Buildings & Cities

Gender and the heat pump transition

SYNTHESIS

JENNY CRAWLEY
FAYE WADE
MANDY DE WILDE
*Author affiliations can be found in the back matter of this article

ubiquity press

ABSTRACT

Decarbonisation in moderate and cold climates is reliant on the replacement of existing heating technologies with electric heat pumps. Heat pumps work differently from incumbent technologies, including in how they are controlled, their distribution of heat around the home and their space requirements. Despite evidence that domestic practices and interests associated with women played an important role in previous heating transitions, policy and research have not yet considered how heat pumps might interact with traditionally gendered needs and concerns. This could have significant implications for the success of the heat pump transition. This synthesis uses a framework of evidenced heating needs, incorporating wellbeing, resources, ease of use and relational dynamics, to structure a narrative literature review on how experiences of heat pumps may be gendered. Indicative evidence suggests that heat pumps have the potential to improve female thermal comfort, but that other possibly gendered heating needs such as minimising perceived waste and easy controllability are not always addressed. Amidst a lack of empirical studies exploring women's needs, and whether they are met by heat pumps, a series of recommendations is provided for multidisciplinary research on the topic and to enhance consideration of gendered needs and experiences in policy development.

POLICY RELEVANCE

Ensuring that heat pumps, and strategies designed to promote them, cater to diverse preferences and needs could support the current energy transition. This paper specifically considers experiences and practices traditionally understood as women's priorities. Despite these playing a key role in previous heating transitions, current policy and industry strategies designed to support the heat pump transition have not yet taken gender into account. In addition, this article demonstrates that how traditionally female practices and experiences mingle with the use of heat pumps has not been taken into account in research, and that empirical evidence on this is currently limited. Consequently, policymakers urgently need to support a strengthening of the evidence base on gendered aspects of heat pump adoption and use. Against such evidence, heat policy can more fully consider and engage women, ultimately contributing to the success of the heat pump transition.

CORRESPONDING AUTHOR:
Jenny Crawley
UCL Energy Institute, University College London, Central House, 14 Upper Woburn Place, London WC1H 0NN, UK
jenny.crawley@ucl.ac.uk

KEYWORDS:
domestic heating; energy transition; gender; heat pump; heat strategy; heating needs; social practices; thermal comfort; women

TO CITE THIS ARTICLE:
Crawley, J., Wade, F., & de Wilde, M. (2023). Gender and the heat pump transition. *Buildings and Cities*, 4(1), pp. 948–964. DOI: https://doi.org/10.5334/bc.392

DOI: 10.5334/bc.392

1. INTRODUCTION

As of 2023, 26 countries globally have set a net-zero target in law (Climate Watch 2023). This requires action across all end uses of energy, including decarbonisation of space and water heating in residential buildings (Knobloch *et al.* 2019). The electrification of energy services is a 'key pillar' of the transition (IEA 2021) since electricity generated by renewables can be decarbonised. For heating domestic buildings in moderate and colder climates, the most efficient technology is the heat pump (Lowes *et al.* 2020), which uses electricity to upgrade heat from a cold source to a warm sink. This process is normally powered by electricity[1] and employs a refrigeration cycle to move heat; this is different from incumbent technologies such as boilers which directly produce heat via combustion (Figure 1).

