Physiological Considerations for Maximum Indoor Temperatures

A report from an expert workshop held by The Physiological Society and the UK Health Security Agency (UKHSA)

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The Physiological Society

UK Health Security Agency

Contents

Introduction:

Establishing maximum indoor temperature thresholds in the UK for a variety of vulnerable groups and settings is a complex challenge but one that public health professionals are increasingly grappling with. Globally we are seeing an increase in development of guidance and legislation focusing on maximum temperature thresholds within indoor working environments. Exploring the evidence-base for potentially establishing maximum temperature thresholds for indoor environments in the UK is of increasing importance with hotter summers becoming more frequent. Indeed, the 10 warmest years recorded in the UK have all been since 2003 and the UK recorded its first air temperatures of above 40°C in 2022.

Since 1992, the Approved Code of Practice associated to the *Workplace (Health, Safety and Welfare) Regulations* have recommended that an indoor working space should not go below 16°C or 13°C if employees are engaged in physically-active tasks. This recognises that prolonged exposure to low temperatures increases the health risks to workers through not only hypothermia but also musculoskeletal injuries and respiratory conditions. No similar maximum temperature guidance exists for the general population beyond UKHSA's *Adverse Weather and Health Plan* published in April 2023.

There is a need to include physiological considerations when assessing existing and evolving evidence on the ability of individuals to mitigate the effects of heat in order to inform maximum permissible indoor temperature guidance. Our collaborative approach to sharing physiological data and research and co-creating will ensure that the latest and most conclusive physiological evidence is in place to inform new guidance on maximum indoor temperatures.

Workshop

The Physiological Society and UK Health Security Agency (UKHSA) held a joint workshop on Tuesday 3 December 2024, 'Physiological Considerations for Maximum Indoor Temperatures'. It brought together 45 delegates from around the world, covering topics from current research efforts, to improving the interactions between thermophysiologists and those with the responsibility for developing guidance and legislation (with the UKHSA's remit specifically related to health and social care). Expertise of the workshop participants included thermophysiology, ageing, public health and clinicians. While the primary focus of the workshop was indoor working environments, the open nature of the discussion means that indoor home and residential environments were also discussed.

This report summarises the discussions and key findings from that workshop.

Report objectives

The purpose of this report, and the related evidence-development workshop, was to explore the role of physiologists and physiological research in developing responses to the following topics:

- Establish whether there is sufficient physiological evidence to support the establishment of maximum indoor temperature thresholds in England.
- Identify groups, settings, regions or scenarios where a different maximum temperature would be required and rationale for this.
- Identify research gaps that need to be filled, and how these research gaps can be addressed.
- Identify areas of prioritisation where the setting of potential thresholds is most urgent.

Executive summary:

Summary of findings

1. A fixed, 'binary' temperature was not considered to be suitable, as variations in response to temperature play a significant role in normal physiology, and stress responses can differ depending on those variations.

2. The complexity of heat stress indices should be considered, with simpler categories (e.g., risk categories 1-5) to ensure accessibility to the public and provide the nuance that reflects the additional vulnerabilities that might increase an individual's risk level.

3. Vulnerable groups, such as those with mental health conditions, neurological disorders, or those in care homes, lack prioritisation and research dedicated to them.

4. While older adults are often considered to be a homogenous group, there is significant variation in health and activity levels among them. Physical activity is key for healthy ageing, and interventions should also promote staying active to build resilience, not just addressing acute high indoor temperatures.

5. Certain settings are less able to take advantage of sustainable cooling techniques and others will require specific interventions for effective cooling. This is because that intervention is less effective among the majority of people (e.g. fans are less effective in some vulnerable groups); there are limits on airflow owing to security or infection control (e.g. prisons or ICUs) or workers can't rest or cool down owing to scheduling or personal protective equipment requirements.

6. There is a lack of clarity on defining clear endpoints for mitigation techniques. Participants noted that it is important to define what the endpoint for studies should be since strategies will differ depending on the goal. Suggested endpoints included discomfort, cardiovascular disease (CVD), high body temperatures, adverse health outcomes, or mortality.

Key recommendations

1. Improve interdisciplinary collaboration to identify barriers to implementation of physiological research on heat across academia, government and health and social care

2. Research gaps on building resilience, particularly among key groups should be prioritised

3. Explore a range of risk categories and related actions for individuals, businesses, specific settings and the government

4. Better communicate risk and low-carbon cooling solutions

5. Develop clear endpoints for trials into extreme heat thresholds for consistency across research groups in different institutions

6. Promote existing examples of good practice from other parts of the world on building heat resilience

Next steps

Develop an academic paper to promote the outputs of the workshop and encourage other stakeholders to engage with future

Develop further workshops with wider field of experts to discuss implementation of agreed thresholds

Evidence and obstacles for establishing maximum temperature thresholds and research gaps

What are the health effects of acute and chronic exposure to both moderate and high temperatures and humidities?

