Written evidence submitted by Imperial College London

Heat Resilience and Sustainable Cooling

Explanatory note:

This response has been developed by Imperial College London colleagues from across the College's expertise.

In this submission, the full names of contributing researchers will appear at the beginning of their first answer and any subsequent answers will begin with their initials. A full list of contributors is included at the foot of the document.

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

Dr Daniela Fecht (DF), Dr Gary Konstantinoudis (GK) and, Aina Roca-Barcelo (ARB):

Humans require a stable core body temperature between 36.5 and 37.5°C to ensure optimal physiological functioning. Deviations of 1 to 2°C are tolerable and cause minimal disruptions. The human body has highly effective thermoregulation to maintain the optimal body temperature despite greatly changing outdoor temperatures. Problems with the thermoregulation or exposure to prolonged and extreme temperatures may have short-term direct impacts on the health of individuals, causing their internal temperature to rise to life-threatening levels. In the case of heat, the body will suffer from hyperthermia, that is, increase in the core body temperatures, which is likely to lead to life-threatening medical conditions such as dehydration, electrolyte disorders, and heat exhaustion and its progression, heatstroke. Heat will cause additional stress to the organs and systems of individuals with underlying health problems (such as lung or heart conditions), making them more likely to suffer from health complications. Some medical conditions (for example, diabetes) and some drugs (such as diuretics) can also cause problems with the thermoregulation, increasing the likelihood of life-threatening conditions. All of these factors are highly likely to lead to hospitalisation, or in the most dire circumstances, could potentially result in death.[1]

As temperature deviates from the optimal temperature, the negative impacts on health start to increase. There is no universal definition of a heatwave but in the UK a heatwave is defined as occurring when there are at least three consecutive days where the daily maximum temperatures meet or exceed the heatwave temperature threshold. The temperature threshold is set at the county level and varies from 25-28°C across different geographical locations.[2] The duration and intensity of a heatwave are key predictors of heat-related mortality and morbidity.[3] Although the largest risk is by far associated with extreme temperatures, the largest absolute impact (~60% of the deaths attributable to heat) is seen for mild temperatures as they are much more frequent.[4]

[1] WHO Heat and Health fact sheet 1 June 2018

[2] Met Office website What is a heatwave? (accessed 28 July 2023)

[3] The association between consecutive days' heat wave and cardiovascular disease mortality in Beijing, China, BMC Public Health, 2017

Also, a US-based study has shown that first-of-season heatwaves and consecutive events are likely to result in higher health impacts than subsequent heatwaves in a particular season.[5] This highlights the importance of having good surveillance and early warning systems in place.

There is a large body of evidence which underpins these links, showing that heat causes health effects within a few days of exposure to high temperatures. However, there are also indirect effects, where heat aggravates mediating factors that affect health, for instance ambulance response times, infrastructure damage, food and waterborne diseases, work related accidents and so on.[6]

Long-term heat exposure, over months or years, can also impact various health conditions, yet the evidence is scarcer than for short-term exposures.[7] Changes in temperature (both moderate and extremes) over longer time periods are more likely due to climate change and policy makers should be aware of those changes, how they affect health and adjust adaptation strategies accordingly.

Populations have evolved physiologically and socially to adapt to a certain range of temperature. Nevertheless, the capacity for adaptation is unevenly distributed across different populations, with some more vulnerable population groups having a higher likelihood to suffer from the negative consequences of temperature. This vulnerability can be due to physiological factors (such as genetics, underlying health conditions and medication), demographic factors (for instance age and sex), behavioural factors (such as restricted mobility, alcohol or recreational drug misuse) social factors (such as occupation, those living on their own) or factors related to external characteristics of the built, nature and socioeconomic environment they live in (for example, socioeconomic status, green space, air pollution).

People with underlying lung or heart disease are of higher risk of death during heatwaves, and to a smaller extent, those with chronic kidney disease and diabetes.[8] There is strong evidence that socio-economic deprivation is a main driver for these differences.[9] Several correlated factors may explain this, including differences in building infrastructure,[10] in house air-conditioning, proximity to green or blue space and occupational exposure, all reported to modify the relationship between heat and health. There is no consensus about sex, with most of the studies reporting higher vulnerability in women. There are limited studies examining the effect of heat on people with COVID-19, but the negative health effects are likely to be higher.

