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Hot and cold: Policy perspectives on overheating and cooling in United Kingdom homes

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ABSTRACT

Under the current climate, overheating is already a problem in UK homes, causing discomfort, ill health, and mortality. As temperatures continue to increase due to climate change, the problem will worsen. Cooling offers a solution and its use in the domestic sector is expected to grow, but active cooling technologies can create emissions which contribute to climate change and can have wider social impacts. Policy needs to be developed to protect people from heat risks, whilst limiting the impacts from any cooling. These are emerging research and policy areas within the UK and other temperate countries, and this paper explores these challenges and opportunities using an avoid-improve-shift cooling decarbonisation framework, through semi-structured interviews with 74 policy actors. The results show the main challenge is the existing stock, that the market for domestic cooling is immature, and there are opportunities to support the adoption of passive measures, improve cooling products, and manage cooling within the energy system. Overall, the paper highlights the need for action to create homes that are fit for the future through the development of a balanced, integrated cooling policy. This can be achieved by acting quickly and comprehensively; seeking synergies with wider energy policies; supporting people to take low-carbon, climate resilient behaviours; making use of best practice; and through effective leadership.

1. Introduction

1.1. Overheating in a warming climate

Globally, 2023 was the hottest year on record, with an average temperature of 1.48 °C above pre-industrial levels [1]. The trend in high temperatures has continued into 2024 [2] and the UN has suggested there is a high probability it will be another record-hot year [3]. Based on current commitments, the world is on a trajectory of up to 2.9 °C of warming beyond pre-industrial levels this century [4].

Extreme temperatures have economic, social, and environmental impacts including widespread and pervasive loss and damage to ecosystems, people, settlements, and infrastructure [5,6]. Their impact on human health and wellbeing is a key concern, with high and extreme temperatures resulting in discomfort, mortality, and morbidity [7,8]. The risks from exposure to heat are a growing global challenge which will make the delivery of global Sustainable Development Goals more difficult [9,10]. There can be direct impacts such as dehydration, heat stress, exhaustion and stroke, exacerbation of existing health issues, and impacts on mental health [8,11–13]. As well as indirect impacts such as increased risks of accidents, sleep disruption, higher levels of violence and stress on health services [8,11,14]. Risks are higher for some parts of the population, such as people over 65, those with chronic diseases and longer-term illnesses, people with drug and alcohol addiction, the homeless and the very young [11,15,16].

Turning towards the UK, risks to health from high temperatures have been identified as a priority issue within national climate risk assessments, with calls for more urgent policy to adapt to increases in the intensity and extent of heatwaves[1] [17–20]. Heatwaves have been experienced in four

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[1] Extended periods of hot weather when a location records a period of at least three consecutive days with daily maximum temperatures meeting or exceeding the heatwave temperature threshold. This varies by UK county from 25 °C to 28 °C [6].

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Abbreviations

AC	Air Conditioning
CPD	Continuing Professional Development
F-Gas	Fluorinated greenhouse gases
GHG	Greenhouse Gases
HFCs	Hydrofluorocarbons
MEPS	Minimum Energy Performance Standards
SUDS	Sustainable Urban Drainage Systems
UHI	Urban Heat Island

of the last five years, with the one in 2022 seen as unprecedented with temperatures exceeding 40 °C for the first time [6,17]. 2022 and 2023 were recorded as the two hottest years on record [21] and there is a recognition that the coming decades will see increases in average summer temperatures, the number of hot days, and heatwave events across all regions of the UK [17,22].

UK data suggests there were over 3200 excess deaths in 2022 due to heat, 6.2 % above the five-year national average [23], but the number may be as high as 4500 [6,16]. Projections to 2050 suggest heat-related deaths could rise to 7000–10,000 per year without adequate adaptation [14,16,24]. Whilst heatwaves are a concern, moderate heat rises may have more of a health impact overall [25]. Lost sleep impacts productivity and can reduce concentration, alertness, and cognitive performance [8], costing the UK economy around £60bn per year [16].

The rise in global average temperatures and increases in the frequency and intensity of extreme heat events [26] are resulting in overheating within homes becoming more common, including within temperate countries [27,28]. There is a growing body of research into the health impacts from heatwaves and overheating, with concerns that these represent an 'invisible risk' and 'silent killer' which policy is not yet adequately addressing [7,14,29–31]. Overheating[2] is a considerable risk within the built environment because people spend around 90 % of their time indoors [28,32]. However, in colder temperate climates, buildings have tended to be designed to retain heat in winter [28,31,33] and they are therefore not resilient or well equipped for dealing with overheating in the summer [14,34]. A combination of factors influences the level of risk, including climate, building characteristics, wider geography, the urban heat island effect (UHI), as well as people's behaviour [16,28,35,36].

Within the UK it is suggested that around 20 % of homes already experience overheating in an average summer [14,16,37], which could increase to 90 % of the stock if the climate warms by 2 °C [33]. A range of factors can influence the level of overheating risk, linked to building type, tenure and occupancy, and wider social factors like home working, income and vulnerability, and wider inequalities [8,16,17,28]. These issues are not helped by the nature of the UK housing stock, which is old and one of the least efficient in Europe [38]. An estimated 80 % of the 2050 stock is already built, suggesting that significant retrofitting will be needed to reduce overheating risks, and more widely improve energy efficiency and the decarbonisation of homes [8,17], a comprehensive approach to housing retrofit is needed [16,39–41].

1.2. *Cooling, a solution and a problem*

Cooling offers a solution to overheating, effectively helping to reduce temperatures, provide thermal comfort, and reducing health risks [42,43]. It can be provided passively, linked to urban planning and design of cities and places, as well as through design decisions of individual buildings, such as thermal mass, orientation, and material specifications [10,33,44]. Passive cooling can be further enabled through building level measures, such as shading, insulation, ventilation, and the use of cool roofs and reflective surfaces [16,33,45]. Furthermore, the effective use of green and blue infrastructures in isolation and/or combination can provide a range of passive cooling benefits, reducing urban temperatures by several degrees [46,47]. This can include green space and structures, such as trees and plants, green roofs and walls, as well as blue infrastructure like water features and urban water bodies; these can passively cool through a number of different routes, such as shading, evapotranspiration and evaporation [47–49]. Passive measures provide cooling without the ongoing use of energy [14] and have the potential to reduce overheating risks in up to 80 % of UK dwellings under 2 °C of warming [33].

