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Cooling is hotting up in the UK

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ABSTRACT

The cooling of buildings is currently responsible for about 20% of total electricity use worldwide. It is estimated that the electricity needed for cooling will more than triple by 2050. Despite this concerning outlook, little attention has been paid to cooling demand in policy and research in the United Kingdom (UK). The demand for space cooling in the UK's domestic and non-domestic buildings is currently small—about 10% of total electricity use. However, this has the potential to increase as the climate warms and expectations of comfort grow. This paper reviews UK cooling demand and how this has been considered in energy policy. Following a thorough review of the existing literature using a cooling decarbonisation framework (Avoid, Improve and Shift), it is clear there is a limited understanding of the future UK cooling demand for domestic buildings in a warmer future as well as how policy makers and households should act. More importantly, this sector appears under-represented in the UK research and policy landscape compared to heating despite obvious technological crossovers associated with electrification. Several policy and research recommendations have been made based on these findings.

1. Introduction

In July 2022, heatwaves hit Europe, North Africa, the Middle East, and Asia, as temperatures climbed above 40 °C in some places and broke many long-standing records (NASA, 2022). Persistent heat extremes have severe impacts on ecosystems and societies, such as excess mortality, wildfires, and harvest failures (Rousi et al., 2022). Along with the increase in the magnitude and frequency of heatwaves and rising average higher temperatures, demand for space cooling through fans and air conditioning is growing to reduce the heatwave impacts on comfort and health (Viguié et al., 2020). Future cooling demand increases will lead to increased energy consumption, with more greenhouse gas emissions, and will place significant burdens of peak demand on electricity grids around the world (EIA, 2021).

The cooling of buildings accounts for about 20% of total current electricity use worldwide (Post Note 642, 2021). It is estimated that the electricity used for cooling will more than triple by 2050 due to anthropogenic climate change alongside the increasing demand for comfort (IEA, 2018). Increased home working and changes in lifestyle may also need to be considered when making cooling demand projections (Ugalde-Loo, 2021). In 2020, sales of air conditioners (ACs) increased due to COVID-19 lockdowns and heatwaves in several regions around the world because a large share of the population was working from home (Delmastro et al., 2021).

Cooling demand and overheating studies are mostly conducted for regions with hot climates where the current high cooling energy demand is already high. Yet climate change impacts are also significant in the cooler western countries where most of the residential buildings are not equipped with cooling systems and are still being built for cooler climates (Farahani et al., 2021). Nonetheless, most energy studies have continued to focus on indoor heating, and little attention has been paid to the growing energy demand for cooling especially in European countries (Thomson et al., 2019; Khosla et al., 2021). Existing literature shows that cooling demand and overheating have long been underrepresented in the European energy policy landscape (Thomson et al., 2019). Thus, cooling energy demand and growing demand for ACs 'is one of the most critical blind spots in today's energy debate' (IEA, 2018). This paper, therefore, aims to review the cooling demand at a national level in the UK and the extent to which cooling has been considered in the UK energy policy. Our review will have value for countries at similar latitudes and with similar climates.

The paper is structured into four sections. The research methodology is explained in Section 2. Section 3 presents the review of the UK current cooling demand, the status of cooling sector in the UK policy debate, and

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a discussion on the gaps of the current cooling demand in UK policy. Finally, research and policy recommendations are provided in Section 4 and close the paper.

2. Methodology

With UK legislation requiring net-zero greenhouse gas emissions in 2050 (Purohit et al., 2022; Lowes et al., 2020b), there is a need for radical building decarbonisation which implies considering cooling alongside heat decarbonisation. A literature review has been conducted to understand the various aspects of UK current cooling demand. This was followed by a literature search for a conceptual framework to explore the UK energy policy gaps for cooling decarbonisation. Literature shows that cooling decarbonisation to achieve net-zero carbon emission targets needs implementing a combination of policies such as passive strategies coupled with low-energy space-cooling solutions (Zhang et al., 2021). In this regards, a Climate Action Pathway for Net-Zero Cooling, which is the outcome of a collaboration between the Kigali Cooling Efficiency Programme, Cool Coalition, and Carbon Trust, introduces a framework of three strategies (Avoid, Improve, Shift) to reach net-zero in the cooling sector (Fig. 1). This paper uses this framework to review the UK energy policy for the cooling sector.