Finally, interaction with other external factors such as high levels of air pollution and relative humidity,[11] have been shown to result in larger health impact, directly by interfering in the

---

[4] Mortality risk attributable to high and low ambient temperature: a multicountry observational study, The Lancet, 2015

[5] Heat-Related Hospitalizations in Older Adults: An Amplified Effect of the First Seasonal Heatwave, Sci Rep, 2017

[6] WHO Heat and Health fact sheet 1 June 2018

[7] Longer-term outdoor Temperatures and Health Effects: A Review, Curr Epidemiol Rep, 2018

[8] Effects of Air Temperature on Climate-Sensitive Mortality and Morbidity Outcomes in the Elderly; a Systematic Review and Meta-analysis of Epidemiological Evidence, EBioMedicine, 2016

[9] Temperature-related mortality: a systematic review and investigation of effect modifiers, Environmental Research Letters, 2019

[10] What individual and neighbourhood-level factors increase the risk of heat-related mortality? A case-crossover study of over 185,000 deaths in London using high-resolution climate datasets, Environ Int, 2020

[11] The Association Between High Ambient Temperature and Mortality in the Mediterranean Basin: A

thermoregulatory response or indirectly by aggravating mediating factors. Several guidelines recommend using indices combining temperature metrics and relative humidity as surveillance metrics, such as the heat index.[12]

Dr Rhiannon Thompson and (RT) and Dr Neil Jennings (NJ): There is evidence that higher temperatures, especially heatwaves and unusually hot temperature for a particular time and place, are associated with higher rates of suicide. In our recent systematic review and meta-analysis, we found that a 1°C increase in mean daily temperature corresponded to 1.7% more suicides and 10% more psychiatric hospitalisation.[13]

People with pre-existing mental health conditions are three times more likely to die due to high temperatures compared to people without a mental disorder.[14] This trend has been identified in different geographical settings including Italy[15] and Canada[16] and is partly due to the impact that a number of common psychiatric medications can have upon people's ability to thermoregulate, which can make them more vulnerable to the physical health impacts of heat.[17]

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?

Salvador Acha and NJ:
The consensus drawn from the literature is that climate change will affect buildings by increasing the cooling demand in summer and by reducing the heating demand in winter.[18] A study of possible Italian future climate scenarios concluded that energy use attributed to air conditioning and cooling during the hotter months could double by 2040 relative to today's levels.[19] It is therefore of vital importance that buildings are designed for both mitigating and adapting to climate change.

A study investigating how effective climate change adaptation measures were for residential buildings in the Netherlands found that natural ventilation and solar shading provided the most optimal outcomes.[20] Furthermore, they found that increasing the level

---

Systematic Review and Meta-analysis, Curr Envir Health Rpt, 2023

[12] Importance of humidity for characterization and communication of dangerous heatwave conditions, NPJ Clim Atmos Sci, 2023

[13] Ambient temperature and mental health: a systematic review and meta-analysis, The Lancet Planetary Health, 2023

[14] Mental Health Disorders and Summer Temperature-Related Mortality: A Case Crossover Study, Int J Environ Res Public Health, 2020

[15] Mental Health Disorders and Summer Temperature-Related Mortality: A Case Crossover Study, Int J Environ Res Public Health, 2020

[16] Schizophrenia pinpointed as a key factor in heat deaths, Science, 2023

[17] Ways to stay safe if your psychiatric medication impairs temperature regulation, Mental Health Today, July 2021

[18] Strategy for achieving long-term energy efficiency of European single-family buildings through passive climate adaptation, Applied Energy, 2021

[19] Resilient optimal design of multi-family buildings in future climate scenarios, E3S Web of Conferences, 2019

[20] On the predicted effectiveness of climate adaptation measures for residential buildings, Building and Environment, 2014

of insulation to reduce the heating demand in winter had a negative impact on thermal comfort in summer. As a consequence, building standards need to be adapted to the specific climate of regions. Governments need to prioritize reducing heat demand in places with harsh winters, while finding ways to cool down the buildings during summer periods. An evaluation of design strategies to counteract climate change in buildings in Argentina suggests incorporating sufficient natural ventilation into buildings, reducing solar gains through sun shading and painting buildings and roofs white as the best low cost options to offer sustainable cooling.[21]

In addition, the incorporation of blue (for example ponds or water gardens) and green (such as trees or green roofs) infrastructure into urban areas can help to reduce the urban heat island effect. It can also reduce the need for mechanical ventilation and its associated impact on electricity demand.[22] Following the strategic placement of trees in a development at Zagreb University, for example, indoor summer temperatures in adjoining buildings were measured to be 4°C lower and indoor winter temperatures were 6°C higher, compared to a situation with no trees.[23] The regulation of temperature by these trees led to a 26% drop in energy consumption in the adjoining building (a combination of reduced cooling in summer and reduced heating in winter).

Such green or blue space can provide a host of other benefits to society, including greenhouse gas mitigation, improved biodiversity, and improved mental and physical health of populations.[24] Such nature-based solutions to cooling are also important because of the inequity in access to mechanical cooling such as air conditioning - the poorest in society generally have least access to mechanical cooling.[25] The inequity in access to mechanical cooling can cause poorer communities to be exposed to even higher temperatures as heat from air conditioning units is dumped into the air around people's properties. That increases the urban heat island effect and heat exposure for those without access to mechanical cooling.