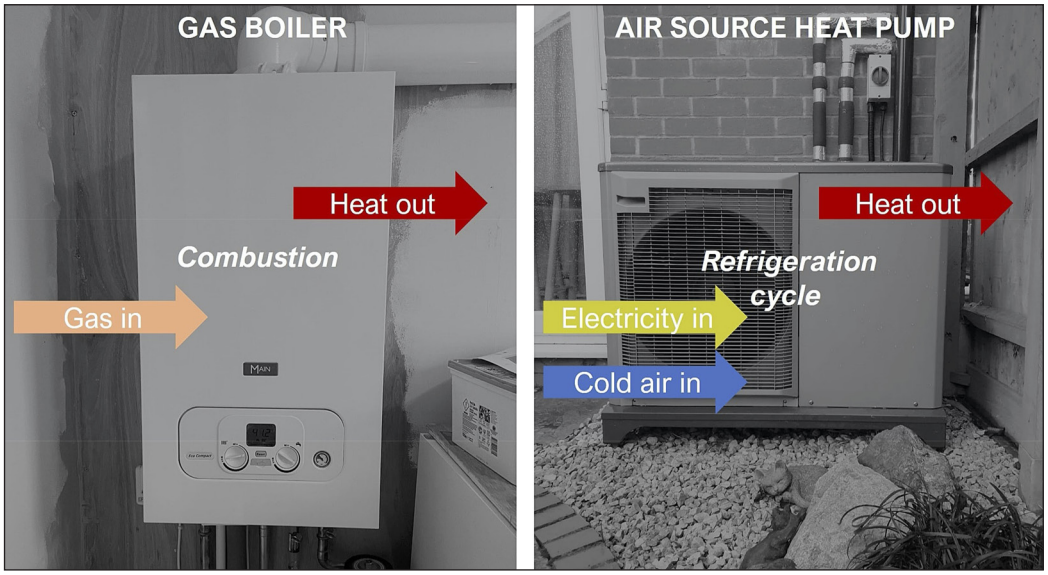

Figure 1. Comparison of a boiler and a heat pump through their visual appearance, physical inputs, thermodynamic mechanism and outputs.

Sources: Dominic Humphrey and Jez Wingfield; labels added by the authors.

1.1 EXISTING UNDERSTANDINGS OF THE HEAT PUMP TRANSITION

The 'heat pump transition' refers to a massive upscaling of heat pump installations (*e.g.* around 27 million in the UK by 2050; CCC 2020). However, with an increase of only 3% in 2020, global heat pump market growth is falling short of the rates needed to meet climate targets (Rosenow *et al.* 2022). A reason for this could be that research and policy efforts to date have overlooked the potential role of concerns and experiences often relegated as 'women's' in shaping uptake of and experiences with heat pumps.

Technical analyses have been concerned with heat pump performance (Lowe *et al.* 2017; Oikonomou 2022), modelling changing electricity demand with widescale heat pump deployment (Watson *et al.* 2023), and the impacts of this on the grid and renewable energy generation (Durham Energy Institute & Element Energy 2015; Love *et al.* 2017; Neirotti *et al.* 2020). More policy-focused efforts have considered the training needed to develop the installer workforce (Gleeson 2016; Wade 2022) and the regulation, finance, carbon standards and energy efficiency obligations that might support widespread uptake (Hannon 2015; Lowes *et al.* 2020; Rosenow *et al.* 2022).

A growing body of research has investigated householders adopting and living with heat pumps. Here, users have been identified as crucial actors for successful heating transitions, even potentially playing roles in lobbying (Martiskainen *et al.* 2021) and system design and innovation (Hyysalo *et al.* 2013a, 2013b). Research has also reported high levels of user satisfaction with the thermal conditions provided by heat pumps (Caird *et al.* 2012; Owen *et al.* 2013; Nesta 2023). However, studies in all these areas have so far largely overlooked dimensions of gender (Bradshaw 2018).

DOI: 10.5334/bc.392

1.2 THE ROLE OF GENDER IN HEATING TRANSITIONS

A recent *Buildings & Cities* special issue on 'Energy, Emerging Technologies and Gender in Homes'[2] concluded that 'oversight of gendered dynamics puts the energy transition at risk' (Strengers *et al.* 2022: 842). Failing to explore potentially gendered differences in views and experiences of energy technologies could limit their potential (*e.g.* if certain practices may impact on their effective operation) and lead to missing potentially powerful messaging opportunities (Johnson 2020; Mechlenborg & Gram-Hanssen 2020).

Gender is a social identity, often ascribed to individuals on the basis of the gender assigned at birth (informed by an assessment of biological criteria), which dictates status, roles and norms for behaviour (Kelly 2016). The concept of gender captures the fact that differences between men and women, their socially defined roles, privileges, attributes and relationships, are also socially constructed (Khamati-Njenga & Clancy 2002). Gender is fluid and not binary; an individual's gender can change over time, and gender roles and relations differ over time, space and cultures (Bradshaw 2018). Such gender identities and relations can shape an individual's interactions with energy technologies, with policymakers and industry attributing preferences, values and norms according to specific socially constructed identities (Akrich 1994; Mort 2019).