Many passive measures are affordable, low maintenance and easy to apply [50]. Examples of no and low-cost options (less than £150 per meter square) include internal shading, natural ventilation, reflective surfaces, and window film [33,45]. External shading can range from £100 to over £500 per meter square, whilst a green roof may cost approximately £25–50 per meter square (50), with other cool roof interventions costing more, such as reflective tiles (£125 per meter square) or solar PV (£1750/kW) [51]. Actual costs will vary depending on the type, size and location of a building, the level of cooling sought, and the climate, with a recognition that costs will be lower when designed in from the start, rather than later retrofitted [33,50]. Some of these costs will bring additional benefits, such as lower building running costs and carbon savings [33].

Keeping cool can also be enabled through a range of non-passive measures. Simple technologies like free-standing or ceiling mounted electrical fans can increase air velocity to improve thermal comfort, with low energy demand and costs [28,52,53]. Stand alone or hybrid configurations of earth air tunnels can also provide a more sustainable route for cooling (and heating) helping reduce energy demand whilst improving thermal comfort [54]. There are other active or mechanical cooling options available for cooling buildings, and ongoing innovations around a range of technologies [45], but the dominant route to provide residential space cooling globally is via vapour compression air conditioning (AC) [10,55,56]. Refrigerant-based AC can be polluting due to the indirect emissions from higher energy use, if from fossil fuels, as well as direct emissions from the use of hydrofluorocarbons (HFCs) or fluorinated gases (F-gases) used in refrigerants [43,57]. These impacts can be exacerbated by users choosing cheaper, lower efficiency, AC products, with research showing a considerable gap between those purchased and the most efficient on the market [10,55,57]. As well as contributing to climate change, increased energy demand means AC adds to household bills, puts pressure on electricity networks, and can have implications for equity [58–60]. It also generates waste heat, which if dispersed to the atmosphere increases urban temperatures and the UHI [8]. Currently, AC is the incumbent space cooling technology and there are concerns it will become the default solution to cooling homes, with other solutions overlooked [10,61]. There are purchase and on-going running costs for active cooling, which range from a few tens of pounds for a portable fan, to a few hundred pounds for single room portable AC units, through to a few thousand pounds for a multi-room AC split system [45,50].

As with overheating, to date, action on cooling has been described as under-represented and a policy blind spot [42,55,57], although this is starting to change within many temperate countries as the impacts and risks from overheating become more apparent [26,28]. Within the UK, work has been underway to better assess building level overheating risks and solutions, energy demand and energy system impacts, as well as cooling emissions data [62–65]. In 2023 the UK signed the Global Cooling Pledge, which commits it to publishing a national cooling action plan or equivalent by 2026 [66].

These are important developments and should help to overcome the

[2] Overheating relates to the energy balance between heat gains and losses, when the gains exceed the losses for a prolonged period overheating occurs [28].

current low levels of understanding on active cooling demand within the domestic [45]. It is currently estimated that around 5 % of UK households have some form of active cooling, and that the number of units may rise from around a million today to 17–18 million by 2050 [45,67,68]. These may turn out to be conservative estimates, as a recent study using cooling degree days,[3] suggests the UK could see a 30 % increase in the number of days with uncomfortably hot temperatures if 1.5 °C of global warming is exceeded [59]. That could result in a surge in active cooling demand, particularly as the additional impact of heatwaves were not included within the study [69,70]. The growing demand for cooling will also play out within the energy system [71], with new summertime loads potentially coinciding with increased system stress due to higher ambient and extreme temperatures [17,72].

1.3. Research overview

As the climate warms and overheating in homes becomes more common, the demand for cooling will increase. Whilst a global challenge, it is a relatively new phenomena in cooler temperate countries like the UK, where the focus has tended to be on keeping homes warm in winter. Without sufficient policy attention there is a risk that AC will become the default solution to household cooling, with wider opportunities missed, resulting in a range of unintended consequences for people, energy systems and climate mitigation. The goal of this research is to better understand the challenges of overheating and cooling within homes, through the perspectives of UK policy actors, to help identify routes to decarbonise cooling within this sector.

Whilst not a state-of-the art, comparative country study, research on cooling homes in the UK is limited and our approach provides novel insights on the policy challenges and opportunities for addressing overheating and cooling within the domestic sector. These sit across the intersection of policy, people, energy technologies and systems, and as such this research will be of interest to policymakers, actors, and researchers working on the relationships between energy systems and society. Whilst focussed on the UK, the findings will be of relevance to other countries that face similar challenges for cooling homes.

Section 2 describes the research methods used to understand the challenges of overheating and the decarbonisation of cooling from the perspectives of UK policy actors. The results are then set out within Section 3 and discussed within Section 4. In the final section we provide conclusions and some insights for policymaking for cooling homes.

2. Research methods

To help address the challenges associated with overheating and cooling within homes a framework for decarbonising cooling was adopted, Section 2.1. This was then used to shape the research design and methodology, set out in Section 2.2.

2.1. Framing the decarbonisation of cooling

An initial review of the literature identified an established typology, the avoid-shift-improve framework, that was developed in Germany in the 1990s to help reduce the environmental impact of transport [73]. As well as being widely used within transport studies, the framework has increasingly been more broadly applied to demand-side, consumer-based approaches to reduce emissions and support behaviour change [73–75]. It has also been used within the Climate Action Pathway for Net Zero Cooling [43]. Within that publication, a partnership between the Carbon Trust, Cool Coalition, High-Level Champions, Kigali Cooling Efficiency Program, and Oxford Martin School, used the framework as it's theory of change for decarbonising cooling by 2050 and considered how it could be applied to the domestic AC market for mitigating emissions.

The avoid-shift-improve framework provides a route to consider policy options and consider cross-sectoral approaches [73], and it was applied to the UK energy policy landscape in respect to the cooling sector by Khosravi et al. [57]. To effectively decarbonise cooling, action across all three areas of the framework is needed, with the behaviours and decisions of people also playing a central role. This research has adopted the approach taken by Khosravi et al. [57], where improve and shift within the framework are switched. This reflects the often used energy hierarchy of using less energy, using it efficiently, and then meeting the remaining demand through low carbon supply [76], which is widely used within planning for the built environment, such as the London Plan [77]. Thus, the approach to decarbonising cooling, illustrated in Fig. 1, sets out the need for a passive first approach (avoid), considers actions to shape and improve products within the market (improve), as well as strategies to meet and manage cooling loads within energy systems through low carbon supply (shift). This helps to avoid fossil fuels coming onto the system to meet demand, an issue that has already been seen within the UK [16].

Overall, the avoid-improve-shift framework provides an effective route for considering the decarbonisation of cooling within the UK and a suitable framing for our research. It also enables some of the relevant policy areas to be mapped to each area of the framework within Fig. 1. This shows the wide range of policies that impact cooling within the UK, with likely similarities for other countries, given the broad relationships to buildings, products, and the energy system, particularly the common challenges related to the decarbonisation of supply, and the design, operation, and management of energy systems [10,39].

