaves occurred across Europe and an estimated 61,000 people lost their lives, either as a direct consequence of the heat itself or because of complications due to underlying health conditions [1]. The analysis of these deaths found that there were 56% more heat-related deaths in women, while more than half were in people over the age of 80[2]. Humidity, however, plays a crucial role in health and productivity as higher humidity levels can hinder physical activity, impacting industrial sectors where there are high levels of physical activities such as construction and in factories [3]. Prolonged exposure to heat can result in chronic heat exhaustion, sleep disturbances, and increased susceptibility to minor injuries and illnesses as individuals lose concentration, take on increased risks and lack opportunities to appropriately recuperate overnight as sleep deprivation takes hold.

3. Dehydration, resulting from hotter days, can put individuals at risk for heat exhaustion, as well as reduced cognitive function. Frequent dehydration may lead to permanent kidney damage [4]. As temperatures rise, the incidence of metabolic diseases, heart attacks, and strokes is likely to increase. Heat exposure has also been associated with temporary infertility in both men and women.

4. High temperatures also have significant effects on the mental health and wellbeing of individuals. Exposure to high temperatures cause disrupted sleep patterns, make individuals irritable, decrease

cognitive function and induce psychological distress and anxiety. Extreme weather events, including heatwaves, can result in damage to property and local environments, fostering a feeling of helplessness and a lack of control, contributing to climate-induced migration. Physical activity is known to reduce the risk for various illnesses and diseases and has several mental health benefits. However, as temperature rise and extreme heat events become more frequent and intense, engagement in physical activity can reduce. Medications taken for mental health conditions can disrupt the body's temperature regulation, posing fatal consequences in combination with extreme heat. During the 2021 heat dome event in British Columbia, Canada, individuals with mental illnesses were more susceptible to death, and those with schizophrenia had three-time higher risk of dying [5].

5. Heatwaves and extreme heat events have been linked to increased short-term mortality rates. In England and Wales, the period between June and August 2022 saw five high heat-periods and led to the number of deaths being 6.2% higher than the five-year average [6]. Elderly individuals, those with pre-existing health conditions, and socioeconomically disadvantaged populations are especially vulnerable.

6. During the 2021 Canadian heat dome, 67% were 70 or older and more than half (56%) lived alone [7]. Most of the deceased lived in socially or materially deprived neighbourhoods and were without adequate cooling systems. The unhoused community are at increased risks of being hospitalised as temperatures rise. Recent research has found that hospitalisation risk for London's unhoused was 35% more likely when temperatures exceed 25°C compared to 6°C [8].

7. Rising temperatures pose serious health risks to workers toiling outdoors in the sun for long hours. Occupations which involve greater physical exertion, like heavy lifting and manual labour, are likely to be more affected, since individuals become exhausted faster and metabolise heat less effectively under strain [9]. Jobs that necessitate workers to wear heavy clothing and personal protective equipment (PPE) are also more likely to be affected by heat stress [10]. Workplace injuries across various sectors surged by 180% during the Canadian heat dome, attributed to insufficient workplace cooling and a lack of awareness about the risks of heat [11].

How can sustainable cooling solutions and adaptation strategies be implemented in such a way as to minimise overheating, reduce energy consumption and prevent overloading of the electricity grid during peak demand?

8. Cooling is a significant contributor to greenhouse gas (GHG) emissions, currently accounting for more than 7% of the world's annual anthropogenically derived total, yet it is a fundamental adaptation tool for dealing with increased temperatures and heat extremes [12]. This dual characteristic presents the UK with a challenge as the nation seeks to adapt. At the core of this challenge is the fact that artificial cooling, primarily delivered through the deployment of mechanical-based technologies (ie 'active cooling') such as traditional air conditioning (AC) units, is typically energy intensive, inefficient, and a high emitter of CO_2 and other GHG emissions. AC units also reject hot air into the external environment and when installed in city and other urban settings can exacerbate the issue of urban heat islands [13].