The workshop participants discussed various aspects of how high indoor temperature impacts health. Key points included:

- **Direct and indirect effects of heat:** while the direct effects of heat stress are critical, the individual and combined impact of indirect effects (e.g., mental health issues, behaviours such as increased alcohol consumption) must also be better understood through laboratory-controlled, and real-world, trials.
- **Disruption to sleep-wake cycles:** heat can interfere with sleep, which in turn affects overall health, wellbeing and productivity. Sleep conditions should be considered separately from daytime temperatures as the physiological needs for sleep comfort differ.
- **Older populations:** older adults, especially those over 60, are most at risk from extreme heat, with most heat-related deaths occurring in people aged over 60 in homes without air conditioning, particularly among those living alone. Cardiovascular issues, dehydration, incontinence, reduced mobility, and use of prescription and non-prescription drugs all increase risk of negative health effects and are more likely to affect older populations.
- **Health-related vulnerabilities and physical activity levels:** sedentary individuals may experience higher body temperatures due to high metabolic rates.
- **Heat exposure:** participants noted that moderate heat exposure can be beneficial for adaptation, but too much exacerbates risk of adverse effects of heat. Workshop delegates noted that clear definitions are needed to distinguish between acute (e.g., <9 hours) and chronic (e.g., >3 days or more) exposure, and research needs to be in place to understand the threshold or transition points between the two.
- **Cultural norms that reduce the impact of heat adaptation practices and behaviours:** examples include, inappropriate hydration practices (e.g., cultural differences in what to drink and when) and longer periods of time to acclimatise to heat among certain populations contribute to vulnerability. Buildings in the UK are designed for cold climates, unlike those in hotter regions, which are built to reduce heat stress.

What evidence exists for the development of guidelines for indoor temperatures, either a specific temperature or graded temperatures, based on factor such as exposure duration or physical activity requirements?

Workshop participants discussed several key issues related to develop effective guidance for indoor temperature limits to combat heat stress. These include the variation in impact of heat on health, and the challenges in assessing and mitigating its effects, particularly in occupational and home environments:

1. **Temperature Guidelines**: a fixed, 'binary' temperature was not considered to be suitable, as variations in response to temperature play a significant role in normal physiology, and stress responses can vary depending on these variations.
2. **Heat Metrics and Models:** metrics like Wet Bulb Globe Temperature (WBGT) were considered necessary to inform models, as they better reflect heat stress than air temperature alone. WGBT is important for occupational settings

since it provides a comprehensive measure of environmental heat stress, taking into account not just air temperature but also humidity, radiant heat from sunlight, and air movement, allowing for a more accurate assessment of the potential risks to workers exposed to hot conditions. A number of these factors are less likely to apply to non-working vulnerable populations such as those in care settings. As such, temperature and humidity alone may suffice. The complexity of heat stress indices should be considered, with simpler categories (e.g., risk categories 1-5) to ensure accessibility to the public and provide the nuance that reflects the additional vulnerabilities that might increase an individual's risk level.

3. **Factors Impacting Productivity:** certain groups, such as women during menopause or pregnancy, may experience increased heat sensitivity, which can affect productivity in occupational settings. Similarly, night-time temperatures are crucial for sleep quality, and understanding their impact on sleep disruption (and therefore productivity) is a key consideration for productivity and safety risk profiles.

4. **Variability in Temperature:** day and night temperatures vary, and their cumulative effects need to be studied, especially over extended periods (e.g., a worker's full workweek rather than just for short bursts in controlled environments). This variability complicates the understanding of heat stress on productivity and health.

5. **Research Gaps and Insufficient Data:** workshop participants noted significant research gaps, including understanding the impact of prolonged heat exposure on the general population and specific groups (e.g., breastfeeding mothers), as well as how to help people cool down during extreme heat.

What are the barriers that exist to the effective development and implementation of maximum indoor temperature guidelines?

Workshop participants discussed the complexities of managing heat in certain setting such as NHS facilities, prisons and care homes and developed a short list of different factors that need to be considered in mitigating heat-related risks.
Key points include:

1. **Defining clear endpoints for mitigation techniques:** participants noted that it is important to define what the endpoint for studies should be since strategies will differ depending on the goal. Options include discomfort, cardiovascular disease (CVD), high body temperatures, adverse health outcomes, or mortality.

2. **Setting-specific challenges:** certain settings are less able to use sustainable cooling techniques, either because that intervention is less effective for the majority of people (For example, fans are less effective for those with reduced sweating); limits on airflow owing to security or infection control (e.g. prisons or intensive care units (ICUs)) or workers can't rest or cool down owing to scheduling or personal protective equipment requirements (e.g. striking a balance between the physical demands on care workers compared to older residents in the same setting).

3. **Legal and Policy Issues:** there are challenges with enforcing temperature limits, as temperatures in some NHS settings routinely exceed recommended maximums and self-employed workers may argue that they shouldn't be limited in their ability to work beyond existing health and safety guidance. Legal frameworks around temperature limits and occupational health guidelines should be considered with the different considerations for salaried, self-employed and gig workers in mind.

4. **Financial and carbon costs of interventions:** the costs of heating and cooling need to be considered, both in terms of finance and carbon emissions.