The AIS (Avoid, Improve, Shift) framework for transitioning towards a net-zero future in the cooling sector relies on three categories of strategies and actions (Cool Coalition, 2019; EIA, 2021).

1) **Avoiding (reducing) the need for mechanical cooling:** Focusing on energy demand reduction and a "using less" approach is the most cost-effective in a decarbonisation programme (Lowes et al., 2020a). In the cooling sector, the simplest way to achieve this is through passive cooling strategies, which typically involves building design to reduce the overall heat gain and minimise requirements for active cooling (ESMAP, 2020). Such design could include better air tightness and ventilation, greater levels of insulation and reductions in solar gain.
2) **Improving efficiency of cooling equipment and reducing fluorinated greenhouse gases (F-gases) use in ACs and refrigerents:** In parallel with reducing the cooling energy demand through passive cooling strategies, actual cooling should be met through the most energy efficient equipment to reduce overall energy demand increase to support the net-zero goal. Efficient equipment is a vital aspect of cooling decarbonisation since the International Energy Agency (IEA) estimates that most AC units sold around the world have energy efficiencies less than half of the highest achievable (IEA, 2018). F-gases use is another impact area to manage in sustainable cooling. F-gases are powerful greenhouse gases with a global warming effect up to 23, 000 times greater than CO_2. Most refrigerants, ACs and heat pumps use manufactured F-gases (Post Note 642, 2021, UNEP-IEA, 2020).
3) **Shifting cooling to renewable energy:** Future cooling demand increases will lead to increased energy consumption with more greenhouse gas emissions, and this could place significant burdens of peak demand on electricity grids (EIA, 2021). A shift to renewable energy sources with an integrated approach to cooling and heating to meet heating and cooling demand is vital to reduce energy consumption and carbon emissions (De la Cruz and Ugalde-Loo, 2021). This shift requires a significant source of energy (usually electricity generation), infrastructure such as thermal energy storage, district cooling, and reversible heat pumps (Barns et al., 2021). This transition to renewable-based solutions could follow several possible pathways depending on resource availability and priorities of each country, including electrification with renewable power, renewable-based gases (hydrogen), sustainable bioenergy use, and direct use of solar resources (IRENA, 2020).

3. Considering UK cooling demand and its status in the UK policy landscape

3.1. Current cooling demand in the UK

Global warming is already being felt across the UK, according to the most recent analysis of the UK climate published in the Royal International Journal of Climatology, the State of the UK Climate 2020. The past decade (2011–2020) has been on average 0.5 °C warmer than the 1981–2010 average, and 1.1 °C warmer than 1961–1990. The Met Office predicted that heatwaves, like that of summer 2018, are now 30 times more likely to happen due to climate change (Met Office, 2021). For the first time, temperatures of 40 °C have been experienced in the UK in July 2022, breaking the previous UK record of 38.7 °C set in July 2019 (Met Office, 2022a). The UK's 2019 climate projections predict that heatwaves will become normal events for UK summers by 2040 (Murphy et al., 2019; Brimicombe et al., 2021). According to the Met Office (2022b), the UK could experience temperatures exceeding 40°C every three years by the end of century under a very high emissions scenario.

High temperatures particularly from heatwaves are linked to excess mortality and serious health risks (Sanchez et al., 2017; Drury et al., 2021). For instance, the European heatwave of 2003 caused 70,000 excess deaths across Europe including 2000 in England alone (Johnson et al., 2005; Murage, 2020). In the UK, there are 30,000 annual excess winter deaths which is a figure signicantly higher than heat-related deaths (Committee on Fuel Poverty, 2020), which stand at around 2000 deaths per year (Kovats and Osborn, 2016). However, it must be noted that fuel poverty is not the only contributing factor into excess winter deaths, and it is estimated that only 21% of these are related to the coldest quarter of housing (Committee on Fuel Poverty, 2020). Heat-related deaths are estimated to grow to 7000 per year by 2050 (House of Commons, 2018; Kovats and Osborn, 2016), which is an alarming projection requiring serious policy concern to mitigate heat-related impacts.