9. There is a need to ensure that in the design and implementation of cooling, considerations of climate change mitigation outcomes and environmental impacts are fully embedded in adaptation strategies, programmes and actions, in essence a net-zero approach to cooling is required. Delivering net-zero cooling, whilst in parallel balancing environmental, social and economic

benefits and leaving a positive lasting sustainable legacy for future generations, is “Sustainable Net-zero Cooling”.

10. In line with the Energy Hierarchy, the most sustainable option is to reduce the need for cooling in the first place by utilising behavioural change and passive cooling techniques [14]. Beyond doing that, demand for artificial cooling can be met through more sustainable approaches including the use of nature-based cooling solutions, such as water bodies and other heat sinks; making use of renewable and waste energy resources for cooling provision; using energy efficient technologies that avoid refrigerants with high global warming potentials (GWP); and taking a life cycle analysis and circular economy approach to raw materials sourcing, equipment design, manufacturing, deployment, operation, reuse, remanufacturing and end-of-life decommissioning.

11. A whole systems thinking approach which considers the full range of drivers and feedback loops within a system is essential in the case of cooling provision if the UK aims to minimise the demand for active cooling equipment and ensure individual cooling technologies are supported by the broader infrastructural landscape in which they are embedded (such as manufacturing, energy, transport, waste management, etc.), as well as that interdependencies are understood and managed and that components work synergistically and efficiently together.

12. A whole systems approach will also support wider energy system decarbonisation by:
    - reducing the investment need for increased power grid and generation capacity;
    - freeing up limited renewables capacity for other uses;
    - reducing peak energy demand, and therefore preventing overloading of the power grid;
    - creating more room for intermittent renewable and waste thermal energy sources through thermal energy storage systems.

13. At the core of this new way of thinking about UK cooling there needs to be a clear recognition of the primary barrier to progress today, which is that when considering energy provision, the scope of current policy vision is typically constrained by defaulting to electricity and the use of batteries for storage [15,16]. This restricted view misses the point that, in reality, the majority of the energy services required to support a modern society are in fact thermal (i.e. for the provision of heating and cooling). It therefore results in a sub-optimal energy system, potentially making the challenge of transitioning to net-zero and sustainability more difficult than necessary.

14. Specifically, policymakers need to recognise that the provision of cooling could often be better served by [17]:
    - Reducing the need for active cooling in the first place through encouraging behavioural change and deploying passive solutions.
    - Aggregating multiple demands for efficient use of supply, by for example using district cooling network infrastructure.
    - Harnessing available thermal energy resources to meet thermal services, many of which are present in the local natural environs, such as water bodies and other heat sinks, and can often be sustainably utilised.
    - Harnessing thermal energy resources rejected by other human processes and therefore currently regarded as ‘waste’ – waste thermal streams from one process can be used to provide valuable thermal services to another process (for example using the waste cold from LNG regasification), thereby replacing primary energy consumption.
    - Using thermal methods of storage and the utilisation of thermal energy carriers instead of electricity and (chemical) batteries, thereby unlocking otherwise redundant resources of

renewable or waste energy and boosting system flexibility by enabling cold and heat to be used where and when needed.

15. The principal challenge in improving the energy efficiency of active cooling equipment is the pace required to make improvements, which is far beyond what has been historically achieved by technology developers through a 'business as usual' approach. In this regard, overcoming technical constraints to the speed at which efficiency is improved is essential. The Global Cooling Prize has recently illustrated what, given appropriate incentivisation and a concerted effort, can be achieved in overcoming such technical constraints in the case of room air conditioners [18].

16. A key barrier to the uptake of 'best available' high energy efficient technologies is that they often require a greater upfront capital investment cost compared to incumbent cooling options. While per-unit manufacturing costs and market prices may be higher, economic cost savings are often possible from new equipment that meets higher energy efficiency, but these cost savings are typically realised over a relatively long-time frame. The latter can discourage investment, especially where quick returns are expected to drive growth.

