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Sustainable cooling

Cooling in buildings, industrial processes and supply chains accounts for 7% of global greenhouse gas emissions (GHGs) from the use of energy and refrigerants. Demand for cooling is forecast to rise further, presenting challenges for meeting climate change goals.

Overview

- Cooling is key to public health, food security and productivity. It provides thermal comfort in buildings, prevents overheating, avoids food waste, and keeps vaccines safe.
- Cold can be provided by avoiding heating (through buildings' design) or using technologies such as air conditioning. The latter result in greenhouse gas emissions from refrigerants and power generation.
- Cooling is key to sustainable development, but access to it is unequal. The UK funds sustainable cooling projects abroad.
- There is relatively little cooling-specific UK policy beyond overheating and device efficiency. Building and cold chain policy changes can improve UK cooling provision.

Background

Cooling is a process that addresses a range of society's needs.[1] It provides thermal comfort in buildings, preventing risks from overheating, and is required to keep food fresh and medical products safe. A lack of access to cooling is a barrier to development and cooling has a role in all UN Sustainable Development Goals (SDGs), though it does not feature explicitly in any of them.[2–4] Recently, potential disruptions to food and vaccine provision have also increased awareness of the value of cooling in the UK and developed nations with milder climates.[5]

Under existing international emission pledges, average global temperatures could reach 3°C above pre-industrial levels by the end of this century.[6] Around 1°C of global warming has already taken place, with increasing severity, duration and frequency of extreme events, such as heatwaves, leading to localised spikes in temperature.[7–9] As the climate warms, global demand for cooling, including in the UK, is forecast to rise.[10] In developing countries often located at warmer tropical latitudes, socio-economic trends such as population growth, urbanisation and rising prosperity are further driving demand for cooling.[3,11–13]

Conventional cooling contributes to climate change in two ways. First, it often requires electricity or diesel, with associated carbon dioxide (CO_2) emissions (a GHG). Estimates of global cooling-related CO_2 emissions tripled from 1990 to 2018 (to 1,130 million tonnes, equivalent to the CO_2 emissions of Japan).[14] Second, many cooling systems use fluorinated gases (F-gases), which can be potent GHGs when they leak.[15] Cooling accounts for over 7% of global GHG emissions, compared with around 2% from aviation.[16–18] Inefficient cooling devices (like air conditioners) are common, and it has been predicted that global energy demand for cooling may match that of heating by 2060.[11,19] There has been relatively little focus on the growing energy demand for cooling compared with that of heating.[2,14] Reducing F-gas use in line with international agreements could avoid 0.4°C of warming by 2100.[20] Increasing global access to cooling therefore challenges GHG emission reductions if policy does not incentivise the use of approaches that minimise energy demand and F-gas use.[21,22]

Sustainable cooling includes approaches that aid climate change mitigation and adaptation, are affordable and accessible, and support the SDGs.[2,23] The UK has significant cooling research and innovation expertise and is a major contributor to cooling programmes abroad.[24–26] This POSTnote examines UK and global demand for different forms of cooling, ways of meeting it, and technology and policy options to do so more sustainably.

Demand for cooling

Cooling is used for indoor space cooling and cold supply chains ('cold chains'). It is also used in industrial processes and power generation.[27] In 2018 the size of the global market for refrigeration and air conditioning exceeded that of solar panels.[3] Global electricity demand for space cooling alone is forecast to triple by 2050.[14] Residential cooling is currently the largest source of total global demand. However, cooling demand is expected to grow fastest within the industrial and

The Parliamentary Office of Science and Technology, Westminster, London SW1A 0AA
02072192840 post@parliament.uk parliament.uk/post @POST_UK

transport sectors before 2030, mainly due to expanding cold chains,[3] particularly in India and other developing economies.[28] Cold chains currently account for 2–4% of UK GHG emissions.[28] The use of data centres in the UK may grow by 70% before 2050 with an associated growth in cooling demand.[29]

Box 1: Overheating risks and impacts

Overheating is difficult to predict with accuracy due to demographic, behavioural and building type dependencies.[30] UK risks in dwellings and public buildings are currently not well quantified.[8] Thermal models can be used to assess the likelihood of overheating in new and existing buildings; direct measurement is often more accurate but also more complex and time consuming.[31,32] Warmer locations and dense urban areas are typically exposed to higher risk.[33]