Despite the UK's latest climate projections showing an increase in average summer temperature and research showing that up to 20% of homes currently experience overheating during an average summer,

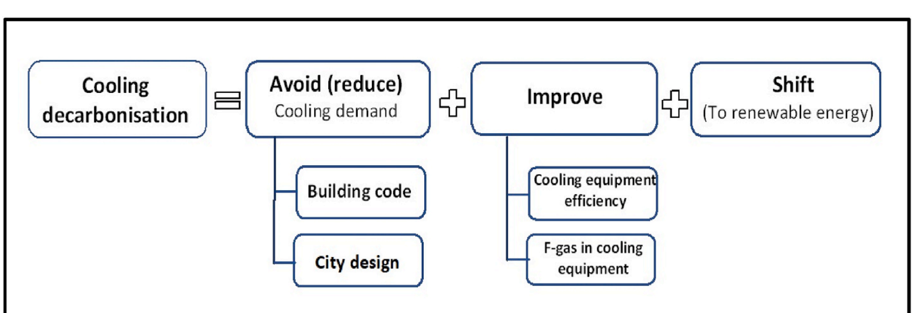

Fig. 1. Adapted AIS (Avoid, Improve, Shift) framework to reach cooling decarbonisation (Cool Coalition, 2019; EIA, 2021).

houses are yet not obliged to consider overheating in their designs (Wilson and Barton, 2018; Brimicombe et al., 2021). Hence, there is a concern that the number of UK houses suffering from summertime overheating is increasing due to global warming (DEFRA, 2017; Wright et al., 2018). In this regard, the UK statutory advisor of the Committee on Climate Change (CCC) stated that houses in the UK are not ‘fit for the future’ (CCC, 2019; Lowes et al., 2020a) and recommended that passive cooling measures should be adopted in renovation works and new homes. Some of these measures, notably insulation, will also lower heating demand in winter (CCC, 2019). Following this, the government has recently published revisions to the existing Building Regulations that set some passive cooling measures (Part O) to tackle overheating in all new residential buildings which came into force from June 2022 in England (HM Government, 2021).

The current cooling demand in buildings is still small. For example, in 2016 cooling demand was estimated at 3% of the total energy demand (CCC, 2016), which accounted nearly 10% of total UK electricity demand (Post Note 642, 2021). The cooling demand is dominated by non-domestic buildings. In 2019, this was approximately 6187 GWh (BEIS, 2021a). As Fig. 2a shows, the office sector accounts for over half of all non-domestic cooling energy use in the UK.

Two main methods are used to achieve cooling: active and passive. Active methods satisfy the cooling needs usually through the use of electricity, whilst passive cooling refers to design features developed to cool buildings without energy consumption, such as insulation, window shading, and ventilation (Oropeza-Perez and Alberg Østergaard, 2018; Geetha and Velraj, 2012). The most common active cooling technologies (refrigerant–based) are split, variable refrigerent flow (VRF) and chiller technologies. Fig. 2b describes the proportions of various types of active cooling technologies currently used in the UK. These are based on UK sales data for each cooling technology type in 2016 taken from BSRIA “UK Chillers” and “UK Splits systems” (BEIS, 2021a). It is worth mentioning that this is the most up to date data on the UK active cooling technologies. Based on Fig. 2b, split ACs, which are currently the most used appliance in commercial buildings (Purohit et al., 2022), can been seen to be the preferred type of AC in use in the UK, representing almost 80% of total sales. The second most common type of unit are VRF systems (10.7%), which tend to be used in higher-end new build and refurbishment projects.

District cooling systems are another type of active cooling system which are recognised as energy efficient compared to equivalent conventional cooling systems being operated in individual buildings (Wu and Chen, 2015). Common in the Middle East, they have also been deployed in Scandinavia, Germany and France, and are more widespread in the northern than in the southern European countries (Buffa et al., 2019). District cooling systems are noticeably absent in the UK.