17. Other adoption barriers that may slow down the transition include:
    - a lack of relevant standards and regulations;
    - insufficient coordination, cooperation and collaboration;
    - insufficient trust in new, innovative technologies that have low market penetration, and;
    - the additional training required to implement and maintain the new technologies.

18. These barriers need to be addressed through market interventions, such as awareness raising, changes in approaches to procurement practices, financial levers for manufacturers, increased price transparency and innovative business models. Public funding is needed to provide the necessary resources to address key barriers and accelerate the transition to sustainable net-zero cooling practices. For example, public funds can be utilised for 1) supporting training courses for cooling equipment maintenance providers, leading to improved installation and servicing practices; 2) initiating campaigns that discourage the use of inefficient and unsustainable cooling technologies.

19. Specifically, in the case of additional training, the achievement of a sustainable net-zero cooling economy and meeting increasing cooling demand, will be underpinned by appropriate skills and capacity, which if not achieved, carries significant social, economic and environmental risks and may lead to missed opportunities. The demand for the knowledge and skills required to successfully develop and adopt these new technologies will manifest at multiple levels of education and training. While the skills required to design, manufacture, commercialise and market sustainable cooling solutions are high, training of technicians of various grades requires equal attention to ensure proper installation and servicing of next generation, more technically complex, data- and system-connected equipment with alternative refrigerants with low/ultra-low GWP.

20. In addition to closing the skill gaps at all technical levels and attracting new engineers and technicians into the sector, broader training is also needed to create a better prepared market for absorbing these new technologies and ensuring the associated economic, social and environmental benefits are realised. In this regard, continuous education and training provision is needed for all stakeholders, including project developers, contractors and end users, to raise awareness of the benefits of sustainable and resilient cooling access, facilitate behavioural change

and increase the uptake of systems thinking, best-in-class technologies and best professional practice.

What actions can be taken to protect those most vulnerable to the impacts of extreme heat?

21. To protect the most vulnerable from the impacts of extreme heat, several actions can be taken. Firstly, the UK should implement a comprehensive heat health action plan which incorporates early warning systems, timely public and medical advice and improvements of housing and urban planning. It will be vital to prepare health and social systems so that they are able to respond effectively. The Met Office heat health alert initiative is a good first step.

22. The specific needs of vulnerable groups, such as seniors will need tailored approaches. An example of this from British Columbia, Canada, was the recent introduction of free air conditioning to seniors and vulnerable. However, these units need to be "best available" high efficiency models and this approach must be a short-term response whilst retrofitting and energy improvements are made to existing housing. Ideally, rather than air conditioning, housing and buildings will be designed to use natural and passive cooling techniques.

23. To protect workers, employers and employees should co-design strategies for dealing with heat stress which are tailored to the specific needs of the different categories of workers and their workplaces. Setting a meaningful universal upper temperature limit in regulation will be difficult to implement as specifics will vary from industry to industry as working conditions, level of PPE and work-load are sector-dependent, however, sector specific guidance should be produced. Those who work within the gig-economy sector such as food delivery bike riders are particularly vulnerable to extreme weather conditions as breaks and delays impact on their ability to earn.

24. Establish cooling shelters and hubs, particularly focused on supporting economically disadvantaged and unhoused communities. These are energy-efficient and climate-friendly temperature-controlled hubs which are being tested in countries like India and Kenya by the University of Birmingham led Centre for Sustainable Cooling, can provide crucial relief during extreme heat events. Such communal spaces should be strategically located to maximise accessibility for rural communities, in a similar way to natural disaster relief shelters are co-located with motorway service stations in Japan.

To what extent do the Government's Climate Change Risk Assessment and National Adaptation Programme (as well as other related strategies such as the Net Zero Strategy and Heat and Buildings Strategy) identify and address the risks from extreme heat? (Note: The third NAP, covering the five-year period from 2023-2028, is expected to be published in the summer of 2023)

25. The Climate Change Committee's UK Climate Risk Assessment published in 2021, CCRA3, contains a wealth of detailed robust information and sensible recommendations regarding current and future climate change related heat impacts and how to adapt to them. The issues of overheating as well as the provision of cooling approaches as an adaptation strategy is covered extensively in Chapter 5 "Health, Communities and the Built Environment", for the case of people, buildings, and health services, and in Chapter 4 "Infrastructure" with regard to the nation's infrastructure. The latter also addresses the issue of climate change impacts on the availability and quality of water for industrial cooling systems (with particular focus on the power generation sector). Air conditioning and energy demand is extensively covered in Risk H6.