5. **Individual autonomy:** Certain populations are limited in their ability to respond to guidance and thresholds because of wider environmental or safety concerns. For example, residents in care homes, or some office workers, are often unable to open windows independently.

How do we develop studies and trials that are impactful and disentangle the environmental factors that compound the effects of chronic heat exposure?

1. **Develop standards for clinical trials to ensure replicability and reproducibility of data into the effects of heat exposure:** consensus between different labs on research methods and findings is crucial for ensuring consistency and reproducibility in scientific studies. When designing trials, especially in areas like heat exposure and its effects, it's important to establish clear protocols for control groups, including how they are selected and what baseline conditions (such as control temperature) are used. This ensures that findings can be compared across studies, preventing duplication and supporting the generalisability of findings.

2. **Developing real-world data and international collaboration:** in the UK, challenges arise in studying extreme temperatures because the country does not currently experience frequent extreme heat, resulting in limited real-world data on how these conditions affect vulnerable populations. International collaborations with countries that experience a broader range of temperatures are a useful proxy but this approach introduces complications due to variations in environmental conditions, cultures, and healthcare systems across different regions.

3. **Ethical considerations for trial and study development:** ethical considerations are also a significant barrier when researching vulnerable groups, as laboratory studies that simulate extreme conditions are designed to put participants at risk. To address this, researchers must develop ethical standards for studying heat stress in a controlled environment. Studies in real-world settings, are crucial for studying the impacts of heat on vulnerable populations, such as those with pre-existing health conditions, but the challenge associated with controlling variables and accounting for the Hawthorne Effect in these studies must be taken into consideration.

4. **Trials to identify the short- and long-term impacts of chronic heat exposure:** research should not only focus on acute physiological responses but also consider how heat affects long-term health, particularly cardiovascular and respiratory systems, and how these factors contribute to disease progression more widely.

What are the key research gaps and what steps need to be taken to build a more exhaustive evidence base?

1. **Understanding vulnerability and increased risk to heat:** Thermoregulatory challenges for older adults are well-documented. However, other vulnerable groups, such as those with mental health conditions have not been the focus of research to date. Older adults are often considered homogenous, but there is significant variation in health and activity levels. Physical activity is key for healthy ageing, and interventions should also promote staying active to build resilience, not just addressing high indoor temperatures through interventions during extreme heat.

2. **Interaction between Indoor Air Quality and Temperature:** The interaction between temperature and air pollution has been observed but is not well-understood. For example, the impact of ozone levels during heatwaves have been observed to have health impacts, especially when combined with high indoor temperatures, but more research on these combined effects, and their impact on different organ systems, is needed.

   There is limited evidence on how indoor temperatures interact with factors like air pollution. Outdoor air pollution may infiltrate indoor spaces inadvertently where mitigation strategies for high indoor temperatures such as ventilation could increase exposure to outdoor air pollution.

3. **Physical activity and Vulnerable Populations:** participants argued that most exercise guidelines focus on healthy individuals, but higher risk groups (e.g., those with comorbidities) may need adjusted parameters for safe exercise in the heat in order to build resilience.

4. **Modelling and Parameters:** workshop participants noted that current research often uses insufficiently- sensitive methods (e.g., time-weighted averages) to assess heat exposure across different conditions. More inclusive parameters for modelling the environmental impacts of heat on human health are necessary, especially considering factors like obesity and individual variability.

5. **Wearable Technology:** wearable tech, such as smartwatches, could help collect accurate data on individual temperature and activity levels, improving understanding of personal thermoregulatory responses.

Identification of vulnerable groups

Vulnerability within populations

What are the key physiological vulnerabilities to extreme heat which are specific to indoor settings?

Workshop participants discussed a number of physiological vulnerabilities and how they relate specifically to extreme heat exposure in indoor settings.

Key vulnerable groups discussed include:

1. **Older adults**, individuals with respiratory illnesses, neurological or mobility impairments, and those on medication affecting thermoregulation are at heightened risk.
2. **Shift workers** face exposure to extreme temperatures, lack of sleep, and changing conditions, which contribute to heat vulnerability.
3. **Workers who wear personal protective equipment (PPE)** such as the emergency services
4. **Women** throughout the life-course (peri/post-menopausal, pregnancy, breastfeeding) have specific heat-related vulnerabilities.
5. **Specific disease-related vulnerabilities to heat:** people with multiple sclerosis, cardiovascular disease, motor neurone disease (MND), diabetes, or mental health conditions like schizophrenia face additional risks owing to heightened sensitivity to temperature changes or the impact of medication on physiological processes for managing heat.
6. **Those less able to change their behaviour in response to heat**
   a. **People with cognitive impairment:** heat can affect decision-making, particularly in older adults or those with dementia or who use drugs or alcohol.
   b. **Children:** while less affected by heat-related deaths, children need proactive measures and awareness for heat-related risks. Children, especially pre-puberty, have lower sweat rates and are less likely to compensate for extreme heat. Specific guidance is required for these groups so parents and teachers are clear about the additional risks posed to children by heat.
   c. **People with physical disabilities:** those with spinal cord injuries or visual impairments may also face challenges in managing heat due to impaired thermoregulation or mobility.