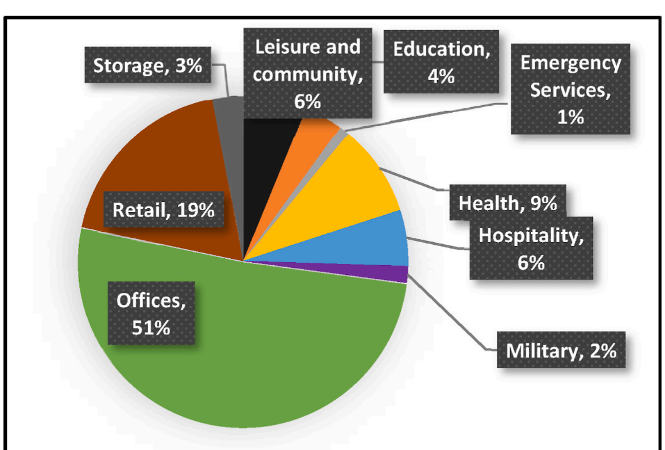

Fig. 2a. UK energy consumption for cooling of non-domestic buildings IEA, 2019 (BEIS, 2021a).

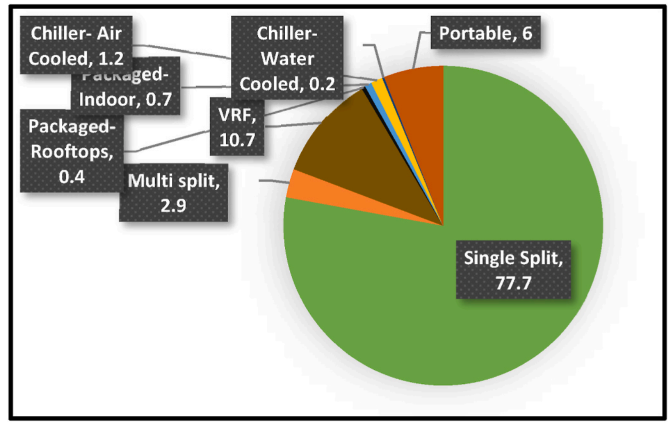

Fig. 2b. Various types of active cooling technologies currently used in the UK (BEIS, 2021a).

Our review of UK cooling demand reveals the most complete dataset on cooling energy consumption in the non-domestic sector is available through the ‘Energy consumption in the UK’ data (BEIS, 2021a). However, there is limited understanding of how domestic buildings and households respond to extreme heat, and consequently how this might create greater demand for indoor space cooling (McLachlan et al., 2016; BEIS, 2021a). The single available data source for domestic buildings is from the Energy Follow Up Survey (EFUS) 2011 which estimates that approximately 3% of households surveyed have some form of portable or fixed cooling unit. A 2017 questionnaire survey revealed that 44% of English households used no cooling equipment, 50% used portable fans, and just 2% reported using an AC system (BEIS, 2021b; Drury et al., 2021). Although this demand for cooling is arguably small (BEIS, 2021a), National Grid has estimated a likely uptake of active cooling methods in the UK households, especially ACs, from less than one million devices today to 18 million units by 2050 (National Grid, 2018). They estimate that this would add up to 39 GW of peak electricity demand on a typical summer weekend day. With an expectation of such a large increase in UK cooling, we next examine whether and how this increasing demand has been considered in the UK energy policy landscape.

3.2. Status of cooling demand in the UK policy landscape: review and discussion

The literature shows that cooling demand has been underpresented in European energy policy and many energy policy studies have been focused on indoor heating (Thomson et al., 2019). The European Commission recognised this gap and launched the Cooling Strategy in 2016. The Cooling Strategy links indoor heat to poor building quality and recommends some passive cooling strategies such as insulating ceilings, walls and foundations to improve thermal comfort (European Commission, 2016). The review on the UK policy landscape conducted in this section confirms that cooling is almost invisible in UK energy policy and research. We review UK cooling policy based on the AIS framework adopted in Fig. 1.

3.2.1. Avoiding (reducing) the cooling demand through passive cooling strategies

Taking an ‘efficiency first’ approach costs less and delivers more value than investing on other decarbonisation strategies (Lowes et al., 2020a). Passive strategies such as insulation, natural ventilation, shading, cool roofs, and double glazing could achieve savings of up to 62% (Sharifi, 2021). For example, Nematchoua et al. (2019) show how the use of thermal insulation allows savings of up to 40% of cooling energy cost in hospital buildings. This reduction in space cooling demand reduces the use of ACs and electricity (McLachlan et al., 2016). Therefore, using less energy to cool buildings through improved insultation, heat reflection and other passive strategies should be the first target of cooling decarbonisation.