Indeed, in historic heating transitions such socially constructed identities, including the traditional roles of women and practices gendered towards them, were given significant attention. Historical work on the gendered use of domestic energy technologies in the Global North shows how women sometimes preferred to retain familiar technologies over modern options as they offered multifunctionality of heating, drying and cooking (Parr 1990). This work also shows how the introduction of gas stoves, water heaters and furnaces in the 19th century meant new, additional responsibilities for women (Schwartz Cowan 1983). Catering to female-gendered cooking practices was particularly important in the US transition from wood-burning fires to solid-fuel stoves (Harris 2008) and the UK transition to gas cooking stoves, for which manufacturers addressed concerns about the quality of food cooked over gas by hiring female cooking demonstrators (Clendinning 2000). It has also been suggested that the qualities of 'High Speed Gas' in the UK transition from manufactured gas to natural gas (1948–77) were 'particularly valued by working women' (Arapostathis *et al.* 2013: 34, citing Barty-King 1984: 237–239; Falkus 1988: 84). Appealing to women's concerns was also a strategy of the British Electricity Development Association (EDA), which targeted middle-class women with slogans such as 'For Health's Sake—Use Electricity' to support the growth of electric domestic heating (1957–62) (Carlsson-Hyslop 2016). Thus, in past domestic heating transitions, what were considered to be women's priorities were taken seriously by industry and policymakers. Yet, in the current attempted transition to heat pumps, neither academia nor policymakers are attending to women—or rather, to experiences, concerns or priorities that are traditionally associated with women.

To address this gap, this article synthesises existing evidence to explore the ways in which the adoption and use of heat pumps could be gendered. This focuses on experiences and concerns that are understood as gendered in many cultures, *e.g.* doing laundry. This is not to reinforce existing gendered ideas of the home or minimise the diversity of women or households, but instead to focus on experiences and practices where previous research has identified that gender may be important. Throughout this paper, then, 'gendered practices' should be understood to indicate practices that are stereotypically relegated to one gender, and not an essentialist description.

The article is structured as follows. The following section outlines the synthesis approach and framework which explores different heating needs, incorporating wellbeing, resources, ease of use and relational dynamics. The physical differences that heat pumps create are then detailed. Using technical and social scientific literature, the paper then brings this all together to explore how heat pumps could interact with potentially gendered heating needs. From this analysis, it identifies significant gaps in the evidentiary base, and recommends next steps for research.

2. SYNTHESIS APPROACH AND FRAMEWORK

2.1 APPROACH: NARRATIVE LITERATURE REVIEW

The lack of studies that explicitly consider heat pumps and gender means that a systematic review or meta-analysis is not feasible here (see Sovacool *et al.* 2018 on the suitability of different review strategies in energy research). Instead, insight is derived through a narrative review that synthesises evidence from a range of disciplines (Sovacool *et al.* 2018). Specifically, this consists of:

- *Technical literature* on heat pump operation and resulting indoor environmental conditions. The dearth of empirical evidence here also led to the inclusion of studies of modelled heat pump thermal conditions
- *Physiological studies* that considered thermal comfort and biological sex. None of these studies considered heat pumps, but they do provide an important context for what heat pump thermal conditions might mean for women
- *Social science literature* which initially focused on studies of heat and gender. However, so few of these are specifically about heat pumps that the search was expanded in two directions to include studies on household thermal comfort which explore gender, and studies on heating practices in homes with heat pumps which might indicate under-researched gendered experiences.

While the studies cover a broader number of countries and the overall findings may be useful internationally, the analysis is primarily rooted in studies conducted in moderate to cold climates where heating is the predominant thermal requirement. The specific concern is how a heat pump creates different thermal conditions than a fossil-fuelled boiler heating system. As such, the technology focus is air-to-water (ASWHP) and ground-to-water (GSWHP) heat pumps. These are suitable for installation in existing hydronic central heating systems, which normally pump warm water around a network of radiators. This necessarily bounds the geographical scope to countries that have hydronic heating systems, *e.g.* the UK and the Netherlands. Different embedded socio-technical infrastructures mean that air-to-air heat pumps are more common elsewhere, *e.g.* in Scandinavia, the US and Southern Europe. Air-to-air heat pumps create quite different thermal distribution characteristics (including infrastructure and resulting thermal conditions) and are, therefore, mostly excluded from this analysis (for a review of the variety of heat pumps available and their uses, see Singh Gaur *et al.* 2021).