Health risks from heat stress

Extended periods of temperature above 25°C are associated with increased mortality, heatstroke and hospitalisation.[34] Chronic illness, older age and certain disabilities can increase risk,[33,35] and infants and rough sleepers are also vulnerable.[36] The Climate Change Committee (CCC) estimates that 2,000 heat-related deaths occur in the UK annually and project that this could grow to 7,000 by the 2050s without intervention.[8] It also found that 20% of UK homes currently overheat, even in mild summers.[37]

Productivity risks from thermal discomfort

Thermal discomfort is determined by factors such as air temperature and humidity,[38] as well as a person's subjective tolerance to heat.[39] It can negatively impact workplace and learning productivity, and sleep.[37] The 2003 heatwave is estimated to have cost £400–500m in UK manufacturing output.[8] Heatwaves are expected to intensify in the future.[40]

Loss in efficiency and capacity of infrastructure

Some IT and energy infrastructure relies on cooling. Thermal power plants (gas and nuclear) need cooling to function efficiently and a warmer future climate would reduce plant efficiency.[41] Servers in data centres also rely on cooling.[42]

Space cooling

Space cooling involves reducing indoor temperatures in response to heating from sunlight or internal sources (such as occupants, lighting and machinery). High temperatures can lead to overheating risks for occupants and infrastructure (Box 1).[27] Some cooling measures can improve indoor air quality by reducing humidity, aiding ventilation, changing airflow patterns or purifying air inflows.[43] This can mitigate indoor spread of airborne pathogens.[44] Space cooling accounts for nearly 20% of global electricity demand in buildings.[14] A 2016 study estimated that 10% of total UK electricity demand is for air conditioning (AC) – mostly in non-domestic buildings such as offices – and AC use in the UK grew an estimated 2% per year between 2012 and 2019.[45–48] Data on cooling demand is not routinely collected and modelling is often used to estimate demand.[30,33,47]

Cold chains

A cold chain is a system of temperature-controlled logistics in the supply chain of perishable products, primarily food and pharmaceuticals. These are cooled to maintain quality and prolong shelf-life. Cold chains comprise food processing plants, refrigerated warehouses ('cold stores'), supermarket cabinets and domestic refrigerators, as well as temperature-controlled vehicles.[49] UK cold chains include around 700 large cold stores and 30,000 vehicles,[50] and support more than 100,000 direct jobs.[49] Cold chains use chilled, frozen, and cryogenic (-70°C and lower) temperature ranges. Most food is chilled, but demand for frozen food is growing.[49] Cryogenic stores are mostly used in the medical sector (e.g. for certain vaccines).[51]

Cold chains underpin population health and security.[1,52] 70% of food in the developed world relies on cold chains.[1] In 2018, UK food trade included £24.5bn imports and £5.9bn exports of temperature-controlled products.[53] Globally, 25% of liquid vaccines and 200m tonnes of food are lost annually due to limited cold storage and refrigerated transport.[54,55]

Cooling and sustainable development

Cooling is needed to achieve each of the SDGs.[2,4] Over 1 billion people lack access to cooling,[5] which disproportionately affects less affluent groups in the Global South.[3] Worldwide, 72m full-time jobs are predicted to be lost as a result of climate induced heat stress,[56] and 90% of medical facilities lack access to modern cold chain equipment.[57] Broken cold chains lead to food loss and, in turn, malnutrition, as well as income loss.[54] In developing contexts they can lead to a widening gender gap, as a large proportion of agricultural workers are women and cold storage reduces time burdens from food provision trips.[58,59]

Approaches to cooling provision

Spaces and products can be cooled either by avoiding heat gains (through passive strategies or changing behaviour), or by actively sourcing, storing and distributing cold thermal energy.