2.2. Research methodology

We used a two-stage qualitative methodology, using semi-structured interviews based on the avoid-improve-shift framework, with content analysis to identify challenges and opportunities for the decarbonisation of cooling. The semi-structured interview format is provided in Appendix 1 which is linked to the framework and the overall methodology is summarised in Fig. 2. The following research questions were used:

1. What are policy actor perspectives on the current state of overheating and cooling in homes, and how can any impacts from active cooling be reduced?
2. Are there opportunities for aligning cooling to wider energy policy areas?
3. What insights and policy implications does the research provide for cooling homes within the UK?

The research approach recognises that politicians and civil servants do not create policy in a vacuum [78], rather a wide range of policy actors are involved in policy development and debate, constructing narratives, providing evidence, shaping implementation and delivery [79]. As overheating and cooling are both emerging policy issues and the responses to deal with them are still developing, seeking policy perspectives can help identify knowledge to inform decision making [80]. To help ensure depth and breadth across social, technical and policy and governance, policy actors from a range of sectors were approached – Table 1. However, we do recognise that whilst this design provides insights across a range of relevant disciplines, there are some limitations given the number of interviews in some sectors is relatively small.

Interviewees were identified through cooling literature and snowballing, and 65 interviews took place over MS Teams, with 74 participants. Audio recordings were transcribed verbatim and analysed in NVivo 10, with coding reflecting the interview design, used to help identify meaning, both on the surface and implied, and provide an

[3] A measure used to assess and predict cooling needs of different regions, based on how hot the outside air temperature is in relation to the designated standard temperature for the region [59].

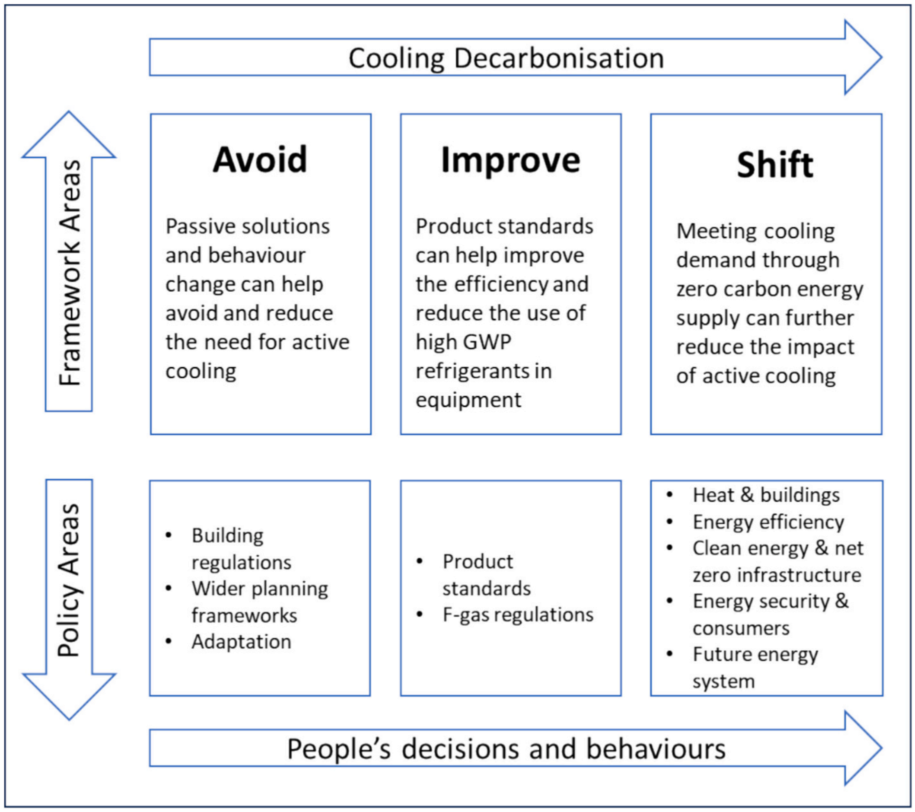

Fig. 1. The avoid-improve-shift cooling decarbonisation framework.
Updated from Khosravi et al., [57].

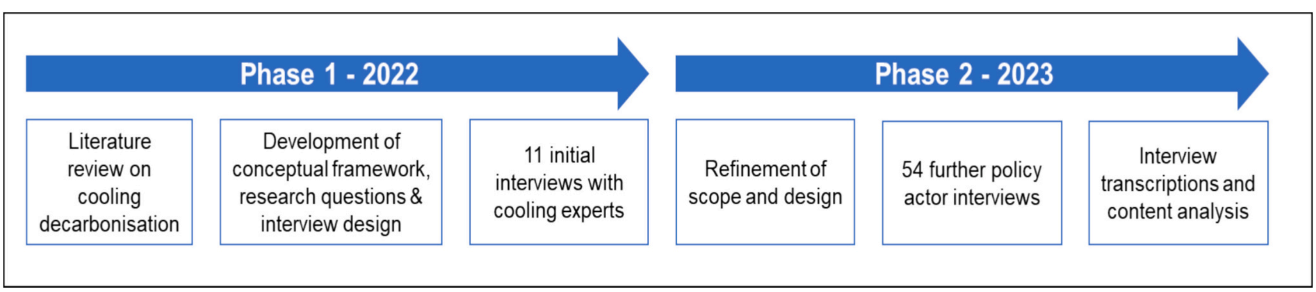

Fig. 2. Overview of research methodology.

Table 1
Overview of policy actor interviews.

Sector classification	Sector description	People interviewed	Interview coding
Government	Civil servants within government departments and the Devolved Administrations.	13	C31, C32, C34, C35, C36, C43, C46, C54, C65
Local government	Officers working on energy, climate and planning, and local government advisory organisations.	7	C1, C3, C5, C8, C21, C33, C39
Advisory organisations	Statutory advisors, and third sector energy and social advice providers.	5	C9, C13, C25, C47, C48
Energy industry	Network operators, energy suppliers, associated trade associations, the energy regulator.	10	C2, C22, C23, C37, C40, C44, C49, C53
Wider energy sector	Technology companies working within heat, cooling, and storage. Associated trade bodies.	11	C10, C12, C14, C15, C18, C27, C50, C51, C52, C59, C61
Consultancies	Energy and built environment consultancies, building modellers	13	C6, C11, C20, C24, C26, C30, C38, C41, C45, C60, C63
Wider civil society	NGOs and charities working on energy, climate, buildings, sustainability, and innovation	6	C7, C16, C17, C19, C29, C57
Academia	Academics working on cooling, the built environment, energy, and planning	6	C28, C42, C56, C58, C62
Think tanks	Working on energy, climate, and sustainability	3	C4, C55, C64

organised summary of key insights [81,82].