All academic literature searches used Google Scholar and searched over the past 20 years, when the installation of heat pumps has accelerated. The search terms used and primary journals included are listed in Table 1.

TOPIC	JOURNALS	SEARCH TERMS
Technical: Heat pump operation and indoor environmental conditions	*Applied Energy*; *Buildings*; *Buildings & Cities*; *Building Research & Information*; *Building and Environment*; *Energy*; *Energy Efficiency*; *Energy Policy*; *Energy and Buildings*; *Indoor and Built Environment*; *Renewable Energy*; *Sustainability*	• 'heat pump' AND 'internal temperature'/'internal conditions'/'radiant temperature' • 'domestic heat pumps' AND 'noise'/'responsiveness'
Physiological: Thermal comfort and gender	*Building Research & Information*; *Building & Environment*; *Journal of Thermal Biology*; *Indoor Air*; *European Journal of Applied Physiology*; *Autonomic Neuroscience*	• 'thermal comfort' AND 'gender'/'thermal comfort' AND 'sex'
Social and cultural: Studies of heat pumps in use, and gender	*Buildings & Cities*; *Building Research & Information*; *Energy Research & Social Science*; *Energy Policy*; *Environment & Planning A*; *Environmental Innovation & Societal Transitions*; *Energy Procedia*; *Gender, Work & Organisation*; *Journal of Consumer Culture*; *Nature Energy*; *Science & Technology Studies*; *Science, Technology & Human Values*; *Social Studies of Science*; *Technology Analysis & Strategic Management*; *Women's History Review*	• 'thermal comfort practices'/'domestic heating practices'/'heating'/'heat pump' AND 'gender'/'woman'/'women'/'female'/'socio-demographics' • Broadened to include: 'thermal comfort practices'/'domestic heating practices'/'heating'/'heat pump' AND 'household'/'user'/'occupant'

Table 1 Search terms used to identify relevant articles and journals included in this review

Note: Several energy journals are highly interdisciplinary and therefore provided sources of both technical and social literature.

DOI: 10.5334/bc.392

The variety of literature was brought together within a framework outlining different heating system needs, described in the following section.

2.2 FRAMEWORK: HEATING SYSTEM NEEDS

In order to explore how heat pumps may or may not address gendered needs and concerns, it is useful to first set out what householders perceive heating systems are required to do. Mallaband & Lipson (2020) suggest four categories of need that householders seek to fulfil with the use of domestic heating: wellbeing, resources, ease of use and relational dynamics. Each need is defined in Table 2. Drawing on insight from 2500 UK-based participants, Mallaband and Lipson's framework encompasses a broad range of heating needs likely to be relevant to countries with similar climate and heating systems that also aim to decarbonise by 2050. However, despite experiences of the home being highly gendered (Sullivan 2018), the authors do not consider how gender might interact with these heating needs. In addition, the framework does not consider how these needs might differ with distinct heating systems, such as a heat pump. Therefore, Section 3 details the key physical changes associated with heat pumps. In Section 4, the heating needs framework is then used to consider how heat pumps interact with potentially gendered needs.

Table 2 Mallaband & Lipson's (2020) range of heating needs in households

HOUSEHOLDER NEED	DESCRIPTION
Wellbeing: Health and comfort	Keeping healthy; wanting to feel clean, safe and secure; wanting to keep the home clean and looking, feeling or smelling nice; being comfortable; being able to rest and relax; feeling in control
Resources: Cost and waste	Primarily about avoiding cost and waste. This includes: finances; waste management and property maintenance; energy costs; the value or cost of one's home; concern for the environment; avoiding wasted energy
Ease of use: Control and convenience	The extent to which people want and are able to actively be in control of their heating. This includes: convenience; control; habits; maintaining everyday routines; doing what is easiest
Relational dynamics: Harmony and hospitality	Relationships within and beyond the household; wanting to avoid arguments and disagreements in the home; caring for other members of the household; appearances; the needs of others

3. KEY PHYSICAL CHANGES ASSOCIATED WITH HEAT PUMP INSTALLATION AND USE

For most users, installing ASWHP or GSWHP will lead to some key physical differences compared with their previous heating system, whether this was an individual gas/oil boiler, electric resistance heating or connection to a heat network. The main components are shown in Figure 2.