Passive cooling strategies

Space cooling can often be provided passively, without using mechanical systems that require energy inputs.[60]

Building design

The combination of heat exposure, internal heat sources, insulation and ventilation affects a building's cooling demand.[45] Most heat enters a space via glazed areas (windows) and poor ventilation reduces the capacity to dissipate it. Shading (from blinds or shutters), and to a lesser extent light-coloured external surfaces, can reduce heat gains.[61] Novel types of glazing can also be effective thermal barriers.[62] Dense building materials such as brick can reduce temperature fluctuations during short-term heatwaves. Orientation also affects heat gains due to varying sun exposure.[61] High-rise flats are less able to reject heat due to their lower ratio of external surfaces to floor area.[63] When these are situated in less affluent areas,[64] poorer residents are often exposed to overheating risks,[61,65] and have the least ability to install and run cooling measures.[66]

Passive strategies depend on the local climate and raw material availability.[67] In many warmer countries, traditional architecture developed over generations uses passive cooling strategies.[67,68] In the UK, multiple tools exist to help planners identify and mitigate overheating risks in early-stage building projects.[66,69]

Urban heat islands and green infrastructure

Globally, cities are on average 5–9°C warmer than rural areas, due to the urban heat island (UHI) effect.[70–72] Artificial surfaces, such as concrete and tarmac, store heat during daylight hours and slowly release it, raising night-time temperatures.[36] Increasing urban vegetation (re-greening) has been shown to lower air temperatures.[73–75] Parks, street trees, green walls and roof gardens ('green infrastructure') can provide the co-benefits of improved air quality, biodiversity, and physical and mental health (PN 538).[20,76,77] Nearby bodies of water, such as rivers, can also contribute to cooling.[66] Access to green space in England is correlated with income and ethnicity.[78]

Occupant behaviour

Occupant interactions with buildings and equipment, which are influenced by social norms and personal preferences, can affect cooling demand.[2,79,80] Different cultural expectations, and uses of behavioural strategies such as looser clothing[81] and consumption of cold food and drink products, can reduce active cooling demand.[63,82,83] A key aspect is occupants' knowledge of how best to use passive tools such as opening windows and internal doors for cross-ventilation.[84] Night-time ventilation is most effective for cooling but security, air pollution, and noise can be barriers.[36,85] Proposed government guidelines ask developers to produce a Home User Guide on a dwelling's overheating, ventilation, and energy efficiency strategy.[86] The NHS and Public Health England provide heatwave advice.[36,87] Occupants typically adapt to wider temperature ranges in naturally ventilated buildings without AC.[88,89] Use of smarter control systems, such as thermostats with flexible thresholds, can be more effective while also lowering energy demand.[90–94]

Box 2: Refrigerants

Refrigerants are chemicals that can exist either as a gas or liquid at relatively low temperatures. They absorb heat when evaporating to a gas and release it when condensing to a liquid.[14] Many refrigerants are GHGs if released to the atmosphere. Global Warming Potential (GWP) typically describes the warming effect of the gas compared to the same mass of CO_2 (whose GWP is 1) over 100 years.[95,96]

Fluorinated gases (F-gases)

Most refrigerants are manufactured F-gases, with estimated GWP values ranging from less than 1 to 23,500.[97,98] 35% of global cooling-related GHG emissions come from F-gases.[99]

- **Hydrofluorocarbons (HFCs)** make up 95% of F-gas emissions.[100]
- **Hydrofluoroolefins (HFOs)** generally have lower GWPs than HFCs. Some concerns have been raised around marine ecosystem damage when HFOs degrade, but there is no evidence of environmental and health risks.[101–103]

Natural refrigerants (NFs)

NFs are increasingly used to avoid F-gases. Commercially available NFs include water, CO_2, air, ammonia and hydrocarbons (isobutane, propane). They have GWPs of between 0 and 3, are less energy intensive to produce than F-gases (including HFOs),[104] and can reduce indirect emissions. Some carry separate risks, for example hydrocarbons are flammable, ammonia is toxic and CO_2 needs higher operating pressures.[105]

Active cooling technologies

Active cooling uses an energy input such as electricity.[38] Most active devices work by circulating a refrigerant (Box 2) in a closed system.[14] Heat from the environment is absorbed at one location (where cooling is needed) and released at another.[14] The most commonly used active technologies include:

- **Air conditioners (ACs)**. Can be fixed electricity-powered units used to cool buildings,[45] or mobile fossil-fuel (e.g. diesel)-powered units in refrigerated transport vehicles.[104]
- **Chillers** are often thermally-driven units that deliver cooling via chilled water for larger buildings and industrial processes, often within a district network (PN 632).[14]
- **Refrigerators.** Including smaller electric domestic fridge-freezers and the centrally-cooled cabinets found in larger supermarkets and cold stores.[106]

Globally, 135 million AC units are sold each year and the International Energy Agency estimates that most of these have energy efficiencies less than half of the highest achievable.[11] Several lesser-used active cooling technologies can result in lower GHG emissions.