26. The CCC's CCRA3 considers the use of cooling as an adaptation strategy for overheating impacts within the context of the UK needing to achieve its Net-zero targets and therefore the requirement that approaches to its provision must be developed and delivered through the lens of emissions reduction (ie mitigation). In this regard it considers passive cooling approaches as well as the use of low-carbon active (i.e. mechanical) cooling technologies.

27. There is very little evidence in the Government's Climate Change Risk Assessment (CCRA - published in 2022) that the detailed information contained in CCRA3 on climate change induced heat impacts and adaptation using appropriate cooling provision has been integrated. Indeed, there is even less evidence of this, or the adoption of the CCC's recommendations, within the Third National Adaptation Programme (NAP3). The latter has only three mentions of cooling within its 138 pages and references to overheating largely confined to Building Regulation "Overheating: Approved Document O", implemented in June 2022 by the DLUHC [19].

28. Building Regulation "Overheating: Approved Document O" only applies to the construction of new residential buildings, the retrofit of existing homes and non-domestic buildings being identified in NAP3 as being the subject of measures to be developed by DESNZ and further research on relatively long timescales by DLUHC, DESNZ, DHSC and UKHSA. This despite the urgency of action needed on overheating and sustainable cooling provisions and the wealth of information on the topic available within the CCC's CCRA3, as well as more broadly across the peer-reviewed and 'grey' literature. Additionally, within NAP3 there is minor reference made to overheating and adaptation measures in relation to contracts for NHS buildings, as well as in the case of the nation's school and prison estate.

29. The Government's Heat and Buildings Strategy published in 2021 recognises the issue of climate change induced overheating of buildings and the use of cooling as an adaptation strategy, but is focussed on instigating further research and review activities rather than the urgent delivery of specific implementation actions.

Does the current planning framework do enough to encourage heat resilience measures such as cooling shelters, water bodies, green infrastructure and shading to be integrated into urban planning? Where such measures are incorporated, how accessible and successful are they?

30. The UK National Planning Policy Framework (NPPF) sets out the UK wide strategies which should be reflected and adopted within regional local plans [20]. This includes a section with Climate Change requirements. Unfortunately, the level to which the NPPF is adopted varies widely between local authorities, with many having little or no consideration for the measures set out. For example, the requirements are largely reflected within the London Plan, however in many cases the lack of a clear methodology means that they are not well implemented [21].

31. A Daylight Sunlight Overshadowing (DSO) assessment is required by most local authorities. In general, the methodology used across the UK is *BR 209 2022 Site layout planning for daylight and sunlight a guide to good practice* [22]. This includes a requirement to consider sunlight into public amenity spaces with the goal being to maximise the amount of sunlight and to minimise the shading created by new buildings. Clearly, with increasing seasonal ambient temperatures and more frequent, prolonged and intense heat extremes, there is a need to evolve the methodology to consider shade provision in cities during the hottest months of the year.

32. Wind assessments are required by most local authorities for taller buildings. There isn't a common methodology required by local authorities across the UK and the quality of the assessments undertaken is variable. The exceptions are Leeds and the City of London who have published Wind Microclimate Guidelines setting out the minimum standard of assessments to be undertaken [23,24]. Current wind assessments look to reduce wind speeds at ground level with a focus on strong winds which can present a safety issue for pedestrians. During a heatwave event, the provision of a breeze is a key strategy to reduce the urban heat island and create comfortable spaces. This is not currently a consideration by local authorities in their wind assessment requirements. The provision of an "air ventilation assessment" which looks to increase breeze is common practice in warmer climates such as Singapore and could be considered for the UK.

