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ARE WE PREPARED TO COOL DOWN IN A WARMING WORLD?

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Introduction

We are facing an unprecedented man-made climate emergency threatening life on our planet. Limiting global surface temperature rise to 1.5°C above pre-industrial levels is key not only to meet the legally binding Paris Agreement, but also to ensure irreversible effects for nature and people are not triggered. Heatwaves are a stark reminder of the severity of global warming, due to their dramatic effect on ecosystems and societies, as evidenced, for example, by the recent wildfires in France, significant heat-related excess mortality tolls in Europe, and ambient temperatures reaching 40°C in several countries.

Decarbonizing energy is crucial to mitigate the effects of climate change. In 2019, the UK became the first major economy in the world to pass legislation to end its contribution to global warming by 2050 by reducing its greenhouse gas (GHG) emissions to net-zero, while the European Union confirmed its commitment to meet this objective through the European Green Deal. A significant reduction in emissions has been achieved in the electricity sector, where the grid integration of renewables has played a key role. However, progress has been more muted in other areas, such as heating.

Heating, including space cooling, accounts for over a third of GHG emissions in the UK. Heating and cooling are central to our lives for comfort, daily activities, to facilitate productive workplaces, and to run a myriad of industrial processes. Decarbonizing heating and cooling are thus a cornerstone to meet net-zero targets.

Scratching the tip of the iceberg in cooling decarbonization

Decarbonization of heat has received increased awareness from key stakeholders, with some heat decarbonization pathways proposed and already under assessment, and some development of heat policy. Notably, the UK's Department for Business, Energy & Industrial Strategy (BEIS) considers that 'decarbonizing heat is our most difficult policy and technology challenge to meet our carbon targets'.[1] The government's approach to decarbonize heat has considered a range of measures, such as the '£3B pledge' to improve the energy efficiency of buildings within the post-Covid19 green recovery programme.[2] Efforts are underpinned by innovation aimed to reduce heat demand, increase low-carbon heating, and define a long-term policy framework ahead for a national transition (see footnote 92). The growing demand for cooling had not previously received a similar attention, but this is now changing.

[1] 'Clean Growth – Transforming Heating. Overview of Current Evidence', Department for Business, Energy & Industrial Strategy, December 2018.
[2] 'Chancellor set to announce £3bn green investment package', *The Guardian*, 6 July 2020.

Cooling is mostly used for cold supply chains and for indoor space cooling. Space cooling includes air conditioning, electric fans, and dehumidification. Cooling is key for public health, food security, and productivity, as cooling services provide thermal comfort, prevent overheating, avoid food waste, and keep medical products safe.[3]

In the UK, it is estimated that up to 10 per cent of all electricity is used for cooling,[4] but this figure will likely increase. The UK's ten warmest years have occurred after 2002[5] and climate modelling estimates a temperature increment of 3–5°C for the average regional summer by 2080 and an increase in the number and frequency of heatwaves.[6,7] Globally, space cooling accounted for approximately 20 per cent of total electricity use worldwide in 2020, and this may more than triple by 2050 as the climate warms.[8]

The cooling challenge

Decarbonizing cooling poses major obstacles. This is not only a technical challenge, as transforming effectively large systems such as the energy sector relies on social elements (including public expectations, beliefs, and acceptability of novel technologies and solutions, behavioural changes, and policy and institutional change), as well as how these factors interplay with the various technical elements.[9] At the same time, driving low-carbon outcomes likely will require policy and legislative support, given that system change can be slow because of lock-in and incumbency.

Summertime cooling of buildings is becoming prevalent, and consumer demand for greater comfort levels will also increase the energy used for cooling services, while increased working from home and changes in lifestyle may need to be accounted for. In the UK, the National Health Service have confirmed an increase in space cooling demand due to overheating. However, how will overheating be predicted for a large variety of domestic buildings? Thermal models may be employed to assess the likelihood of overheating. While it may be easier to model new buildings, doing this for an ageing housing stock may not be straightforward due to the diversity of materials used in foundations, walls, windows, doors, roofs, and insulation, and consequently in the heat transfer coefficients and indoor heat gains used for calculations. This is without considering geographical conditions, such as latitude, ambient temperatures, solar irradiance, orientation, or humidity. All these attributes play a role in quantifying cooling demand.