3. Results

The structure of results and discussions follow the avoid-improve-shift framework (Fig. 1) and the wider coding structure. To help connect to the underlying data, relevant quotes are included with their coding reference, which can be linked back to the sectors in Table 1.

3.1. Avoiding active cooling

There was a widespread recognition across the interviews around the importance of passive measures for reducing overheating risks, improving comfort and health, and for the creation of more resilient buildings. Many interviewees felt it would also help avoid the unnecessary take up of active cooling, for example "*most of our modelling work across different building types shows that you could probably achieve satisfactory indoor conditions in the summer with a combination of passive measures*" (*C42*). Suggestions for passive measures reflected the wider literature, such as cool surfaces and roofs [51], as well as the importance of occupant behaviour, with many feeling that some passive approaches "*can cool simply and cheaply*" (*C33*), making them a potential important enabler of equity. Passive measures were also seen as central to improving the efficiency and running costs of any active cooling.

3.1.1. Reducing and managing heat gains

Avoiding internal solar gains was seen as a key mechanism for reducing heat risk. Whilst partly about the design of buildings, it is also shaped by behaviour, with simple things like shutting windows, and closing blinds or curtains seen as an easy way to reduce temperatures by several degrees. External shading was seen as more effective than internal shading, with options including shutters, façade design, and solar shading being mentioned, with a view that the UK should start to "*encourage a more continental vernacular*" (*C45*). Reducing unnecessary internal heat gains is also important [28].

Managing airflows within a building with cross-ventilation to replace hot air with cooler air from the outside, is also an important component of passive cooling. It was recognised that this is shaped in part by the type of building and its design, with single aspect flats singled out as a key challenge. More broadly, the ability to open windows sufficiently was also seen as a key enabler of natural ventilation, with issues linked to safety, security, local noise or pollution, potentially limiting window openings. Effective ventilation also reflects the behaviour of building occupants, with many feeling "*people don't know what the right thing to do is*" (*C13*), requiring education to "*learn how to drive and use buildings,…to draw cooler air through*" (*C16*).

3.1.2. The local environment

Temperatures within a building can also be reduced by the wider local environment, "*if you have a tree right in front of your window, it'll be a very different thermal environment compared to if you don't*" (*C42*). Reflecting the wider literature, many highlighted the importance of green and blue infrastructure for reducing urban temperatures and the UHI, whilst also providing access to cool spaces [16]. Examples of the role of urban planning for passive cooling included housing density, the amount of concrete, and hard surfaces, with a view that solutions can also be brought together: "*cool pavements, permeable pavements, SUDS,*[4] *are all things that when combined help cool the city*" (*C33*).

Both national and local planning policy were seen as important enablers of passive cooling. Concerns over the lack of attention to overheating and cooling within national planning policy mirrored the wider literature. Several participants felt that local policy might be better placed to help address this gap, in part because local authorities can understand risks and opportunities, support households, and shape the built environment, they are "*able to see things in the round and spatially in the context of the locality*" (*C19*). The ability for local authorities to go further than national policy was also seen as an important enabler, with a view that "*as long as there is due process, being able to set our own local targets has been really, really beneficial*" (*C39*). However, there were also concerns, "*there is this uncertainty about whether we can set policy locally that exceeds national policy, including how different inspectors take different views – that is a major constraint and extremely wasteful in terms of resources and causes some authorities to not even try*". (*C21*). For both adaptation and mitigation to heat, it was felt that local powers, Local Plans and supporting documents would be central to dealing with future risks. Although there was also a perception that both nationally, and locally, "*mitigation dominates the policy space and adaptation's been the Cinderella side of it*" (*C32*), an issue recognised within the wider literature [83,84].

3.1.3. Improving homes

For new builds, getting things right at the design and build stage was universally seen as the best way to avoid overheating risks and the need for later retrofits: "*we don't want to be building houses that overheat, that's quite a simple one*" (*C64*). Part O of Building Regulations was seen as an important development, although monitoring its impact as homes start to be lived in, and its wider application to building conversions and renovations were seen as important, as highlighted elsewhere [16].

Across the interviews, dealing with the existing stock was felt to be the main challenge for overheating and cooling. Retrofitting to reduce overheating risks is difficult because you need to work with the existing fabric and design of a building. It is clear within the wider literature that this is further complicated by the stock age, quality, and non-uniformity, housing can be "*unique to pretty much every development or at least every street*" (*C39*). Whilst some measures like internal shading and airflow management are economic and easily achievable with the right knowledge, other passive measures can be more complicated and present broader challenges, including:

- disruption - you are "*going into houses to do these works*" (*C48*), so you need to work around people;
- renovations - tend to happen in phases, but for cooling it is important to think "*about the whole house in retrofits, balancing energy efficiency, heat and cold*" (*C17*);
- tenure- "*can impact what people can and can't do*" (*C9*) or what they are willing to do.

Costs are also important, whilst "*interventions in [the] retrofit space could be quite moderate potentially, shading, proper window openings…it can get very expensive if dealing with an extension that's fully glazed*" (*C31*). People highlighted that national modelling [33] for passive measures, estimate costs upwards of £10,000 per house, although there was a view that costs could be reduced and be less disruptive if combined with wider works: "*if housing associations and local authorities are looking at retrofit schemes, they should include overheating as part of that*" (*C30*). Additional concerns were mentioned for the owner occupier and the private rented sectors, which respectively make up around 63 % and 19 % of the existing stock [85]. Work in these sectors "*needs to be private investment led*" (*C32*) and whilst some felt it is improving, there was a general view that, it remains difficult, as "*there are not many good ways to access either funding or finance*" (*C47*).

Cost concerns also link to the wider supply chain, "*it's hard to find an installer,… so you end up paying over the odds, because there aren't the skills and supply chain in place, demand is increasing, but supply hasn't changed*" (*C43*). There are also structural challenges for the retrofit supply chain, with many characterising it as a fragmented industry, with sub-contracting across and within trades common. The sector includes lots

[4] Sustainable Urban Drainage Systems.

of micro and small businesses that struggle to upskill. It was mentioned that "*small builders aren't attending CPD*[5] *…because they don't have time*" (*C30*), which can create problems as people do not know how to go about "*balancing issues like insulation, ventilation, and overheating*" (*C13*). In respect to the wider landscape for passive alternatives, "*there's no market, no economies of scale, no product maturity*" (*C30*), which can mean for things like "*solar protection devices, even if consumers aware, it's hard to access products*" (*C56*).