33. In practice, the wind and DSO assessments are typically undertaken by different consultants and there is no requirement to cross reference the shading and wind speeds in a particular urban location. The exception to this is the City of London who require a full Thermal Comfort assessment which considers the risk of high temperatures combined with high humidity, direct sun and low wind speeds and requires building massing to be developed to mitigate the risk [25]. The first iteration of the guidelines published in 2020 considers building massing only and not the benefits of green infrastructure and water bodies.

34. In addition, London Plan policy D9 requires that wind, daylight, sunlight penetration and temperature conditions around the building(s) and neighbourhood must be carefully considered and not compromise comfort and the enjoyment of open spaces, including water spaces, around the building. However, the lack of a stated methodology means that this is currently not implemented consistently across planning submissions.

35. London Plan Policy G5 requires all major developments to include urban greening as a fundamental element of site and building design. The policy introduces the use of an Urban Greening Factor (UGF) to evaluate the quantity and quality of urban greening provided by a development proposal. This is currently only a requirement for "major developments" and not all projects. There isn't a similar requirement set out by other urban planning authorities outside of London.

What can be done to protect the UK's existing public and private sector housing stock from the impacts of extreme heat while ensuring that homes are sufficiently warm in the winter months?

36. The UK has an incredibly diverse range of housing stock, with a range of property age, architecture and scale, and associated regulatory requirements that vary significantly. For new build properties there is a requirement to meet part L of the building regulations which ensures that the buildings are reasonably airtight, preventing unwanted drafts and heat loss through the building fabric during colder winter months. Overall, the entire focus of Part L is to reduce the heating energy requirements for buildings and does not consider the impact of the requirements on summertime overheating.

37. The Daylight Sunlight Overshadowing (DSO) assessment undertaken during the planning process set out minimum daylight levels for new residential properties. Typically, the requirements set out within BR 209 are not met by new developments in urban locations due to the density of buildings and the overshadowing that this creates. The other challenge with achieving the daylight levels set out within BR 209 is that if they are met, they result in unacceptable levels of overheating of the

property during summer months. There is a need for clear guidelines which set out achievable daylight targets and targets which manage the overheating risk from too much solar gain during the summer season.

38. One approach to manage the solar gain within new and existing residential properties during the summer months, whilst ensuring good quality daylight during the winter is installing adaptable shading or blind systems. However, these come at a price which is often unattainable for lower cost housing. Another possible approach would be the addition of shutters which are traditionally included on buildings across continental Europe.

39. Ventilation is a key factor in keeping a property cool. During a normal summer, natural ventilation if well designed can keep a residential property cool. However, during the heatwave that the UK saw in 2022, and predicted future heatwaves, the outside air temperature during the day was too high to provide the required cooling. Active cooling through air conditioning is a high energy option which would ideally be avoided for the majority of properties. Nighttime cooling where air is actively or passively pushed through a property combined with a high level of thermal mass can significantly cool the fabric of a building to provide cooling during the daytime. This would require UK properties to use more material than they currently are and to have actively controlled ventilation systems installed which operate at nighttime and not during the day.

40. A further suggestion would be the installation of ceiling fans as a low energy approach to create air movement which provides cooling during hotter and more humid conditions. This is commonly used in other countries.

What role might reversible heat pumps (which can act as both heating and cooling systems) and other emerging technological solutions, such as the development of smart materials, play in meeting future cooling demands?

41. Heat pumps use electrical power so that although they do not produce carbon emissions at their point of use, they do depend on electricity grid decarbonisation for their low-carbon / zero carbon credentials and their use will result in an additional electricity demand burden on the UK's power generation and grid infrastructure. Heat pumps are highly efficient, outputting several units of heat for every unit of electrical power input. In the context of sustainable cooling provision, they have the advantage of being reversable, in general making them a sensible choice for buildings seasonally needing both heating and cooling. It is important to note, however, that heat pump technology does not provide a universal solution, particularly in the case of displacing fossil fuel use for heating in off-gas-grid areas, or where their use is considered unsuitable.