Lastly, local governments need to support the urban planning of more green spaces throughout cities as both rich and poor communities often lack these spaces to help them mitigate the risks from overheating.

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

DF, GK & ARB:

We suggest some improvements that could be made to the UK Heat Health Action Plan (HHAP), which would help to improve protection for those most vulnerable to the impacts of extreme heat:

---

[21] Impact of climate change on energy use and bioclimatic design of residential buildings in the 21st century in Argentina, Energy and Buildings, 2019

[22] Integrating green and blue spaces into our cities: Making it happen, Imperial College London Grantham Institute, 2019

[23] Blue Green Solutions. A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development, Imperial College, 2017

[24] Integrating green and blue spaces into our cities: Making it happen, Imperial College London Grantham Institute, 2019

[25] Air conditioning and global inequality, Global Environmental Change, 2021

- The definition of a heat event should be updated to include relative humidity and particularly focus on vulnerable groups.
- There should be guidelines for individuals with pre-existing conditions, for example in people with diabetes (age groups of concern, changes in medication, people with additional comorbid conditions).
- City or region-specific thresholds may also be adequate in certain settings as risk profiles differ substantially across the country.[26]

The Italian Heat Health Prevention Plan in Lazio, Italy, is a good example of a successful HHAP which includes city and region-specific thresholds, comprehensive risk metrics which include relative humidity and with a comprehensive and systematic screening for vulnerable groups.[27]

Despite their proven effectiveness,[28] HHAPs only provide protection to heat extremes. While it is the case that extreme events are associated with the highest risk of health impacts, mild temperature increases have the highest death toll (because they occur more frequently) and so they should not be neglected. Moreover, long-term adaptation should be prioritised as extreme events and mean temperature will continue to increase in the future as a result of human-caused climate change.

In addition to this, other actions should be taken to reduce the exposure to high temperatures and address the factors underlying heat vulnerability. These should address both direct and indirect impacts, and combine individual, institutional and infrastructural changes.

Some interventions may focus on reducing exposure to extreme temperatures. For example:

- increasing the prevalence and access to greenspaces, cooling centres, fountains and water sprayers, or
- improving housing standards with better insulation and ventilation.

Alternatively, interventions may focus on reducing vulnerability. For example:

- by increasing awareness of heat prevention practices (for example to reduce physical activity and time outdoors, and increase drinking water),
- by increasing surveillance of people at risk through phone and home visits (for example elderly people, people with disabilities or living alone and people with comorbidities),
- by revising medication of patients with treatments that may impair thermoregulation system, or
- by implementing workplace heat-response plans, especially for outdoor workers, whose work requires physical exertion.

Air-pollution related interventions are also important to reduce the unequal health-related burden of temperature. As there is an established link between temperature exposure and health in populations exposed to higher air-pollution levels. Policies related with air-pollution such as the Ultra Low Emission Zone in London are expected to lead to co-benefits. The health and economic benefits are yet to be evaluated.

Any intervention should be based on up-to-date setting and group-specific evidence which identifies barriers and opportunities. Experience from other settings can help inform these

[26] Small-area assessment of temperature-related mortality risks in England and Wales: a case time series analysis, The Lancet Planetary Health, 2022
[27] Italian Heat health prevention plan and warning system, 2016
[28] Overview of Existing Heat-Health Warning Systems in Europe, Int. J. Res. Public Health, 2019

decisions. At this stage, it is important to map potential co-benefits and co-harms of the considered interventions and conduct a comprehensive cost-benefit assessment. Finally, interventions should be monitored, evaluated and adjusted as deemed necessary based on the results. Health benefits and costs should be key elements in such assessments and evaluations.

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?

SA:

Reversible heat pumps are slowly becoming commonplace in the market. Several leading manufacturers are now offering them. Technically speaking they are viable in the right settings but their performance will vary from a conventional air conditioning or gas boiler system; consumers will need to get familiar with how to operate them properly.

Policy makers should emphasize under what building conditions the technology is most attractive, while making it clear that in certain circumstances a complementary technology (such as thermal storage) might be needed.

Governments and industry need to work together to overcome the many challenges new technologies face when trying to enter the market. These include:

1) a lack of trust in a new technology,
2) the need for a skilled work force to install and commission such systems,
3) Financial/regulatory support to increase market uptake, and
4) R&D between academia and industry to refine the solutions and improve their cost and performance.

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?