3.1.4. Supporting people

The need for equity within overheating and cooling was a common concern from the interviewees. As well as issues linked to the quality, type of stock, its location, low income was commonly mentioned, with concerns that some will not be able to afford even minor passive adaptations, let alone an active cooling solution, "*if you are financially struggling, you might sacrifice your health because you're just not capable of buying or running something*" (*C44*). There was also a recognition that some people face additional barriers in the energy transition, which may be mirrored for cooling, including "*people in the private rented sector,.. people who are digitally disadvantaged... and people on low incomes, [who face] risks in terms of being excluded*" (*C25*). Some felt that for overheating there could be considerable crossover in vulnerabilities for those who also struggle to keep warm in winter.

More generally the importance of awareness raising within the public was commonly mentioned. As well as its role in helping people manage heat and cooling within the home and adopt passive measures, there was a view that there is still a psyche in the UK were "*heat in general is not taken very seriously yet, almost the opposite, hot weather is still seen as a positive*" (*C42*). As well as health, examples were given of how a lack of information could result in some poor outcomes for cooling:

- "Most people probably wouldn't even consider shading as a first step" (C41);
- "I have friends that have bought AC…. because of not knowing what other solutions are around, or how to operate in hot conditions" (C39);
- "When [overheating] becomes more common, they will just get fed up and if you have no information and don't know what to do, you walk into a shop and it's £200 for a portable AC unit" (C31).

3.2. Improving cooling

The need for awareness raising extends into the discussions on cooling technologies. There is a risk that "*people will just buy a portable AC or fixed unit, with little thought to its impacts*" (*C57*). This could happen due to information deficits, or because there is a perception that cooling is only needed for a limited time, leading to people buying "*the cheapest option available, which often [is] the least efficient*" (*C55*). There were also concerns that once people have AC, they may well run it for far longer than is needed. With a growing market pull from consumers, many felt there was also a clear market push from manufacturers and suppliers, with increased availability, and visibility of products: "*you see in [the] summer, stores stacking up portable AC units*" (*C21*). This may be further encouraged by growing media attention on cooling, including best buy advice for AC. Whilst many felt there is a gap in understanding how people are responding, similar concerns were often expressed, if "*you have temperatures that are consistently uncomfortable you could get a tipping point where AC demand ramps up rapidly*" (*C40*).

Views on policy and regulation for energy efficiency and F-gases had some commonalities, with interviewees highlighting that a joined-up approach across the different policy areas could help improve products more effectively. Many flagged the importance of supporting global efforts to improve cooling, whilst remaining closely aligned to the EU trading bloc, as given the small size of the market compared to Europe, "*it's not likely manufacturers are going to develop a slightly different product for the UK*" (*C6*). However, some did feel the UK should consider the opportunities to just ban less efficient products, "*you could take F & G appliances out of market*" (*C58*).

More broadly on product standards, the importance of MEPS and their role within wider policy packages came through as a key mechanism for "*increasing standards so the market knows what it needs to work towards… [helping] eliminate the worst products from the market*" (*C18*). Their use, alongside eco-design and labelling, and financial incentives were felt to be an opportunity to improve the market more rapidly. On this package approach, the lack of financial incentives in the UK was highlighted. Given that the cooling market is expected to grow, some felt, "*funding support for the best options… will be important*" (*C41*). This could be particularly true for the more vulnerable in terms of access to cooling, but it could also support wider market transformation.

For F-gases, participants felt the UK is well regulated, but should keep up with the EU and consider opportunities for picking up the pace, as we "*need reductions in F-gas use to hit climate targets. Regulation…and companies could be doing better*" (*C63*). It was also highlighted, that with the continued decarbonisation of the electricity grid, the impact from refrigerants "*becomes a larger contributor to GHG emissions…. so need strong legislation on what can be sold, all the way through to end of life*" (*C41*). The cradle to grave approach for F-gases was a common point of discussion, and whilst policy was suggested to be reasonably strong, some felt there are "*unknown risks, around refrigerant leakage linked to maintenance or poor installations, where people do things themselves, including disposal*" (*C30*). It was also highlighted that there are tensions in this space, given that whilst quotas for F-gases are reducing, they are used in both heat pumps and AC units and the market for both is growing, with a view that more policy attention and innovation is needed to support a shift to natural refrigerants.

3.3. Shifting cooling

The ability to manage cooling demand will depend in part on the level, timing, and location of that load. Whilst there was a recognition there are gaps in understanding for domestic cooling demand, concerns were generally low, with a feeling that there is adequate capacity and good monitoring in place, with network operators doing "*an annual review of loading on all substation network assets for winter and summer*" (*C53*). Furthermore, given that cooling demand is expected to be much lower than heat demand [45], there was a perception that "*if you have got enough generation capacity for heat pumps, you've got enough generation capacity for cooling*" (*C64*). However, there were concerns that there may be a sudden, and/or very locational growth, "*as we experience more frequent and intense heatwaves, we [may] suddenly see a bow wave of people wanting AC and that might be very clustered, because people can see a neighbour has it and see the benefits*" (*C44*).

To reduce the potential energy related emissions from active cooling will require sufficient low carbon supply. Whilst many highlighted the good match with solar generation during the daytime, later demand might create challenges: "*rapid uptake of residential may mean [we] have to ramp up generation in summer to meet evening peaks, which has not been an issue in the past*" (*C40*). Many felt there would be an opportunity for storage and wider flexibility, at the household or system level, to help reduce emissions. This could help maximise the use of renewables and deliver benefits for the system and consumers [35,45]. Flexibility can also be enabled through the physical properties of a thermally efficient home, as "*energy efficiency is not just about reducing overheating risks, [but] also retaining any active cooling, pre-cooling during the day… [there is] potential for a pre-heat, pre-cool, using the thermal mass, the fabric of the building*" (*C41*). More broadly, there is an important role for wider enablers of flexibility, including interoperability and digitally enabled technologies, as well as routes to build consumer trust, such as the "*ability to opt in and out of things like automation*" (*C17*), with a view that

[5] Continuing professional development.

it will also be necessary to "*create flexibility products to reward people for turn up and turn down at the right time for the system*" (*C61*).

3.3.1. Aligning cooling and heating

In addition to electrical, thermal energy storage can also play an important role in helping manage electricity peaks, including through heating and cooling networks [86]. Many felt the development of these are not being driven by policy currently, instead projects "*bringing heating and cooling together are largely industry driven…, either because end users want it, developers want it, or as a route to deal with constraints*" (*C15*). As cooling demand increases, many interviewees felt so would the opportunities to integrate cooling into heat network delivery, although it was also recognised this may bring additional complexities, with feasibility and economics likely to be site specific.