Follow-up questions arise. How is cooling demand being quantified? How is this demand being considered in energy policy? There is a limited awareness of future cooling demand for domestic buildings. The most complete dataset on cooling energy consumption in the UK is available from BEIS.[10] However, this is restricted to the non-domestic sector, so an understanding on how domestic buildings and households respond to extreme heat, and how this might create greater demand for space cooling, is yet to be developed. Compounded to this, assessing occupant behaviours and strategies in households, influenced by social norms and personal preferences, is important, as these may affect cooling demand. As evidenced during the recent heatwave this summer, a clear guidance towards preventing overheating which effectively reaches households is needed. Depictions associating extreme heat with people happily sunbathing do not help. Is the general population aware of the impacts of overheating, such as health risks, productivity decline, and loss in efficiency and capacity of infrastructure? Have people considered incorporating cooling methods to their homes for thermal comfort? There seems to be a lack of recognition of the importance of cooling and how it affects our lives.

Cooling approaches and technologies

There are two main approaches towards cooling provision. In passive methods, heat gains are avoided, and heat is dissipated, to improve thermal comfort without the use of additional energy. This may involve building design considerations including ventilation, window glazing, sun orientation, building materials, and insulation. Recent literature highlights that energy savings from passive strategies are high.[11] Occupant behaviour is also considered a passive approach. It relies on occupants'

[3] 'Sustainable cooling', *POSTnote 642.* The Parliamentary Office of Science and Technology, April 2021.
[4] 'Study on Energy Use by Air Conditioning: Final Report', A. Abela, et al., BRE Client Report for the Department of Energy & Climate Change, June 2016.
[5] 'UK Climate Projections: Headline Findings', Met Office, September 2019.
[6] 'Adapting to climate change. UK Climate Projections', Department for Environment Food and Rural Affairs, June 2009.
[7] 'UKCP Convection-permitting model projections: Science report', E. Kendon, et al., Met Office, September 2019.
[8] 'The Future of Cooling. Opportunities for energy-efficient air conditioning', International Energy Agency, May 2018.
[9] 'Net Zero. The UK's contribution to stopping global warming', Committee on Climate Change, May 2019.
[10] 'Cooling in the UK', Department for Business, Energy & Industrial Strategy, August 2021.
[11] A. Sharifi, 'Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review', *Science of The Total Environment*, vol. 750, pp. 141642, January 2021.

knowledge to ensure cross-ventilation, night ventilation, and adoption of behavioural strategies to reduce cooling demand. Passive strategies, however, may not be sufficient in urban heat islands lacking green infrastructure, or in less affluent areas of a city (see footnote 94).

The other method is active cooling, where demand is commonly met using electrical energy. Active technologies include air conditioners (ACs), chillers, and refrigerators. A refrigerant, which is a chemical circulated in a closed system, is used to absorb heat when evaporating to a gas, and to release it when condensing to a liquid (see footnote 99). Heat transfer is thus achieved by absorbing heat from the environment to be cooled down and released elsewhere.

Despite the latest climate projections, and research in the UK showing that several households experience overheating during summer, new houses are not obliged to consider overheating in their designs.[12,13] In fact, the Committee on Climate Change (CCC) recently stated that homes in the UK are not ‘fit for the future’.[14] Following recommendations from the CCC, the government considered reducing cooling demand[15] and published revisions to the existing Building Regulations to address overheating through passive methods in all new residential buildings.[16] However, as with heat decarbonization,[17] the large and less energy efficient existing housing stock was ignored. To bridge this gap, it may be required to scale up home retrofitting programmes for existing buildings.

It is estimated that the split AC unit represents 78 per cent of the total sales of active technologies in the UK,[10] although there is a limited understanding on the actual use of AC systems once installed.[18] If this trend continues, with the foreseen increased cooling needs, the knock-on effect on the share of electricity used for cooling would be enormous. Impulsive decisions being made to install ad hoc ACs will increase peak cooling loads, which will strain the electricity system. For instance, the National Grid has estimated an uptake of 18 million units of AC systems in UK households by 2050, which could add up to 39 GW of peak electricity demand on a typical summer weekend day (see footnote 92). At the same time, summer electricity demand is changing dramatically, with a surge in solar PV generation, causing concern for balancing the power system.