SA:

The Kigali Amendment to the UN Montreal Protocol officially ratifies a phase-out plan for high global warming potential (GWP) refrigerants, specifically hydrofluorocarbons (HFCs).[29] Agreed in October 2016, signatory countries are bound to restrict both production and consumption of HFCs, ultimately aiming to achieve 15% of 2011-13 CO_2e emissions by 2036. However, preceding EU regulation from 2014 applies even tighter restrictions on refrigerants with a GWP of 2,500 or above, with a phase-out to 20% by 2030, including a ban on both new installations *and* adaptations to existing plants with refrigerants after 2020.[30]

[29] Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, United Nations, 2016
[30] EU “F-Gas” Regulation 517/2014, 2014

Refrigerant leakage from pressurized cooling systems is challenging to prevent, therefore reducing the GWP of refrigerants in the systems can enable significant emissions reduction. Across the sector there has been historically a lack of transparency on how frequent and abundant refrigerant leaks are.[31] However, going beyond the regulations and using the lowest GWP refrigerants possible can both ensure commercial sustainability in complying with regulation and contribute significantly to carbon mitigation targets.

The report by your predecessor committee on 'UK Progress on Reducing F-gas Emissions' in 2018 identified the 'modest progress' being made by the EU phased market-based quota system.[32] The quota aims to reduce availability of high GWP HFCs (F-gas) and promote transition towards alternatives. This should provide additional incentives for the UK to meet its legally-binding Carbon Budgets. The report also highlights the benefits of successful implementation of global regulations, highlighting that all countries meeting HFC reduction targets would 'reduce global temperature rises across this century by half a degree, significantly reducing the impact of global warming'.

Installing new systems using HFO/HFC blend refrigerants is possible, and business may consider pursuing this option due to its slightly lower capital investment (HFOs – or hydrofluoroolefins – are chemicals that can be used as refrigerants but that have a much lower GWP than HFCs).[33] However, given expected system lifetimes of over 20 years, they would be vulnerable to future regulation.

In terms of natural refrigerants, ammonia and propane may be used in certain applications but the inert, non-toxic, non-flammable nature of CO_2 (R-744) makes it ideal for the food-retail setting, specifically supermarkets and eventually should also be applicable to other systems such as heat pumps.[34] For example, in the UK companies have started offering heat pumps running on CO_2.[35] While efforts are being made elsewhere piloting the technology in commercial buildings.[36] Support for the industry is required to ensure that if consumers are to shift towards sustainable heating & cooling solutions using low carbon refrigerants will be a feature of such systems.

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?

SA:

We don't necessarily need a standalone heat resilience strategy that is separate from other initiatives being pursued by the UK Government. However, it would be sensible to factor heat resilience into the existing Heat and Buildings Strategy by incorporating sustainable cooling solutions. This can be done by upgrading building design standards

---

[31] A roadmap investment strategy to reduce carbon intensive refrigerants in the food retail industry, Journal of Cleaner Production, 2020

[32] UK progress on reducing F-gas emissions, Environmental Audit Committee, 2018

[33] Retail refrigeration: making the transition to clean cold, Birmingham Energy Institute, 2017

[34] Climate-friendly alternatives to HFCs, European Commission

[35] For example, see https://clade-es.com/heat-pumps/about-co2-heat-pumps/

[36] For example, see https://r744.com/frigo-consulting-improves-performance-of-reversible-co2-heat-pumps/

and supporting low carbon technologies as mentioned in previous responses. The fact that this problem has not been addressed or identified specifically by the UK Government indicates that they have lacked the foresight to consider it a significant problem. Nonetheless, it would be wise to revise the strategy and encompass a heat resilience framework in its net zero building program.

Contributors:

DF: Dr Daniela Fecht, Senior Lecturer in Geospatial Health, MRC Centre for Environment and Health, School of Public Health

GK: Dr Garyfallos Konstantinoudis, MRC Skills Development Research Fellow, Department of Epidemiology and Biostatistics, MRC Centre for Environment and Health, School of Public Health

ARB: Aina Roca Barcelo, Research Postgraduate, MRC Centre for Environment and Health, School of Public Health

RT: Dr Rhiannon Thompson, Research Associate, Department of Epidemiology and Biostatistics, School of Public Health

SA: Dr Salvador Acha, Senior Research Fellow and Project Manager, Imperial College-Sainsbury's Partnership, Department of Chemical Engineering

NJ: Dr Neil Jennings, Partnership Development Manager, The Grantham Institute – Climate Change and Environment

Further information:

This submission was collated jointly Imperial Policy Forum and Imperial's Grantham Institute – Climate Change and the Environment working in partnership with Imperial College London's MRC Centre for Environment and Health and Department of Epidemiology and Biostatistics part of the School of Public Health and the Department of Chemical Engineering.

For follow-up correspondence with the submission contributors, or to discuss other ways in which the facilities and expertise of Imperial researchers can support the Committee's work, please contact James Heyburn, Policy and Engagement Officer, Imperial Policy Forum.

August 2023