For heat pumps, although the use of air-to-air was not felt to be a mass market solution in the UK, they may play a role in "*some segments where retrofitting a hydronic heat pump is not necessarily straightforward, such as flats, maybe terraced homes with little space, the hard-to-treat sector…*" (*C43*). Many also flagged that they are relatively cheap and easy to install, which will appeal to some, although a hot water solution will be needed. For hydronic air-source and ground-source heat pumps, views reflected the wider literature: "*there is a perception out there that you can just run a heat pump in reverse to provide cooling, it's not the case*" (*C52*). This is because of condensation risks, although interviewees felt there would be innovations in this space, and there are already work arounds, including control chips to avoid dew points or adding fan-assisted radiators. Whilst more expensive, if used reversibly, some felt ground-source heat pumps are a better option as "*cold water can be circulated without the compressor, making them cheap to run and quiet*" (*C52*); in addition, for air-source technologies, they "*dump heat into the local environment, contributing to UHI… and [have] noise issues in the summertime, when people are outside or have windows open [as the compressor has to run]*" (*C51*). There were also concerns about the additional skills needed to correctly design and size a heat pump installation for heating and cooling loads in an already stretched supply chain.

The use of shared ground loops was also mentioned, which "*sit halfway between heat networks and heat pumps*" (*C52*). Some felt these might play a role in providing street-based solutions in areas that are hard to find another solution for, like rows of terraced houses or blocks of flats. In such systems, "*it's almost a chilled water circuit, right up to each building… with a small heat pump inside. It [is] relatively straightforward to add cooling into the building from that*" (*C51*).

Overall, there was a feeling that heat and cooling policy is "*not joined up and we [are] probably missing an opportunity to sort two problems together*" (*C43*). In addition to the technology points above, some policy actors flagged the value of approaching these issues collectively through an approach based on thermal comfort, "*thermal energy is thermal energy, so heat and cooling could come together*" (*C14*). Such approaches are already used in the commercial sector "*where maintaining a comfortable temperature by managing heat and cooling [is] common and expected*" (*C16*). If work is happening in homes to decarbonise heat, thinking about thermal comfort from the start could help avoid the need to go back and deal with cooling later. This could be an important opportunity currently, as there is "*lots [happening] on the heat side, [and] we will probably need the same around AC and comfort*" (*C22*). The approach also links into the wider development of the heat supply chain: "*shifting thinking to comfort would be a massive opportunity to skill up the workforce now*" (*C6*). More broadly, it was felt this sort of approach could help break down policy silos, we "*will need to start thinking about cooling as an integral part of thermal comfort, not just some add-on or luxury item… thinking about it more from an integrated, holistic approach within local and national policy*" (*C41*).

3.4. Policy framing

Many felt overheating and cooling are both underrepresented within policy currently, in part because of their cross-cutting nature, with no one having overall responsibility, they are "*policy areas that fall in the gaps, because they are across too many departments*" (*C47*). It was also felt overheating and cooling may be a lower priority because they are more temporal in nature, compared to winter fuel poverty, and less visible compared to other adaptation challenges like flooding. In addition, there was a perception that there are bigger policy challenges, the "*2050 net-zero target…is like a brick wall, so focus is on immediate things to achieve it…. cooling is lower down [the] list of priorities*" (*C15*). Furthermore, for domestic cooling, compared to other sectors, there was a suggestion its impacts might be less significant, "*if you're looking at overall emissions and energy consumption, it's not the sector to be worried about*" (*C36*).

The actions and behaviours of people are central to decarbonising cooling, but policy makers highlighted the difficulties in accounting for them within policies when there are lots of unknowns. More broadly on knowledge gaps, there was a view that it is hard to develop an effective strategy "*when the household cooling market has not developed... it's not clear what technologies will unfold...[or] what consumer preferences will look like. I suspect that's why you see* '*and cooling*' *sort of tacked onto the end of policies*" (*C64*). More widely, in a market-based economy like the UK, the tendency is for things to be left to the market, "*cooling is currently just sort of seen as a consumer goods issue*" (*C55*). Some felt this would be problematic, given the nature of the heating, cooling, and wider net zero challenge, "*the question of how much that just left to market, house-by-house with everyone going their own way probably won't work*" (*C47*); whilst on overheating, "*you need a joined-up approach to housing, health and well-being agendas to protect the vulnerable….you can't leave it to the market*" (*C54*).

On risks, the existing literature and wider national modelling on different housing archetypes [33,45] do help identify where action could be prioritised, with some interviewees suggesting we know enough, something reflected more widely [16]. However, some felt that there is a need to do more work to help pull together data on housing stock, locational risks, building types, and information on tenures and vulnerabilities. There is a scale versus precision issue within this, as "*those [national] studies are high level….I feel there is still a last mile evidence gap*" (*C43*). This reinforces the need for local knowledge and local approaches, suggesting an important role for local authorities in helping to deal with overheating, cooling, and wider net zero challenges.

4. Discussion

This research has examined the importance of cooling for managing overheating risks within homes and considers what policy opportunities and responses may be needed to decarbonise cooling and create homes that are fit for the future. The focus is the UK, but the findings are more widely applicable given many temperate countries are facing similar challenges.

4.1. Perspectives on overheating and cooling in homes

Overheating in homes is already a problem and likely to worsen as the climate continues to warm, causing discomfort, ill health, and mortality. Cooling offers a solution and its use in the domestic sector is expected to grow, but active cooling can create direct and indirect emissions which will contribute to climate change. There are also potential impacts for equity, with the level of risk and the ability to respond not distributed equally across society, and shaped by wider social-economic, environmental, and demographic factors [16,87–89]. Often the most vulnerable live in poorer quality housing, have less access to green space, face higher air pollution levels, and can struggle with the costs associated with buying passive and active measures, as well as their running costs [16,88,90]. A policy approach is needed that supports the most vulnerable, whilst more broadly ensuring all people can be protected from heat risks, whilst also limiting the use and potential impacts of active cooling. The main challenge is the existing housing stock and encouraging people to take a passive first approach, many of which are low cost, so that active cooling with AC does not unnecessarily become the default solution [10,61].

One of the concerns within the interviews is that currently policy does not adequately address heat risk or the effective decarbonisation of cooling, something also reflected within the wider literature [14,16,57]. This partly reflects the cross-cutting nature of the challenge, in the absence of a dedicated policy, as well as the way in which overheating and cooling are addressed by current policies, which were mapped to the avoid-improve-shift framework in Fig. 1 and are summarised and critiqued in Table 2 below. The commitment to produce a cooling action plan by 2026 as part of the Global Cooling Pledge may help to address these challenges.