Another relevant aspect is the use of refrigerants in active systems. Most refrigerants in the market are fluorinated gases (F-gas) and constitute 35 per cent of global cooling-related GHG emissions.[19] Among them, hydrofluorocarbons (HFC) make up 95 per cent of the emissions.[20] Reducing F-gas use in cooling equipment is supported internationally through the Kigali Amendment of the UN Montreal Protocol, European regulations, and HFC bans for industrial refrigeration, domestic refrigerators, and ACs. Even when the UK has phased out a significant amount of HFC for cooling-related services, most ACs still operate with F-gas (see footnote 94). Using natural refrigerants such as water, air, ammonia, and hydrocarbons is an alternative, but these come with their risks, such as flammability, toxicity, and demanding operating conditions (see footnote 110).

Integrating heat pumps and thermal stores

Heat pumps (HPs) are energy-efficient devices capable of heating buildings. They operate using electricity and a refrigerant to extract heat from the environment. HP technologies are conventionally named after the medium from which heat is extracted (such as the air, ground, or water). The extracted heat is then circulated inside the building around a heating and hot water system. To provide cooling, the HP operating cycle can be reversed to essentially work as an AC. This way, a reversible HP can be used to decarbonize buildings while meeting heating and cooling demand.

HP units play a key role in most UK heat decarbonization scenarios,[20] although there is limited awareness of the technology among domestic owners and their deployment level is significantly lower compared to other countries.[21] Recent low-carbon heat

[12] W. Wilson and C. Barton, ‘Tackling the under-supply of housing’, *House of Commons Library*, February 2022.
[13] C. Brimicombe, ‘Heatwaves: An invisible risk in UK policy and research’, *Environmental Science & Policy*, vol. 116, pp. 1–7, February 2021.
[14] ‘UK housing: Fit for the future?’, Committee on Climate Change, February 2019.
[15] ‘Heat and Buildings Strategy’, Department for Business, Energy & Industrial Strategy, October 2021.
[16] ‘Building (Amendment) Regulations 2021: circular 01/2021’, Department for Levelling Up, Housing & Communities, December 2021.
[17] ‘Hot stuff: Research and policy principles for heat decarbonisation through smart electrification’, R. Lowes, et al., *Energy Research & Social Science*, vol. 70, pp. 101735, December 2020.
[18] ‘Air conditioning demand assessment’, C. McLachlan, et al., *Tyndall Manchester Climate Research Centre,* University of Manchester, May 2016.
[19] ‘Technical report on energy efficiency in HFC-free supermarket refrigeration’, K. Zolcer Skacanova and A. Gkizelis, *Environmental Investigation Agency*, 2018.
[20] ‘The Sixth Carbon Budget. The UK’s path to Net Zero’, Committee on Climate Change, December 2020.
[21] ‘Important social and technical factors shaping the prospects for thermal energy storage’, D.G. Barns, et al., *Journal of Energy Storage*, vol. 41, pp. 102877, September 2021.

policy is, however, expected to increase HP penetration.[22] The Renewable Heat Incentive supports homeowners in the installation of HPs and other renewable options.[23] However, compared to a gas boiler, HP cost per kWh continues to be high[24] and its up-front cost remains prohibitive for the general population. Installation labour ramps up costs, and this needs to be addressed for HPs to become an economic alternative to gas boilers. In addition, some units rely on F-gases (see footnote 94), and there is concern that new prohibitions from the European Commission may restrict their deployment.[25] Provision of further financial and regulatory incentives towards decarbonizing domestic heat through HP uptake is therefore still required. There is an opportunity to link these initiatives to cooling decarbonization too, but this argument needs to be articulated.

The role of thermal energy storage (TES) could be crucial, as it can be deployed into cooling systems to act as a buffer between supply and demand. TES may also provide flexibility, enabling peak cooling demands to be shaved, electrical loads to be shifted, and electricity costs to be reduced. For example, a thermal store may act as an energy sink during cooler night hours, when cost of electricity is reduced, and operate as a cooling source during peak demand when cost of electricity is high.[26] Latent heat TES is a preferred choice for cooling applications. The storage medium is a phase change material (PCM), which may have a high energy density. PCM units can also be used within cold chains, such as in shipping containers, to reduce reliance on fuel or electricity (see footnote 94).