In the UK, reducing cooling demand through passive strategies has been recently considered by the Heat and Building Strategy (BEIS, 2021c), after recommendations provided by the CCC report on UK housing to introduce a new standard to ensure that the overheating risk is assessed for current and future climates at the design stage of new-build homes or renovations (CCC, 2019). Following this, the government published revisions to the existing Building Regulations in December 2021 that set out passive cooling measures to tackle overheating in all new residential buildings. However, some experts believe the proposed means to address overheating lack a clear plan to retrofit existing homes (Lowe, T., and Gardiner, J. 2021). This means the scope of the overheating requirement is only for new residential buildings (Post Note 642, 2021). This policy gap can also be seen in the heat decarbonisation sector where building regulations tend to target new buildings (Lowes et al., 2020a). Since existing buildings make up a significant number of the UK housing stock (Lowes et al., 2020a) and new buildings are much more energy efficient than older buildings, more emphasis should be given to retrofitting of older buildings. Overall, attempts to avoid the need for cooling demand in existing UK buildings are absent from energy policy and, for new buildings, the impact of updated building regulations for overheating are yet to be seen.

A review of building regulations in other countries could be an opportunity to find the energy policy gaps associated with cooling and net-zero targets. For example, the French thermal regulation RT2012 introduces more stringent regulations of insulation to limit heat absorption in buildings during summer. The regulation covers existing buildings, as 20 million French houses out of 32.2 million of the existing buildings were built before the first thermal regulation from 1975. Their renovation become a priority under RT2012 to reduce energy consumption in existing buildings by 38% by 2020 and to renovate 400,000 dwellings per year from 2013.

3.2.2. Improving the efficiency of cooling equipment and reducing F-gas of air conditioning

The next aspect of cooling decarbonisation is to meet the actual cooling demand needs by using efficient cooling equipment with the least F-gas use. Users mostly purchase cooling products with an efficiency of 1/3 to 1/5 of the potential efficiency standards (Delmastro, and Abergel, 2021), mainly because the most efficient ACs often have higher up-front end-user costs (Post Note 642, 2021). In the UK, using efficient cooling products like other energy-related products are currently regulated under two policies: eco-design and energy labelling. Alignment with the EU eco-design and energy labelling regulations were retained in UK law following Brexit (HM Government, 2021). Cooling products, chillers and fan coil units sold in the EU must have energy efficiency labels and comply with 'eco-design' standards (Post Note 642, 2021). The new 'Eco-design for Energy-Related Products and Energy Information Regulations 2021' came into force on July 1, 2021 in the UK and were referred to as the "Right to Repair Regulations". These mirror technical requirements in equivalent EU regulations and include higher minimum energy performance standards, new material efficiency and information requirements.

Split ACs are the most used cooling equipment worldwide. These units not only increase electricity demand, but also have a global warming impact due to the use of F-gas. The 2014 EU F-Gas regulation came into force in the UK in 2015 and was retained in UK legislation post-Brexit, which requires a 79% reduction in the use of hydrofluorocarbons (HFCs) between 2015 and 2030 (CCC, 2020b). Some bans are already in place in the UK for HFCs in domestic refrigerators since 2015, for car air-conditioning since 2017 and for industrial refrigeration systems since 2020. Under these bans, the UK has already phased out more than 40% of HFCs consumption. The European Commission has recently revised and proposed new regulations to control F-gases more tightly. The proposal contains new bans on heat pump refrigerants, which has worried the European Heat Pump Association (EHPA), as this may restrict the required heat pump deployment to achieve EU's 2030 climate and energy targets (EHPA, 2022).