Table 2
Strategic policy links for cooling decarbonisation within the UK.

AVOID	
Building regulations	Part O (overheating) has been an important development for new build homes, but there is a gap for dealing with existing homes and conversions [8,16,17].
Wider planning frameworks	The National Planning Policy Framework shapes the wider environment in which buildings sit, but currently makes little recognition to overheating risk [14,91], and there is also a lack of protection for public green and blue space [17]. At the local level, Local Plans can address climate adaptation and mitigation including urban cooling [92,93], although a lack of clarity in national planning, regular planning reform, and funding shortages have created uncertainty and delays [91,94,95].
Adaptation	The National Adaptation Plan is the five-year plan to adapt to the impacts of climate change. This has been viewed critically [96] and in respect to heat risk the focus is largely on research, rather than action [14].
IMPROVE	
Product standards	UK policy remains largely aligned to the EU. Although robust there is considerable scope to improve the efficiency of cooling products, requiring effective policies and ongoing international efforts and cooperation [10,55]. The UK is supporting global efforts to increase the market share of highly efficient AC units and will be introducing Minimum Energy Performance Standards (MEPS) by 2030 [66].
F-gas regulations	UK policy was aligned to the EU following Brexit, and the UK remains committed to complying with the Kigali Amendment to the UN Montreal Protocol [57,66,97]. A recent review highlighted that there may be potential for further cost-effective abatement above established targets [97] and the EU is moving more quickly to phase down and phase out HFCs [98], which the UK should seek to match [39].
SHIFT	
Heat and buildings strategy	Sets out plans to decarbonise homes and other buildings [34] with a view that heat pumps and heat networks are the established technologies to best enable this in the coming decades [99]. The strategy does consider future proofing buildings, including cooling, but it is primarily about heat decarbonisation [60,99], and whilst acknowledging overheating risks, it does not include actions or commitments to address them [14].
Energy Efficiency	For new build, there have been numerous updates to Part L of Building Regulations to improve the thermal efficiency of homes, with a further uplift expected in 2025 [100,101]. Existing homes are a bigger challenge, as large parts of the stock are not efficient [41,102] and there has been a dramatic decline in energy efficiency installations over the last decade [38]. Government support and energy company obligations are helping improve the stock for low-income and social housing sectors [103], but there are gaps for owner occupiers and the private rented sector [39,41].

Across the interviews, and in respect to the avoid-improve-shift framework, the actions and behaviours of people are also central to the challenge of overheating risk and the possible routes to keep cool. People play multiple roles in helping reduce emissions [104,105] and decarbonisation requires more than technological change, being shaped by the building itself and requiring policies that enable and encourage actions by individuals [74,106]. A range of factors shape low-carbon and climate-resilient behaviours which can include individual knowledge, social factors like group identity, and practical factors such as ease and price [107]. Information and advice are important for reducing overheating risks, and for encouraging passive approaches and good choices and decisions in respect to cooling products, their use, maintenance, and disposal [16,28,45,74]. Within the interviews it was recognised there could be a range of poor outcomes if people face information deficits, not helped through a policy approach that tends to leave things to the market. This points to the need for a more comprehensive strategy to behavioural and societal change, that uses information-based 'downstream' interventions that shape decision-making but also makes use of more effective 'midstream' and 'upstream' interventions, that consider the wider environment in which choices are made and the rules of the game that shape businesses, markets and institutions [108]. This more comprehensive approach can make particular behaviours easier, and help shift norms or social expectations, and are enabled through government leadership, regulations, and incentives [107].

Considering these and the wider results through the avoid-improve-shift decarbonisation framework provide a range of insights for policy making.

Avoid: Passive measures can help avoid the need for active cooling and help reduce its impact if it is later adopted. Passive approaches can happen at the building level including measures and behaviour change to limit internal heat gains and manage airflows (many of which are low and no-cost options) and are shaped more widely by the local environment. On-going improvement to policies around Building Regulations and wider planning frameworks are both important, as is the role of local authorities who are well placed to understand local risks and the potential opportunities to reduce them.

Improve: The market for active cooling in the domestic sector is still immature but is growing, so continued efforts to support improvements in product standards and the use of F-gases internationally will be important. Policy packages that combine information and advice, MEPS and financial support are likely to be most effective in enabling market transformation. Policy should also examine ways to build the market for passive measures.

Shift: There are uncertainties on how cooling demand will evolve and what this might mean for managing loads within energy systems. Solar generation and energy storage could play key roles in helping meet demand within homes, although the ongoing decarbonisation of supply and wider policies to enable system flexibility will be key enablers for decarbonising cooling demand. Broader challenges may emerge for energy networks and system operators as cooling demand increases, particularly if there is rapid and localised take up of AC, including the management of system constraints and maintenance cycles; areas where more network innovation may be needed.

4.2. Opportunities for policy alignment

Policy alignment is likely to play a central role in enabling the effective decarbonisation of cooling, with opportunities existing across the avoid-improve-shift framework. Given the number of policy areas involved, finding synergies across them, including mitigation and adaptation, could both help drive change and manage complexity [109,110]. Existing homes are the main challenge, so integrating overheating and cooling into initiatives targeting the built stock will be particularly valuable. This includes programmes to improve the thermal efficiency of homes, as these can reduce overheating risks, support passive cooling, improve cooling efficiency, and create opportunities for flexibility. In addition, assessing the need for, and feasibility of, providing cooling alongside decarbonised heating could deliver multiple benefits for energy and climate policy, the energy system and end users.

This could include the use of district heating and cooling networks which are common in many European countries, although less so within the UK [111,112], although with a range of policies in place to help build the sector [57,112,113] there could be opportunities to consider cooling. Heat pumps are another option, with the UK aiming to install 600,000 units a year by 2028 [39]. If run reversibly these could provide a single heating and cooling solution within a home. This is simple with an air-to-air heat pump, which are widely used in other countries, but are less common in the UK homes because of the dominance of wet central heating [114,115]. The use of hydronic ground-source or air-source heat pumps running in reverse is also possible, although risks of condensation make this more complicated [34,45,115]. Whilst options will be site specific, a more integrated approach would enable more strategic outcomes for decarbonisation, provide households with year-round thermal comfort and avoid risks of lock-in and the need for future retrofits within homes.

Considering the insights from the avoid-improve-shift framework and the opportunities for policy alignment, suggests that an integrated approach to the development of policy on cooling will be needed, which looks across buildings, people, technologies, and the energy system, as well as the interactions between them - Fig. 3.