42. The majority of off-gas-grid buildings in the UK, both residential and non-residential (ie commercial and industrial), are in rural locations (for example there are 167,000 such homes in Scotland alone) and typically use bottled fossil fuel derived gas (ie propane etc) or oil for heat provision. In such settings the use of electrically powered heat pumps is often not technically possible and/or undesirable/difficult from the perspectives of householders. The technical issues can relate to high heat losses from buildings that cannot be bought down cost-effectively (ie there is a greater prevalence of colder properties in rural locations, which are hard to treat with fabric refurbishment and energy efficiency measures) as well as a lack of physical space making installation of much larger radiators difficult. The desirability issues can involve concerns around the historic or listed nature of the building or, in the case of more affluent households, aesthetic considerations. Heat pumps can also exacerbate issues of fuel poverty and social inequity in rural areas, where off-gas-grid areas can have significantly higher instances of fuel

poverty than average and heat pump solutions can also potentially exacerbate this issue, particularly in the case of Air-Sourced Heat Pumps (ASHP) which can be relatively expensive to install and run [26, 27].

43. The most important passive system in a building more generally is the enclosure and facade system. Thermal insulation and thermal mass can allow a building to reduce and shift the timing of peak cooling loads, while the choice of material for the facade impacts on the building's ability to reflect solar heat gains. Industrial buildings often have large, darkly coloured and exposed rooftops with poor insulation, which can be a significant path for heat gain. Heat-reflective surface treatments or smart tiles which are opaque surface treatments that change emissivity with temperatures could both be selected to mitigate these unwanted heat gains [28]. Green roofs (ie roofs covered with vegetation), can also provide additional protection from solar radiation. Roofs are also well suited for solar panels, which could provide local energy sources whilst solving heat related issues by, for example, providing shading to the roof and zero-carbon electrical power to drive reversable heat pumps. Tree canopies surrounding buildings can provide direct shading and may also result in neighbourhood cooling by reducing urban heat island effects of hardscape designs.

44. Urban planning and Green Infrastructure will be crucial. Considering the building's surroundings and context, such as urban heat island effects, and implementing strategies like improved paving materials and urban vegetation can help manage extreme heat impacts while offering additional benefits like carbon sequestration, improved air quality, stormwater management, and increased biodiversity and wellbeing. State-of-the-art materials, such as improved paving materials on streets, can help reduce heat impacts, and urban vegetation can have a cooling effect on daytime temperatures [29]. Care should, however, be taken in such schemes to select tree and plant species that can withstand current and future extreme temperatures and drought conditions, as well as climate change-induced stress mortality due to changes in atmospheric vapour pressure deficits and increased threats from pests and pathogens.

45. Natural ventilation can also be an effective means of rejecting internal heat gains when outdoor temperatures allow. Clerestory vents, double-sided cross ventilation and night-time flushing can be effective methods of cooling. The variation of temperatures throughout the day can also be exploited to provide cooling through the storage of coolth at times when temperatures are low (typically during the night) and its subsequent use for absorbing heat when temperatures are high. In this regard, emerging Phase Change Materials (PCMs) are substances that can store and release thermal energy during the process of melting and solidifying. They have the potential to revolutionize cooling systems by providing efficient and passive cooling solutions. PCMs can be integrated into building materials or thermal storage units to absorb excess heat during the day and release it at night, reducing the need for active cooling.

46. As technology continues to advance, there are several other emerging cooling technologies that hold the promise of improving energy efficiency, sustainability, and overall cooling performance. These include: Hybrid and Multimodal Cooling Systems; Radiative Cooling; Magnetic Refrigeration; Thermoelectric Cooling; Electrocaloric Cooling; and Dehumidification technologies. Artificial intelligence also offers promise through being integrated into cooling systems to optimize their performance by predicting cooling needs, adjusting settings in real-time, and identifying areas where efficiency can be improved.