How does the physiology of a person lead to differences in thermoregulatory function resulting in greater heat loads for more vulnerable groups (older adults, young children, those with specific co-morbidities), and place them at increased risk of heat-related morbidity and mortality?

Behavioural thermoregulation—how individuals respond to temperature by adjusting their actions—is generally much more effective than autonomic thermoregulation (the body's automatic responses like sweating or shivering). However, the ability to adjust behaviours (like opening windows or moving to a cooler area) is often limited by physical or environmental conditions. For example, people in prisons may not be able to act to alleviate heat, and building design can exacerbate this. Housing design plays a role in thermal comfort, with large pieces of furniture or inadequate cooling features (e.g., shutters, curtains) contributing to the retention of heat in homes. Proper guidance and the ability to adjust behaviour are critical for reducing heat risks, especially for vulnerable populations. Vulnerable groups, such as older people, may also have impaired thermoregulation due to medication (e.g., antipsychotics, sedatives, beta blockers) that affects sweating, thirst, and blood flow, making them more vulnerable to heat-related issues.

The effect of heat on psychological conditions, such as bipolar disorder, may reduce the effectiveness of heat-related messaging.

Environmental and occupational drivers of vulnerability

Are there environmental drivers of vulnerability to extreme heat which are specific to indoor settings? How does this differ by region?

Key factors influencing indoor climate and heat mitigation methods include building type and design, airflow, use of fans, heat retention, and overall management of the buildings. Different groups will require tailored approaches as not all of these mitigations will be appropriate in every location, setting and context.

The physical exertion requirements of some workers heightens their physiological vulnerability. In the UK, social care buildings, often maintain high indoor temperatures, with some reaching 28°C year-round, even in winter, due to the preferences of the residents exacerbated by age-related alterations in thermal perception and thermoregulatory capacity. This can be problematic, especially in care homes, where care workers are expected to perform periods of intensity physical activity in temperatures that are likely to be uncomfortably such exertion. There is also anecdotal evidence of heating within care homes over the winter set at high levels, often in a response to protect percieved vulnerable individuals from the health impacts of cold. Such conditions can affect safety and wellbeing at work.

This risk is exacerbated by UK building design being focused on insulation and energy usage reduction, which, while beneficial in winter, can create problems during the summer. Workplaces such as factories or distribution centres, where self-paced work may not be possible are likely to further increase vulnerability as workers are put under more stress to maintain levels of productivity.

Areas for intervention, prioritisation and collaboration

Which interventions can improve someone's ability to withstand a given temperature?

Existing standards for heat stress, such as ISO 7243 *(Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index)* and ISO 7933 *(Ergonomics of the thermal environment)*, are designed for occupational settings, especially for individuals fit for work in controlled indoor environments. These standards aim to prevent heat illness caused by exertion at work, but they are not tailored for non-occupational settings or vulnerable groups (e.g., sedentary individuals or those dependent on others for care needs). While these standards could potentially be adapted for such groups, participants expressed uncertainty about which components of heat stress indices are most relevant for different populations.

Heat acclimatisation was highlighted as an important intervention, as avoiding heat entirely can prevent individuals from adjusting to higher temperatures. Additionally, access to power and water is crucial for mitigating heat stress, but these resources may be unavailable during heatwaves. Buildings, both old and new, face challenges in managing heat, particularly in terms of energy-efficient cooling systems that contribute to carbon emissions. There is a complex balance between addressing these challenges and complying with existing building regulations and employer responsibilities and expectations where applicable.

Practical interventions to manage heat stress include work/rest cycles, cooler spaces, public education on temperature impacts, and co-created strategies for delivering heat management messages. Effective solutions should be context-specific, cost-effective, and not rely solely on setting temperature thresholds. Establishing an upper limit for indoor temperatures should be an ambition, but consideration must be given to the lack of evidence for settings and individuals beyond the workplace.

How should these interventions be prioritised and compared for efficacy within different populations?

1. **Flexible Heat Thresholds**: a fixed temperature limit may not be appropriate for all populations. Heat thresholds should be adaptable depending on specific vulnerabilities, considering factors like health, age, and access to cooling.
2. **Public Health Messaging:** continuous and clear messaging is key to ensuring people understand how to protect themselves from heat. This includes practical advice like staying hydrated, avoiding heat exposure during peak hours, and staying in cooler places.
3. **Targeting Vulnerable Populations:** vulnerable groups, including the elderly, children, those with chronic illnesses, and low-income households, will benefit the most from heat protection measures. Strategies must prioritize these populations to reduce heat-related health risks.
4. **Hydration and Cooling Strategies:** simple, low-cost strategies like encouraging hydration and using sustainable cooling methods (e.g., fans, cold compresses) are essential. These measures can be widely promoted through public health messaging.
5. **Community Practices:** checking in on vulnerable neighbours (especially elderly, disabled, and those with pre-existing health conditions) is crucial. Community support systems can significantly reduce heat-related risks.
6. **Built Environment:** it is essential to assess how urban design impacts heat exposure. Measures like shading, green spaces, and reflective materials in buildings can mitigate heat. Cooling strategies should also consider access to air conditioning, particularly for vulnerable groups.
7. **Cooling Access:** ensuring that cooling resources are available, especially in public spaces and for those who cannot afford personal cooling systems. Lack of cooling options will disproportionately affect vulnerable individuals.