5. Conclusion and policy implications

As the climate continues to warm, without sufficient policy attention, overheating in homes will worsen and the uptake of active cooling to address it will increase. This paper contributes to the understanding on these issues by using an avoid-improve-shift decarbonisation framework, providing policy actor perspectives on the challenges and opportunities for decarbonising cooling within the domestic sector. The issues cut across policy and society, and in the absence of specific policies or responsibilities to address overheating and cooling, possible solutions can fall through the gaps, resulting in a range of poor and avoidable outcomes in terms of markets, equity, the energy system and emissions.

As highlighted in Fig. 3, the challenge requires an integrated approach across different national and local government responsibilities and brings in a broad policy landscape. Overall, this research identifies five key opportunities for developing an effective cooling policy for homes, which whilst focussed on the UK, are also of relevance to other temperate countries.

1. Act quickly and comprehensively - There is a clear rationale for action and currently a window of opportunity, given the domestic cooling market is still immature. An approach based on avoiding the need for cooling, improving active cooling technologies, and then managing them within the energy system, is vital. A priority should be to develop policies that support a passive-first approach, before active cooling in homes becomes the social norm. This could help reduce risks in much of the stock for several decades, protecting people, whilst allowing more time for research, technology innovation, supply chain development, and the business and delivery models that will support them.
2. Seek synergies - to help overcome some of the challenges for policy making related to heat resilience and cooling. With the issues sitting across departmental responsibilities and being relatively temporal and less visible than other energy and climate issues, there can be limited policy capacity and policy space. Reframing the challenge around thermal comfort and health as an outcome could help support synergies and break down existing policy silos. There are particular opportunities for seeking better alignment to policies targeting energy efficiency, housing retrofits, and heat decarbonisation. Ongoing work to build the supply chain and skills in these areas provide a low-cost and strategic opportunity, as it could ensure that any contractors going into homes to advise and carry out works, could also assess overheating risks, possible cooling solutions, and potential household vulnerabilities.
3. Support people - to take low-carbon and climate-resilient behaviours, to reduce heat risks, adopt passive approaches, and make good choices on any active cooling technologies, including the way they are used. The provision of information is important, but wider interventions will also be needed to make change easier and help shift social expectations. In addition, ensuring the most vulnerable are supported will be an important and growing policy need, given there are a range of inequalities linked to overheating and keeping cool. These issues cannot just be left to the market.
4. Build on best practice - to identify solutions and help save time and resources. There are examples of best practice for cooling and heat resilience, across mitigation and adaptation within the UK, other temperate countries, and from countries that have been dealing with heat risks for much longer. Collating and sharing these would be a relatively easy and low-cost opportunity.
5. Lead nationally and support action locally - to create an integrated, joined-up, policy approach. The overall priority should be to create resilient homes and localities that are fit for the future, which keep people warm in winter and cool in summer, supporting health, affordability, and equity. Clear leadership and responsibility are needed, including to support behaviour change. Much of the

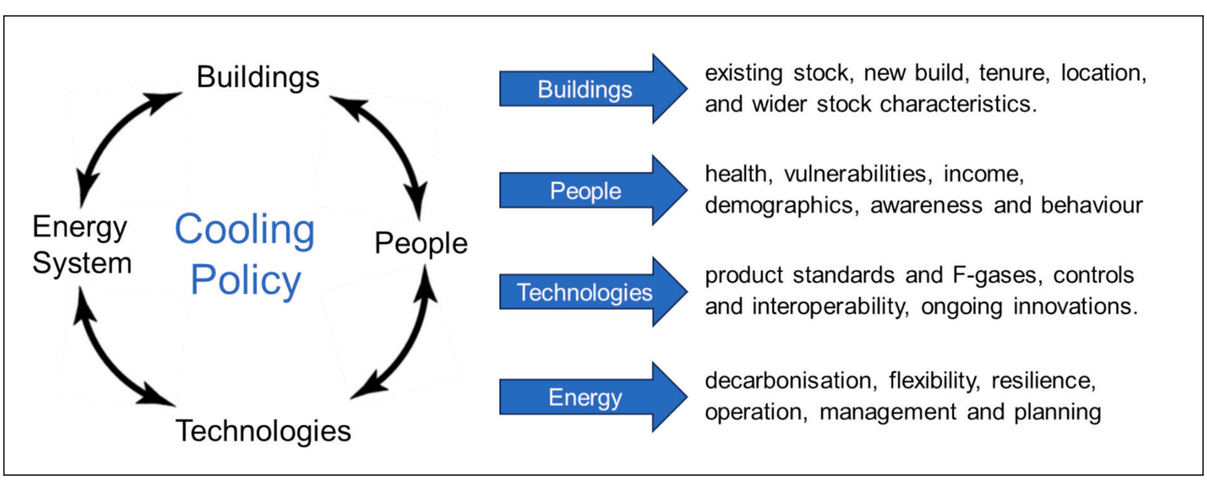

Fig. 3. The policy landscape for domestic cooling.

challenge relates to existing homes and the health and wellbeing of people within them. For the UK this suggests a key role for the Department of Energy Security and Net Zero and the Department of Health and Social Care, but given the nature of the overheating challenge, cross-departmental approaches will be vital, as will strategies to enable and support local authorities to deliver solutions.

CRediT authorship contribution statement

Richard Hoggett: 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. **Fatemeh Khosravi:** Conceptualization, Methodology, Writing – review & editing.

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.

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Appendix 1. Design of semi-structured interviews

Understanding policy actor perspectives on the current state of cooling decarbonisation of UK buildings. Using an avoid, improve, shift framework.

Avoid (the need for active cooling through passive measures at building level & within developments to reduce overheating risk)

1. What are the current policy approaches for reducing the risk of overheating at the building level and are they sufficient?
2. What about the wider planning landscape, are there sufficient policies and tools available to help reduce risks of overheating from the wider environment?

Improve (way in which any active cooling is provided to minimise its impacts)

3. Do you have any insights on how to ensure active cooling can be provided through efficient equipment to help reduce energy demand?
4. Do you think that current plans to phase down F-gas use in cooling equipment are sufficient?

Shift (towards options of meeting cooling demand through low carbon routes)

5. What do you think are the main opportunities for meeting future cooling demands with low carbon supply?
6. What about managing demand on the system to help keep emissions down? What might be needed in this space?

Understanding the wider relationships for decarbonising cooling, in respect to other policy areas – particularly heat decarbonisation, flexibility and storage.

7. Do you think there are any opportunities for trying to align policies around heat decarbonisation with cooling?
8. Are there opportunities for linking cooling into other energy policy areas?

Understanding more about the policy making process

9. How do you think policy makers currently view cooling and overheating in the UK?
10. What do you think will be the biggest challenges for the UK around cooling?

Data availability

The authors do not have permission to share data.

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