How can cleaner refrigerants with low or zero global warming potentials support the UK's cooling needs while contributing to the national emission reduction targets?

47. Work to increase the sustainability of cooling equipment is primarily focused on improving the energy efficiency of individual technologies and transitioning away from high-GWP refrigerants to natural or ultra-low variants. To support the UK's cooling needs while contributing to the national emissions reduction targets, a significant scale-up is required in the roll-out of "best available" high efficiency cooling units using alternative refrigerants, thereby reducing the 'direct' emissions resulting from leakage and/or spillage during use and end-of-life disposal. Overall, worldwide, these direct sources are estimated to be responsible for as much as 20% of the total emissions from commercially available cooling equipment [30]. However, the exact ratio of these direct emissions to the indirect emissions resulting from a unit's energy supply depends on the carbon intensity of a nation's electrical power generation, which in the case of the UK is lower than in many other grids.

48. In the short term, given that around 90% of direct emissions from refrigerants occur at the end-of-life phase, better disposal practices can significantly reduce cooling emissions from equipment that is already in use [31]. Additionally, globally about 60% of total hydrofluorocarbon (HFC) consumption in the cooling sector arises from topping up of refrigerant leakage during the servicing of installed cooling equipment [32], so strengthening the servicing sector could also reduce leakage through improved maintenance of the existing and future equipment stock.

49. Under the Montreal Protocol it was recognised by the Technology and Economic Assessment Panel (TEAP) that "the impact of proper installation, maintenance and servicing on the efficiency of equipment and systems is considerable over the lifetime of these systems while the additional cost is minimal. The benefit of proper maintenance is considerable. Appropriate maintenance and servicing practice can curtail up to 50% reduction in performance and maintain the related performance over the lifetime" [33]. Directly related to this, effective optimisation, monitoring and maintenance can, in fact, reduce total cooling GHG emissions by 13% and deliver substantial energy savings of up to 20% over the equipment lifespan [34]. Additionally, the lifetime of equipment can be improved, and the risk of breakdown can be reduced, through better design, installation, maintenance and servicing practices, thereby preventing downtime and early replacement of equipment. For example, the Indoor Air Quality Association estimates that regular HVAC maintenance can reduce the risk of breakdowns by as much as 95% [35].

Does the UK need a dedicated Heat Resilience Strategy? What lessons can be learned from other nations when it comes to national strategies for heat resilience?

50. The UK would greatly benefit from a dedicated Heat Resilience Strategy. Whilst flooding has received significant attention in recent years due to major incidents drawing public attention, it is essential to recognise the current and future threat of increased ambient temperatures and extreme heat events. Both issues require focus and attention.

51. A comprehensive Heat Resilience Strategy should encompass strategies to safeguard human life and maintain productivity. Collaborative efforts are vital, involving those who are most vulnerable and marginalised. This includes groups such as seniors, those with medical conditions, individuals in poor housing or living alone, pregnant women and the unhoused. A holistic, just and equitable approach is essential. There is also an urgent need to coordinate national agencies for statistics to create protocols integrating and homogenising health data sources.

52. Lessons could be learnt from British Columbia, Canada, who have recently assessed the impacts of the 2021 Heat Dome event and are implementing strategies to safeguard the population against future high temperature excursions [36]. For example, the government have implemented extreme

heat preparedness guides for residents, providing advice on how to stay safe when temperatures rise, as well as regionally specific strategies for adaptation and supporting access to the necessary data. The Government of British Columbia have also commissioned studies on how heat will impact health and productivity, supporting the business case for adaptation. Italy's Improve Resilience of Industry Sector (IRIS) project, centred on industry-focused resilience, highlights the diverse sectors that should be included in such strategies [37].

53. India's Heat Action Plans (HAPs) demonstrate the significance of structured action [38]. These plans provide a blueprint for addressing heat-related challenges and ensuring community well-being. Collaboration, inclusivity, and proactive measures, as showcased in these examples, are key elements that a UK Heat Resilience Strategy should incorporate to effectively tackle the growing threat of extreme heat.

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