Heat pumps are sized to counteract steady state heat loss and maintain a constant indoor temperature, not to provide instantaneous hot water demand or warm rooms up from cold. This means heat pumps are sized smaller (Shah & Hewitt 2015),[3] and therefore have lower heat output, than that of boilers (Bennett *et al.* 2016), resistance heaters or heat interface units on heat networks. Due to their reliance on the refrigeration cycle, heat pumps are also not able to increase their output as rapidly as incumbent systems. This, in addition to their lower heat output, means that heat pumps have a slower responsiveness; spaces do not warm up rapidly.

To increase efficiency, heat pumps also typically operate at lower space heating flow temperatures than other heating technologies (Reinholdt *et al.* 2018). The mean heat pump flow temperature in a large recent sample of UK heat pumps was 38°C (ESC 2023), whereas conventional boiler heating systems are designed to operate up to 80°C, heat networks often run at high flow temperatures (Tunzi *et al.* 2018), and electric heating elements operate at high temperatures (Trust Electric Heating 2023). The low flow temperatures of heat pumps can require new, larger radiators or underfloor heating which has a large surface area to enable heat transfer.

DOI: 10.5334/bc.392

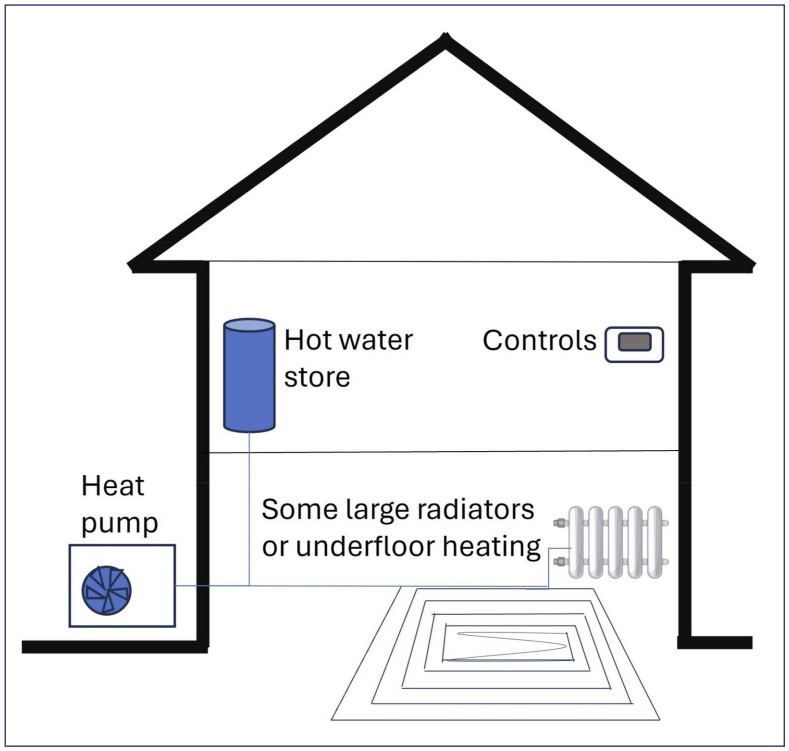

Figure 2 Key components likely to be present in a heat pump heating system.

Note: The example system shown is based on a typical monobloc air-source heat pump.

These physical characteristics are likely to lead to differences in internal conditions compared with previous heating systems. The lower heat output results in longer running hours compared with other systems (Watson *et al.* 2023; Love *et al.* 2017); thus, temperatures over the course of 24 hours may become more stable and night-time temperatures may increase. Heat pump homes may also have higher internal temperatures: a few studies with small samples reported from a 1 to a 2.3°C increase (Watson 2020). Surface temperatures (*e.g.* walls) may also increase and radiator temperatures decrease. Through modelling, this has been predicted to lead to lower speed of convection currents and reduced draughts as well as less vertical temperature stratification in the room (Myhren & Holmberg 2008), although these predictions have not been empirically validated.