Another important aspect of energy efficiency concerns combining heating and cooling systems, such as using reversible heat pumps—a key low carbon heating option as recommended by various sources (Post Note 642, 2021). Reversible heat pumps are one of the most effective cooling technologies available to decarbonise buildings that could deliver heating and cooling in a single system (Lowes et al., 2020b). Some countries have already deployed reversible heat pumps for heating and cooling. For example, China has the largest heat pump market worldwide which alone accounts for 28% of global sales (BEIS, 2021d), and 90% of them are reversible air-to-air heat pumps with a cooling and heating function (Zhao et al., 2017). In Japan, Korea, Europe, the United States and Australia, reversible heat pumps are commonly used for both heating and cooling (Abergel, 2021). However, despite the important role of heat pumps in the heating and cooling decarbonisation, their deployment in the UK is one of the lowest in Europe (Barns et al., 2021; Hannon, 2015). Scandinavian countries have the most heat pump sales in Europe, with Norway reaching 46 sales per thousand households in 2018. The UK's demand for heat pumps is relatively low comparatively, with only 1 sale per thousand households (BEIS, 2020). Besides, data from the EHPA (2019) shows that while reversible air-to-air heat pumps are the dominant type of heat pumps in the global market (Abergel, 2021) and 50% of heat pump market in Europe, the main type of heat pump in the UK market is air-to-water. Air-to-air heat pumps require a warm air circulation system or room blower units to distribute heat (BEIS, 2020). In addition, system design and installation of reversible operation is key to delivering intended efficiency benefits and the UK skills base to do so is currently lacking (Post Note 642, 2021).

3.2.3. Shifting cooling to renewable, thermal storage and district cooling

Shifting cooling demand to use renewable energy supply, thermal energy storage and district cooling networks is a vital aspect of cooling decarbonisation to achieve the net-zero goal (Cool Coalition, 2019; EIA, 2021).

A clean energy shift for district heating and cooling in Europe is supported by the Renewable Energy directive which was presented by the European Parliament in 2009 (European Union, 2009). As part of this directive, renewable sources would generate 30% of the final energy by 2030 (Mazhar et al., 2018). The Energy Efficiency Plan was also introduced in 2011 (European Union, 2011); this requires energy efficient heating to be met through co-generation technologies supplied via district heating and district cooling systems (Mazhar et al., 2018). Sweden, Finland, and Denmark have made significant progress in deployment of municipal district networks (Barns et al., 2021). Particularly, Denmark has become a world leader in this technology, where 46% of the heating demand of the entire country is met by the district heat based on alternative fuels (Mazhar et al., 2018). In these countries (excluding Norway), at least 50% of buildings' heat is provided by district heating and at least about 70% of the district heating is produced by a combined heat and power (CHP) unit (Pylsy et al., 2020). Many of the existing district cooling networks are in the Nordic countries, where the cold water is distributed to the customers in similar ways as the hot water for district heating (David et al., 2017). It is fair to say that countries with established expertise of district heating could pave this way for deployment of district cooling systems (Werner, 2017).

Only 2% of the UK heat demand is provided by district heating (BEIS, 2021c) while district heating could technically deliver 20% of UK heat demand by 2050 according to the CCC and BEIS recommendations (Postnote 632, 2020). Based on the Clean Growth Strategy (2019), district heating in the UK is projected to meet 17% of heat demand in homes and 24% of heat demand in industrial buildings to meet 2050 decarbonisation targets. The low speed of the district heating progress in the UK suggests that the UK is far behind in shifting cooling to networked systems.

Thermal energy storage, which is a significant element in shifting to renewable energy and decarbonisation (Mathiesen et al., 2015), is currently at a niche stage in the UK (Renaldi and Friedrich, 2019). Although, according to the Heat and Buildings Strategy, the UK government has made available new funding for heat networks, it is still a long way to go for deployment of district heating and cooling systems. Apart from national policy, socio-technical factors will affect the transition and deployment of renewable energy in buildings as it requires direct intervention in many millions of homes and businesses (Barns et al., 2021). The use of renewable heating sources is a social-technical consideration at a local level, but the shape of these considerations and the momentum with which localities use renewables is defined on a national scale (Mazhar et al., 2018). Overall, the UK is still lacking a significant national policy and governance to shape and support transition to low carbon heat (Lowes et al., 2020b).

4. Conclusion and policy implications

Our UK cooling energy policy review reveals cooling demand is under-represented compared to heating, despite potential health implications associated with a warming climate and expected overheating, which is one of the top risks in all UK climate risk assessments published to date. The decarbonisation of cooling, as cooling grows, alongside heating decarbonisation, are inevitable for meeting net-zero targets.