Heat pumps

Heat pumps (HPs) are primarily used as an energy-efficient way of providing heat to a building but many can also work like an AC unit to provide cooling ('reversible' types).[107] HPs are not widely used in the UK but their deployment is expected to rise significantly under low-carbon heat policy.[108,109] They use electricity and a refrigerant to extract heat from (or, when cooling, reject heat to) outdoor air or the ground.

Ground-source systems

The temperature tens of metres beneath the ground remains relatively constant throughout the year.[110] This can be exploited by circulating water through the ground to provide both heating (extracting heat from the ground into a building) and cooling (depositing heat from a building into the ground).[111] Ground-source systems use a standard water pump and, in most cases, an HP to boost heat transfer. High up-front costs make ground-source systems more suited to commercial or communal settings.[112–114] The Climate Change Committee's (CCC's) Sixth Carbon Budget advice suggested that ground-source HPs could account for 20% of HPs installed in the UK by 2050.[115]

Waste cold

Cold that is produced as a by-product of an industrial process or power production can be captured and used for cooling. The most common examples are chillers in 'combined cooling, heat and power plants', which recycle waste thermal energy to chill water used for AC or refrigeration.[116,117] A more recent prospect is to exploit liquefied natural gas (LNG),[118] which is stored at -162°C,[27] shipped by tanker and converted back into a gas at destination, releasing cold that is typically wasted.[10] Waste cold is a central part of the wider Cold Economy (Box 3).

Making cooling more sustainable

There is relatively little specific policy for sustainable cooling in the UK. Broad aims to mitigate risks from overheating are outlined in Defra's 2018 National Adaptation Programme (NAP) and, as of 2019, the National Planning Policy Framework.[119,120] More specific policy is focused on the energy efficiency of AC devices and reducing F-gas use. Academic researchers suggest that improving the sustainability of cooling requires measures beyond device efficiency and electricity use. They advocate a greater focus on passive and behavioural strategies, and a circular economy approach that considers the whole life cycle from designing to disposing of systems (PN 536).[2] Doing so could reduce the need for active cooling. Several data gaps exist, presenting barriers to understanding future demand and creating and implementing policy.[114]

Box 3: Cold energy storage and the Cold Economy
Academic and industry groups have developed the concept of a 'Cold Economy': an economy-wide system that uses waste and surplus cold as a way of storing and transporting energy for use in a range of applications other than cooling to reduce environmental impact.[4,118,121] Cold energy can be stored for long periods using 'phase-change materials' (PCMs) such as specialist gels. PCMs can accumulate cold during periods of low energy demand and release it at a different time or place as needed. This can help reduce electricity demand during hot peaks and improve energy system flexibility (PN 587).[55] PCMs can also be used in parts of cold chains, such as shipping containers, to reduce reliance on diesel or the power network.[118,122] Compared with electrical batteries, cold energy storage can be cheaper to run and longer-lasting, and relies less on rare or toxic materials, but its use to date has been limited. Cooling can further enable energy system flexibility:

- Using 'demand-side response', electricity system operators can pay large AC or refrigeration users (such as hotel chains or supermarkets) to briefly turn down their systems in periods of peak electricity demand without compromising food safety or thermal comfort.[123,124]
- 'Liquid air energy storage' uses electricity to cool air to cryogenic temperatures that can later be used to generate power.[125,126] The first commercial project is under construction near Manchester.[127]

Using more efficient cooling devices
Standards and labelling
Efficiency gains in AC units and other active devices can be made by raising minimum energy performance standards and incentivising high-efficiency equipment through voluntary measures.[11] Small cooling units sold in the EU must bear energy efficiency labels and comply with 'ecodesign' standards;[128,129] similar standards exist elsewhere.[130] Several UK industry and government guides for increasing efficiency also exist.[131,132]