The relatively low responsiveness of heat pumps is not compatible with heating strategies which use multiple temperatures at different times of day (Hanmer 2020), since the heat pump cannot respond quickly to these changes. Furthermore, heat pumps normally cannot generate hot water on demand. In the UK, combination boilers that can do this are widespread, and so many homes do not have hot water tanks. When a heat pump is installed, this then also requires installing a hot water tank, potentially impacting domestic space.

Air source heat pumps can be noisier than other types of heating systems. The noise is mainly caused by their fan and compressor (Building Performance Centre 2011) and today's units generate around 40–60 dB (Lowe & Oreszczyn 2020). Air source heat pumps located outside (Figure 1) can sometimes be heard indoors, particularly on the coldest days since noise increases with compressor activity. Heat pumps usually need to run almost continuously in very cold weather conditions,[4] especially if they have to defrost themselves (Song *et al.* 2018), as is typically necessary around 0 to –6°C when air is cold but still contains moisture.

4. WHAT ARE GENDERED HEATING NEEDS AND HOW MIGHT HEAT PUMPS INTERACT WITH THEM?

In this section, the heating needs framework from Section 2.2 is used to structure an exploration of potentially gendered heating needs and the ways in which heat pumps may or may not address them. This draws upon the technical material in Section 3 and existing sociological research.

4.1 WELLBEING: HEALTH AND COMFORT

Wellbeing is the need most highly cited by Mallaband & Lipson's (2020) participants, with 84% (n = 1921) suggesting that 'being comfortable' is a primary need for a heating system. In turn, concerns to do with comfort and what makes the home pleasant may vary with sex and gender. Physiological studies distinguishing by biological sex[5] have demonstrated temperature-related comfort differences between men and women. Most of this research has been conducted in climate chambers or offices (Table 3), which eliminate important aspects of gender in the home such as activity and domestic clothing.

FINDING	CONTEXT	REFERENCES
No clear difference in neutral temperature[a] between men and women	Metareview of studies mostly in climate chambers and offices	Wang *et al.* (2018)
Women experience more discomfort when the temperature deviates from neutral	Offices	Rupp *et al.* (2018)
	Metareview of climate chambers and field studies in different building types including a small number in homes	Karjalainen (2012)
		Liu *et al.* (2018); Yang *et al.* (2021)
	Climate chamber	
Women more likely to experience cold in their extremities	Climate chamber	Castellani & Young (2016); Bartelink *et al.* (1993)
As temperatures decrease, women begin to shiver more quickly than men	Climate chamber	Kaikaew *et al.* (2018)
	Climate chamber plus cooling vests	Sardjoe Mishre *et al.* (2022)
Vertical stratification in air temperatures negatively affects women more than men	Climate chamber	Hashiguchi *et al.* (2010)
Women prefer higher nighttime sleep temperatures	Climate chamber	Pan *et al.* (2012)

Table 3 Summary findings of physiological thermal comfort studies that differentiate women and men by biological sex

Note: [a]The neutral temperature refers to the temperature at which a person feels neither cool nor warm. This does not always map onto whether a person feels comfortable (Shahzad & Rijal 2019).

Research within the home has found that women more frequently experience thermal dissatisfaction (Karjalainen 2007, 2012; Sintov *et al.* 2019) and experience lower temperatures more negatively than men (Carlsson-Kanyama & Lindén 2007). Installing heat pumps, therefore, could be particularly favourable in improving women's thermal comfort. Higher night-time temperatures from heat pumps are indicatively in agreement with studies indicating women's preferences for higher sleeping temperatures. More consistent surface temperatures and reduced convective currents and vertical stratification from heat pumps could also correspond with less discomfort for women around their hands and extremities. For example, one female participant in a qualitative UK study noted that continuous warm temperatures were her 'favourite thing' about the heat pump (Parrish *et al.* 2021). However, these are only indicative assertions, based largely on physiological understandings of thermal comfort; there is no empirical assessment that specifically seeks to explore gendered experiences in homes with heat pumps.