How should prioritisation and future collaboration occur in the next six to 18 months?

Recommendations for Interventions:

1. **Communication of key guidelines and interventions messaging:** public health messaging should be developed using impactful campaigns like the "Float to Live" campaign. This approach uses clear, concise messaging that resonates with the public, often through the "power of three" (a rule of thumb for effective communication). The aim is to encourage organisations, including occupational health bodies, to develop their own evidence-based guidelines on temperature management and related interventions.

   The guidelines should focus on temperature limits and interventions in areas where deaths due to temperature extremes are most likely, especially among vulnerable populations, such as people living alone.

2. **Building design and regulations:** New homes in the UK should be designed with passive heat adaptation measures, reducing the need for air conditioning for the general population. This would involve creating spaces within homes that remain cool even in extreme heat, which is particularly important for vulnerable individuals.

3. **Multidisciplinary Approach:** comprehensive studies involving experts from various fields (physiologists, building engineers, psychologists, etc.) are necessary to identify the most effective interventions for different populations and settings.

4. **Health Markers to assess health risks:** Thermal, cardiovascular, and respiratory measures should be used to assess health risks associated with extreme temperatures to understand how temperature exposure affects different populations, especially over prolonged periods.

5. **Flexible Guidelines:** given the variation in heat acclimatisation throughout the year, guidelines could incorporate seasonal adjustments, and should address the potential for variation in individual tolerance based on age, health status, and other factors.

Improving Data on Physiological Research

1. **Integration of Disciplines:** collaboration across various fields such as physiology, engineering, psychology, and public health can provide a more comprehensive understanding of the impact of temperature extremes on health.

2. **Long-Term and Chronic Exposure:** research should focus not just on acute responses to heat, but also on chronic exposure, especially for vulnerable populations.

3. **Real-World Application:** ensure that interventions (e.g., cooling spaces in homes) are practical and can be implemented in real-world settings, with attention paid to both the general population and those at higher risk of heat-related illnesses.

4. **Thermal and Health Markers:** developing a better understanding of how specific markers (e.g., body temperature, cardiovascular response, respiratory function) correlate with heat stress will help to fine-tune interventions and guidelines for temperature exposure.

5. **Timing of Assessments:** the time of year is important when assessing the impact of temperature. For example, evaluations at the end of summer may show more acclimatised individuals compared to those done at the beginning of the season.

Conclusion: is the evidence in place for maximum indoor temperature thresholds and if not, why not?

The evidence for setting a maximum indoor temperature threshold is not fully in place yet. Several challenges hinder the establishment of a clear threshold. Key issues include defining what specific outcome (e.g., discomfort, health changes, or cognitive impacts) the threshold should aim to prevent, as well as the complexity of individual responses to heat, which vary based on factors like age, vulnerability, and activity level. This is particularly true in settings where different groups of people have differing levels of metabolic heat production e.g. care homes. There is also a concern that setting a threshold might lead to people ceasing work once the temperature reaches that limit, potentially disrupting productivity; or a focus on maintaining temperatures just below this threshold, rather than a wider consideration of healthy indoor working environments. Moreover, thresholds would need to account for various factors like humidity and individual conditions (e.g., vulnerable groups), making a one-size-fits-all solution difficult.

Participants suggested that a general range (e.g., 21-25°C) could work for the majority of the population, but more research is needed to refine this based on specific groups and settings. A personalised, flexible approach would be more effective, taking into account the variability of responses to heat. Additionally, public health messaging and education are essential to ensure people understand and act on any temperature guidelines. Overall, while there is some basis for setting a threshold, it requires further development, particularly in how it would be applied and communicated across different environments and groups.

Appendix 1: Workshop agenda:

The workshop consisted of a main session followed by three break out room sessions. The agenda was as follows:

Item	Lead
Welcome, introductions and declarations of conflicts of interest	Professor Mike Tipton, The Physiological Society and the Extreme Environments Lab, University of Portsmouth
The Physiological Society's interest in climate & health and scope of the roundtable	Professor Mike Tipton
UKHSA's presentation on interest in maximum indoor temperatures and discussion on the findings from UKSHA's recommended maximum indoor temperatures report: HPRU Max Temps final report.pdf	Dr Paul Coleman, UKHSA
Presentation on efficacy of different climate indices for predicting work capacity loss	Professor George Havenith, University of Loughborough
BREAKOUT GROUP SESSIONS	
Session 1: Evidence and obstacles for establishing maximum temperature thresholds and research gaps **A. Impact of indoor heat exposure** • What are the health effects of acute and chronic exposure to both moderate and high temperaturesand humidities generally? **B. What research exists and where are the gaps?** • What evidence exists for the development of guidelines for indoor temperatures, either a specific temperature or graded temperatures based on e.g. exposure duration? • What barriers exist to the effective development and implementation of maximum indoor temperature guidelines? • Can we develop studies and trials that are impactful and reflect the environmental compounding of chronic heat exposure? • What are the key research gaps and what steps need to be taken to build a more exhaustive evidence base?	Breakout Group Chairs
BREAKOUT GROUPS SESSION 1 FEEDBACK TO WHOLE WORKSHOP	