Reviewing current cooling demand in the UK shows there is limited data on domestic cooling demand and little discussion about cooling strategies that households apply in response to overheating events. Other countries have conducted surveys on households to collect cooling energy related information to support their future policy making on cooling. Provision of data on the current cooling demand and users' cooling behaviour (which is correlated with cooling device choice) is the first step to help policy makers to design relevant policies (Hu et al., 2020). Hence, national level research is needed to understand the status of current cooling demand, cooling behaviour, and domestic perceptions of future cooling to support the formulation of future policy.

The UK government has recently taken the first step towards reducing cooling demand by considering passive cooling measures in revised building regulations which came into force on 15th June 2022 (CCC, 2020a). However, revised building regulations require only new homes to be built with a consideration of overheating, and its impact is unknown (there is no data on how well targeted policy proposal can be). Many gaps remain, such as policy to incentivise overheating adaptation in the existing housing stock and in new public and commercial buildings. The government should encourage the take up of passive cooling measures in existing houses at risk of overheating. There are opportunities to propose stronger standards for new buildings at the design stage (CCC, 2019; Khosla and Lizana, 2021) as well as scale up the home retrofitting plans (existing buildings) by considering passive cooling strategies to tackle overheating and support decarbonisation (Lowes et al., 2020a; CCC, 2019).

Furthermore, actual cooling demand should be met through the most energy efficient equipment with low Global Warming Potential (GWP) impact. A significant impact of single ACs results from the widespread use of HFCs which are now subject to global phase-down (not phase-out) under the Kigali Amendment (KA), which has been enforced from 1 January 2019 (Mota-Babiloni and Makhnatch, 2021; Purohit et al., 2022). In advance of KA obligations, several legislations with similar actions have been implemented in the European Union. This led AC manufacturers to switch to HFC-32 (GWP100 = 771) as a lower GWP alternative to HFC-410A. In the UK, under the F-gas regulation, some UK manufacturers have already switched to HFC-32 from R410a (with GWP of 2088), which was the most used heat pump refrigerant in the UK. Therefore, still most ACs and heat pumps rely on F-gases as their refrigerant (Post Note 642, 2021). Some Asian and European manufacturers have been using the natural refrigerant propane (with GWP100 $<$ 1) in portable ACs, which enables a similar device performance to those using HFC-32 (UNEP, 2016) and leads to a higher efficiency than currently widespread appliances using HFC-410A (Purohit et al., 2022). Thus, there is a chance to include significantly more equipment under HFC bans to phase them out over the next UK F-gas regulation revision.

Although there has been limited progress around heating decarbonisation in the UK, ignoring cooling is peculiar. There could be an opportunity for policy makers to consider cooling demand in energy policy alongside pathways associated with heat decarbonisation. Considering cooling demand alongside heating demand will help UK policy makers to focus on combined technologies such as tri-generation or combined cooling, heating, and power systems to switch to low carbon heating technologies in the effort to decarbonise domestic heating. Compared to other countries, cooling networks are still emerging in the UK. Projects integrating district heating with district cooling networks and renewables into a single network are already under operation elsewhere and, given their immense decarbonisation potential, important lessons can be learned (Ugalde-Loo, 2022).

Energy efficiency can also be improved by utilising heat and/or cooling that would have been wasted. For example, the heat removed during cooling could simultaneously be used for hot water production providing very high efficiencies, yet the UK market is poorly developed to consider such combinations. In addition, heat pumps may be the single most efficient technology for heating and cooling. However, despite heat pumps having a significant role in most heat decarbonisation scenarios in the UK, their deployment level in the UK is one of the lowest in Europe due to fundamental barriers including installer skills gap. In this regard, the UK government must provide some policies to incentivise workers to invest in training and re-skilling.

To sum up, with the expected growth in cooling demand and uptake of ACs, focusing only on research and policy towards affordable heating solutions and neglecting cooling is not an option, particularly when it is expected that many buildings will be increasingly electrified with heat pumps which could also provide cooling. This review has identified a need for research to underestand how cooling decarbonisation would relate and integrate to heat decarbonisation policies while considering social, technical, and institutional factors in the UK policy context.

CRediT authorship contribution statement

Fatemeh Khosravi: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Richard Lowes:** Conceptualization, Methodology, Writing – review & editing. **Carlos E. Ugalde-Loo:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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