Cooling as a service
More efficient systems often have higher up-front end-user costs. Reducing electricity consumption also relies on better operation and maintenance.[16,45] New business models such as 'cooling as a service' (CaaS) can address these, and promote innovation and circular economy practices. In CaaS, the end-user pays a specialist provider an ongoing fee to install, run, maintain and decommission its cooling system.[133,134]

Policy for combining heat and cooling
Combining heating and cooling systems (such as by using HPs) can increase technical and cost efficiency.[107,112] The 2020 Energy White Paper outlines a target to increase HP deployment from 30,000 to 600,000 per year by 2028.[108] System design and installation that accounts for reversible operation is key to delivering intended efficiency benefits,[107,135] but the UK skills base to do so is currently lacking.[136,137]

Reducing F-gas use
The UN Montreal Protocol and its Kigali Amendment (Box 4) aim to reduce global HFC use by 80-85% by 2047.[138] In the UK, the retained EU F-Gas Regulation requires a 79% reduction in HFC sales by 2030 relative to 2015,[100] which is more stringent than the Kigali target in the near-term. Defra is assessing how the Regulation's ambition could be increased.[139] Because fixed and mobile ACs have typical lifetimes of around 10 years that 'lock in' associated emissions,[140] as well as illegal HFC trading and historically low leakage and disposal compliance, a shift to natural refrigerants (NFs, Box 2) is advocated by environmental stakeholders.[95,105,141] In the UK, many cold stores and domestic and supermarket systems already use NFs,[105,106] while most AC devices and heat pumps still rely on F-gases.

Promoting passive cooling strategies
Building codes and wider planning laws are the main tool for improving building design and green infrastructure. The UK currently has no formal requirement to increase the use of passive cooling strategies,[83] and the CCC recommends new statutory requirements to reduce overheating in new-build homes.[37] Most existing UK buildings will need to be made more energy efficient to meet decarbonisation targets for heat, but an exclusive focus on retaining heat can lead to summer overheating if cooling is overlooked.[142–146] Embedding passive cooling in new dwellings has been proposed by the 2021 MHCLG Future Buildings Standard consultation,[147,148] but does not cover existing buildings.[37] The 2018 NAP encourages actions to deliver more, better quality, green infrastructure.[119]

Improving cold chains
In 2013 the UK Government renewed the voluntary Food Chain Climate Change Agreement, to incentivise the uptake of energy efficiency measures in the UK cold chain.[146] Its 2020 efficiency targets were surpassed and the scheme has been extended until 2025.[131,149] Few commercialised technologies exist for decarbonising refrigerated transport.[150,151] Aggregating food and medical cold chains via facilities and data sharing can increase resilience and efficiency but would require coordination and cost sharing across multiple actors.[28,152]

International cooling programmes
Globally, cooling programmes relate to both aid and climate finance efforts. The UK Government's ODA has provided around £26m for cooling-related projects since 2011,[153] which includes the BEIS-funded £15m Sustainable Cooling Innovation Fund.[154] Cooling is also part of the £1bn Ayrton Fund, which promotes clean energy technology innovation in developing countries.[155] In 2020/21, Defra co-funded the African Cooling Centre of Excellence (ACES).[156] The UK Government has a leading role in the Cool Coalition (Box 4),[117] and the "Affordable heating and cooling of buildings" challenge for Mission Innovation, a global public-private initiative.[157] Analysts suggest that development finance institutions such as the World Bank Group are key to delivering sustainable cooling projects internationally.[158,159]

Box 4: International efforts for sustainable cooling
Relevant international programmes or agreements include the 2015 Paris Agreement on climate change;[160] the 1987 Montreal Protocol and its 2016 Kigali Amendment, which aim to prevent ozone layer depletion and reduce HFCs (Box 2);[161] and the UN SDGs.[2] The Kigali Cooling Efficiency Programme (K-CEP) is a philanthropic programme that supports the aims of the Montreal Protocol. It helps nations develop National Cooling Plans (NCPs): roadmaps for reducing F-gas use, developing sustainable cooling, and linking these with wider energy, climate and development targets. A tool to identify cooling needs is being developed to support this.[162–164] In 2019, the UN Environment Programme created the Cool Coalition, a global network to promote sustainable cooling.

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