Session 2: Identification of vulnerable groups **A. Vulnerability within populations** • Are there physiological vulnerabilities to extreme heat which are specific to indoor settings? • How does physiology of a person lead to differences in thermoregulatory function resulting in greater heat loads for more vulnerable groups (older adults, young children, those with specific co-morbidities), and place them at increased risk of heat-related morbidity and mortality? • Are certain physiological states more or less likely in certain settings? **B. Environmental and occupational drivers of vulnerability** • Are there environmental drivers of vulnerability to extreme heat which are specific to indoor settings? How does this differ by region? • What combinations of environmental conditions cause differences in thermoregulatory function resulting in greater heat loads for more vulnerable groups (older adults, young children, those with specific co-morbidities), and place them at increased risk of heat-related morbidity and mortality? • How do environmental drivers of vulnerability change by settings and workload e.g. workers and residents in care homes?	Breakout Group Chairs
BREAKOUT GROUPS SESSION 2 FEEDBACK TO WHOLE WORKSHOP	
Session 3: Areas for intervention, prioritisation and collaboration **A. Interventions** • What interventions can improve someone's ability to withstand a given temperature? • How should these interventions be prioritised and compared for efficacy within different populations? **B. Areas of prioritisation and future collaboration** • What would you like to see in the next six to 18 months? • What areas or settings are temperature thresholds the most urgent? • What disciplines and stakeholders would be most useful to engage with?	Breakout Group Chairs
BREAKOUT GROUPS SESSION 3 FEEDBACK TO WHOLE WORKSHOP	
Next steps and timelines for future engagement	Dr Paul Coleman
MEETING CLOSE	

Appendix 2: Archive of suggested papers

Vulnerabilities to heat

Ageing and health inequality directly proportional to socio-economic inequality.. Chief Medical Officer's annual report 2023: health in an ageing society - GOV.UK https://www.cdc.gov/heat-health/hcp/clinical-guidance/heat-and-medications-guidance-for-clinicians.html

Balmain BN, Sabapathy S, Jay O, Adsett J, Stewart GM, Jayasinghe R, Morris NR. Heart Failure and Thermoregulatory Control: Can Patients With Heart Failure Handle the Heat? J Card Fail. 2017 Aug;23(8):621-627. doi: 10.1016/j.cardfail.2017.04.003. Epub 2017 Apr 10. PMID: 28408306. https://pubmed.ncbi.nlm.nih.gov/28408306/

Christogianni, A. et al. (2022) 'Heat and cold sensitivity in multiple sclerosis: A patient-centred perspective on triggers, symptoms, and thermal resilience practices', Multiple Sclerosis and Related Disorders, 67, p. 104075. doi:10.1016/j.msard.2022.104075. https://www.sciencedirect.com/science/article/pii/S2211034822005831

Christogianni, A., Bibb, R. and Filingeri, D. (2023) 'Body temperatures, thermal comfort, and neuropsychological responses to air temperatures ranging between 12°C and 39°C in people with multiple sclerosis', Physiology & Behavior, 266, p. 114179. doi:10.1016/j.physbeh.2023.114179. https://www.sciencedirect.com/science/article/pii/S0031938423001075

Ebi KL, Capon A, Berry P, Broderick C, de Dear R, Havenith G, Honda Y, Kovats RS, Ma W, Malik A, Morris NB, Nybo L, Seneviratne SI, Vanos J, Jay O. Hot weather and heat extremes: health risks. Lancet. 2021 Aug 21;398(10301):698-708. doi: 10.1016/S0140-6736(21)01208-3. PMID: 34419205. https://pubmed.ncbi.nlm.nih.gov/34419205/

Foerch, C. et al. (2008) 'Abrupt shift of the pattern of diurnal variation in stroke onset with Daylight Saving Time Transitions', Circulation, 118(3), pp. 284–290. doi:10.1161/circulationaha.108.771246. https://www.ahajournals.org/doi/10.1161/CIRCULATIONAHA.108.771246

Hospers L, Dillon GA, McLachlan AJ, Alexander LM, Kenney WL, Capon A, Ebi KL, Ashworth E, Jay O, Mavros Y. The effect of prescription and over-the-counter medications on core temperature in adults during heat stress: a systematic review and meta-analysis. EClinicalMedicine. 2024 Oct 24;77:102886. doi: 10.1016/j.eclinm.2024.102886. PMID: 39513185; PMCID: PMC11541675. https://pubmed.ncbi.nlm.nih.gov/39513185/