System integration and district networks

Energy networks have been traditionally decoupled for operation and planning, with their design and implementation being independent, due to regulatory and market arrangements. However, interactions among networks have always existed. In an integrated energy system, different energy vectors are connected through distributed coupling technologies. For example, when using active technologies, a cooling system is coupled with the electricity grid. Similarly, a reversible HP is a coupling technology transforming electricity into cooling energy. Analysing and operating energy networks with a holistic approach may help balancing energy supply and demand efficiently and economically, as sharing energy among networks can enable a flexible operation. For instance, the cooling vector can facilitate demand-side response: large AC or refrigeration users may receive financial incentives from electricity system operators to turn down their systems during periods of peak electricity demand without compromising food safety or thermal comfort (see footnote 94).

Adoption of district thermal networks will also contribute towards achieving carbon neutrality. These networks use infrastructure interconnecting dwellings, buildings, or facilities within a city, district, or neighbourhood to supply thermal energy.[27] District heating has been supported in Europe since the Renewable Energy Directive and the Energy Efficiency Plan. Notably, Nordic countries have made substantial progress with heating and cooling networks. In the UK, only 2 per cent of heat demand in buildings is met through district heating,[28] although it could deliver up to 20 per cent of the demand by 2050.[29] Moreover, the Clean Growth Strategy requires meeting 17 per cent of heat demand in households and 24 per cent in industrial buildings with heating networks to meet net-zero targets (see footnote 92). Compared to successful cooling networks in the Middle East, Malaysia, Canada, and other European countries, these are still emerging in the UK. Projects integrating district heating with district cooling networks and renewables into a single network are already under operation (see footnote 118). Given their immense decarbonization potential, important lessons can be learned.

Conclusions

There is no silver bullet to address the cooling challenge in a warming world. It is thus critical to raise awareness as it has been a 'blind spot' and an often-overlooked issue when discussing decarbonization of energy. It is necessary to stimulate discussion

[22] 'The Energy White Paper. Powering our Net Zero Future', Department for Business, Energy & Industrial Strategy, December 2020.
[23] 'Policy change, power and the development of Great Britain's Renewable Heat Incentive', R. Lowes, B. Woodman, and O. Fitch-Roy, *Energy Policy*, vol. 131, pp. 410–21, August 2019.
[24] 'Experience rates of low-carbon domestic heating technologies in the United Kingdom', R. Renaldi, et al., *Energy Policy*, vol. 156, pp. 112387, September 2021.
[25] 'Press Release on Proposed new F-Gas Regulation: EU risks undermining its own climate and energy security goals', European Heat Pump Association, 5 August 2022.
[26] 'Dynamic modelling of ice-based thermal energy storage for cooling applications', H. Bastida, et al., *IET Energy Systems Integration*, vol. 4, no. 3, pp. 317–34, September 2022.
[27] 'District heating and cooling systems', I. De la Cruz and C.E. Ugalde-Loo, in: N. Jenkins (Ed.), *Microgrids and Local Energy Systems*, pp. 91–126, IntechOpen, London, UK, December 2021.
[28] 'Opportunity areas for district heating networks in the UK. National Comprehensive Assessment of the potential for efficient heating and cooling', Department for Business, Energy & Industrial Strategy, September 2021.
[29] 'Heat networks', *POSTnote 632.* The Parliamentary Office of Science and Technology, September 2020.

involving key stakeholders from the energy sector, government, academia, housing developers, and individual consumers to support future energy policy decision-making around cooling and buildings.

It is timely to investigate how cooling may develop and to understand how cooling and energy storage technologies, and their relationship with heat decarbonization, can support integrated, socially acceptable, cost-effective, and sustainable energy system change. Integrating cooling, storage, and wider approaches to building decarbonization, will involve understanding future cooling demand to strategically inform infrastructure investments. Progress has been limited, and a potential demand increase due to changes in lifestyle could further complicate or slow building decarbonization.

It will be necessary to reinforce the electrical power system to cope with the additional demand, with the possibility of utilizing the flexibility provided from a coordinated operation of heating, cooling, gas, electricity, and perhaps hydrogen networks to maximize infrastructure use while minimizing operation costs – alongside weighing carbon neutrality targets. Anticipating and then successfully integrating cooling loads and low-carbon cooling solutions smoothly, while complex, could have benefits from a cost and consumer perspective, while relieving pressure on electricity networks. Nevertheless, significant investments in the modernization, digitalization, and automation of cooling infrastructure and buildings are needed to ensure a safe, efficient, reliable, and sustainable energy system.