Kenny GP, Tetzlaff EJ, Journeay WS, Henderson SB, O'Connor FK. Indoor overheating: A review of vulnerabilities, causes, and strategies to prevent adverse human health outcomes during extreme heat events. Temperature (Austin). 2024 Jun 4;11(3):203-246. doi: 10.1080/23328940.2024.2361223. PMID: 39193048; PMCID: PMC11346563. https://pubmed.ncbi.nlm.nih.gov/39193048/

Leach OK, Cottle RM, Fisher KG, Wolf ST, Kenney WL. Sex differences in heat stress vulnerability among middle-aged and older adults (PSU HEAT Project). Am J Physiol Regul Integr Comp Physiol. 2024 Sep 1;327(3):R320-R327. doi: 10.1152/ajpregu.00114.2024. Epub 2024 Jul 15. PMID: 39005081; PMCID: PMC11444510. https://pubmed.ncbi.nlm.nih.gov/39005081/

Lei, L. et al. (2020) Effects of diurnal temperature range on first-ever strokes in different seasons: A time-series study in Shenzhen, China, BMJ Open. Available at: https://bmjopen.bmj.com/content/10/11/e033571 (Accessed: 16 January 2025). http://dx.doi.org/10.1136/bmjopen-2019-033571

McCormick JJ, Meade RD, King KE, Akerman AP, Notley SR, Kirby NV, Sigal RJ, Kenny GP. Effect of daylong exposure to indoor overheating on autophagy and the cellular stress response in older adults. Appl Physiol Nutr Metab. 2024 Jun 1;49(6):855-867. doi: 10.1139/apnm-2023-0361. Epub 2024 Feb 23. PMID: 38394645. https://pubmed.ncbi.nlm.nih.gov/38394645/

McCormick JJ, Meade RD, King KE, Notley SR, Akerman AP, Sigal RJ, Kenny GP. Brief ambient cooling preserves autophagy in peripheral blood mononuclear cells from older adults during 9 h of heat exposure. J Appl Physiol (1985). 2023 Nov 1;135(5):969-976. doi: 10.1152/japplphysiol.00537.2023. Epub 2023 Sep 14. PMID: 37707866. https://pubmed.ncbi.nlm.nih.gov/37707866/

McGarr GW, Meade RD, Kenny GP. Indoor overheating influences self-reported symptoms and mood-state in older adults during a simulated heatwave: Effects of mid-day cooling centre use. Physiol Behav. 2023 Nov 1;271:114335. doi: 10.1016/j.physbeh.2023.114335. Epub 2023 Aug 20. PMID: 37607601. https://pubmed.ncbi.nlm.nih.gov/37607601/

Wolf ST, Cottle RM, Fisher KG, Vecellio DJ, Kenney WL. Heat stress vulnerability and critical environmental limits for older adults. Commun Earth Environ. 2023;4(1):486. doi: 10.1038/s43247-023-01159-9. Epub 2023 Dec 18. PMID: 38293008; PMCID: PMC10826365. https://pubmed.ncbi.nlm.nih.gov/38293008/

Setting temperature thresholds

Cottle RM, Fisher KG, Wolf ST, Kenney WL. Onset of cardiovascular drift during progressive heat stress in young adults (PSU HEAT project). J Appl Physiol (1985). 2023 Aug 1;135(2):292-299. doi: 10.1152/japplphysiol.00222.2023. Epub 2023 Jun 22. PMID: 37348014; PMCID: PMC10393325. https://pubmed.ncbi.nlm.nih.gov/37348014/

Cottle RM, Fisher KG, Leach OK, Wolf ST, Kenney WL. Critical environmental core temperature limits and heart rate thresholds across the adult age span (PSU HEAT Project). J Appl Physiol (1985). 2024 Jul 1;137(1):145-153. doi: 10.1152/japplphysiol.00117.2024. Epub 2024 May 30. PMID: 38813613; PMCID: PMC11389895. https://pubmed.ncbi.nlm.nih.gov/38813613/

Cottle RM, Lichter ZS, Vecellio DJ, Wolf ST, Kenney WL. Core temperature responses to compensable versus uncompensable heat stress in young adults (PSU HEAT Project). J Appl Physiol (1985). 2022 Oct 1;133(4):1011-1018. doi: 10.1152/japplphysiol.00388.2022. Epub 2022 Sep 1. PMID: 36049058; PMCID: PMC9550570. https://pubmed.ncbi.nlm.nih.gov/36049058/

Havenith G, Smallcombe JW, Hodder S, Jay O, Foster J. Comparing the efficacy of different climate indices for prediction of labor loss, body temperatures, and thermal perception in a wide variety of warm and hot climates. J Appl Physiol (1985). 2024 Aug 1;137(2):312-328. doi: 10.1152/japplphysiol.00613.2023. Epub 2024 Jun 13. PMID: 38867664. https://pubmed.ncbi.nlm.nih.gov/38867664/

Jay O, Capon A, Berry P, Broderick C, de Dear R, Havenith G, Honda Y, Kovats RS, Ma W, Malik A, Morris NB, Nybo L, Seneviratne SI, Vanos J, Ebi KL. Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. Lancet. 2021 Aug 21;398(10301):709-724. doi: 10.1016/S0140-6736(21)01209-5. PMID: 34419206. https://pubmed.ncbi.nlm.nih.gov/34419206/

Lomas KJ and Li M. An overheating criterion for bedrooms in temperate climates: Derivation and application. Building Services Engineering Research and Technology, Vol.44, Iss.5, p. 485-517 (2023). Doi:10.1177/01436244231183113.

McGarr GW, Meade RD, Notley SR, Akerman AP, Richards BJ, McCourt ER, King KE, McCormick JJ, Boulay P, Sigal RJ, Kenny GP. Physiological responses to 9 hours of heat exposure in young and older adults. Part III: Association with self-reported symptoms and mood state. J Appl Physiol (1985). 2024 Feb 1;136(2):408-420. doi: 10.1152/japplphysiol.00740.2023. Epub 2023 Dec 28. PMID: 38153847. https://pubmed.ncbi.nlm.nih.gov/38153847/

Meade RD, Notley SR, Akerman AP, McGarr GW, Richards BJ, McCourt ER, King KE, McCormick JJ, Boulay P, Sigal RJ, Kenny GP. Physiological responses to 9 hours of heat exposure in young and older adults. Part I: Body temperature and hemodynamic regulation. J Appl Physiol (1985). 2023 Sep 1;135(3):673-687. doi: 10.1152/japplphysiol.00227.2023. Epub 2023 Jul 13. PMID: 37439239. https://pubmed.ncbi.nlm.nih.gov/37439239/

Interaction with other consequences of climate change

McCormack, M.C. et al. (2016) 'Respiratory effects of indoor heat and the interaction with air pollution in chronic obstructive pulmonary disease', Annals of the American Thoracic Society, 13(12), pp. 2125–2131. doi:10.1513/annalsats.201605-329oc. https://www.atsjournals.org/doi/10.1513/AnnalsATS.201605-329OC

Arup report urban heat risk full report — climate-adapt (2014) Europa.eu. Available at: https://climate-adapt.eea.europa.eu/metadata/publications/reducing-urban-heat-risk/11230154/view (Accessed: 16 January 2025). https://climate-adapt.eea.europa.eu/metadata/publications/reducing-urban-heat-risk/11230154/@@download/file/11230154.pdf

Heat at work

Davey SL, Lee BJ, Robbins T, Thake CD. Prevalence of occupational heat stress across the seasons and its management amongst healthcare professionals in the UK. Appl Ergon. 2024 Jul;118:104281. doi: 10.1016/j.apergo.2024.104281. Epub 2024 Apr 5. PMID: 38581844. https://pubmed.ncbi.nlm.nih.gov/38581844/

Foster J, Smallcombe JW, Hodder S, Jay O, Flouris AD, Havenith G. Quantifying the impact of heat on human physical work capacity; part II: the observed interaction of air velocity with temperature, humidity, sweat rate, and clothing is not captured by most heat stress indices. Int J Biometeorol. 2022 Mar;66(3):507-520. doi: 10.1007/s00484-021-02212-y. Epub 2021 Nov 6. PMID: 34743228; PMCID: PMC8850241. https://pubmed.ncbi.nlm.nih.gov/34743228/

Foster J, Smallcombe JW, Hodder S, Jay O, Flouris AD, Nybo L, Havenith G. An advanced empirical model for quantifying the impact of heat and climate change on human physical work capacity. Int J Biometeorol. 2021 Jul;65(7):1215-1229. doi: 10.1007/s00484-021-02105-0. Epub 2021 Mar 5. PMID: 33674931; PMCID: PMC8213606. https://pubmed.ncbi.nlm.nih.gov/33674931/

Foster J, Smallcombe JW, Hodder S, Jay O, Flouris AD, Nybo L, Havenith G. Quantifying the impact of heat on human physical work capacity; part III: the impact of solar radiation varies with air temperature, humidity, and clothing coverage. Int J Biometeorol. 2022 Jan;66(1):175-188. doi: 10.1007/s00484-021-02205-x. Epub 2021 Oct 28. PMID: 34709466; PMCID: PMC8727397. https://pubmed.ncbi.nlm.nih.gov/34709466/

Smallcombe JW, Foster J, Hodder SG, Jay O, Flouris AD, Havenith G. Quantifying the impact of heat on human physical work capacity; part IV: interactions between work duration and heat stress severity. Int J Biometeorol. 2022 Dec;66(12):2463-2476. doi: 10.1007/s00484-022-02370-7. Epub 2022 Oct 5. PMID: 36197554; PMCID: PMC9684271. https://pubmed.ncbi.nlm.nih.gov/36197554/

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The notes from each of the 4 breakout groups for each of the three sessions in the agenda (Appendix 1) were written by a human Scribe and the notes from these groups were then summarised by OpenAI. The summary of the amalgamated Breakout Group notes was then edited for duplication and then reviewed by the Chairs and Scribes of each Breakout Group for accuracy.

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