There is some evidence that heat pump designers and installers hold perceptions of gendered differences in comfort with heat pumps. Using participant observation and focus groups, De Wilde (2021) shows how Dutch heat pump installers ask for women to be at home for the installation so that specific comfort needs can be addressed. Meanwhile, in a qualitative study of Welsh homes with heat pumps, some experts (from a sample including designers, engineers, developers and registered social landlords):

> explicitly noted that women preferred higher indoor temperatures [... but] most did not make gender distinctions.
>
> (Shirani *et al.* 2022: 594)

This may indicate the need for further investigation of how heat pump designers and installers understand gendered differences in comfort in heat pump homes.

Further, women have been found to prioritise the creation of 'homely' comfort (Ellsworth-Krebs *et al.* 2019; Strengers & Nicholls 2018; Hansen *et al.* 2019), in which heating is not solely an object of warmth but is also seen, heard and even smelled (Offenberger & Nentwich 2010; Valdorff Madsen & Gram-Hanssen 2017). However, this has not been studied in heat pump homes. Further research could explore whether there is a broader pattern of gendered perceptions of heat pumps for the creation of homely comfort.

4.2 RESOURCES: COST AND WASTE

Reducing cost and waste, including avoiding energy waste, was the second most prominent factor for Mallaband & Lipson's (2020) participants. Policy efforts to support the heat pump transition have been based on a limited but well-established understanding of end users as economically rational individuals who can be convinced through price signals (Shove 2010). However, the upfront capital (UKERC 2023a) and running costs (UKERC 2023b) of heat pumps can be higher than that of incumbent heating systems, so these price signals are not always achievable, and evidence from the UK suggests that many people perceive heat pumps to be too expensive to buy and use (National Grid 2022). Women in the UK are more likely to report minimising energy use in the home (85% compared with 76% of men) (BEIS 2022), and a study of the top 10 most influential zero waste blogs globally suggests that women bear the burden of avoiding waste, reusing and recycling (De Wilde & Parry 2022). The more constant operation of heat pumps compared with previous heating systems may then be perceived as wasteful, and this may be especially true for women; however, there is currently a lack of evidence examining differences between men's and women's perceptions of heat pumps and resource use.

A survey with a sample representative of the latest UK census suggested that 'likely adopters' of heat pumps are men (National Grid 2022). A Dutch qualitative study focusing on family decision-making for energy saving measures showed that, in heterosexual households, men tend to be responsible for the financial administration and initiate significant household purchases—such as heat pumps—but women had a final say (De Wilde 2019). Through a survey with a representative sample of 579 Chinese households, Jingchao *et al.* (2018) found that women are marginally willing to pay more for heat pumps than men in the context of replacing coal stoves. The authors note that women's responsibility for upkeep of the home amidst the pollution created by coal may contribute to their higher willingness to pay (Jingchao *et al.* 2018).

4.3 EASE OF USE: CONTROL AND CONVENIENCE

Freedom of choice of internal temperature was important to Mallaband & Lipson's (2020) participants. Heat pump owners have been found to complain about not knowing how to operate the system for optimum efficiency and economy (Roy & Caird 2013) and incorrectly conceptualise heat pumps as operating equivalently to their previous gas- or oil-fuelled boilers, with rapid response and high radiator running temperatures (Owen *et al.* 2013; Judson *et al.* 2015). These understandings are not explicitly distinguished by gender, but a female participant in one qualitative study was more comfortable with the heating being on at night once she understood why, whilst her husband was less interested in understanding the reasons for it (Parrish *et al.* 2021). An area for research could therefore be whether education on optimum heat pump function (*e.g.* why they run constantly) has differing impacts by gender. This could be particularly important given that studies have found installers have flexibility over how much advice they provide to users (Gram-Hanssen *et al.* 2017), and can discourage users from intervening with (air-to-air) heat pumps (Smale *et al.* 2019) and not provide households with training or instructions to change heat pump settings (Calver *et al.* 2022). This could also be subject to further enquiry.

Research suggests that there are gendered differences in engaging with heat pump controls. Trials of heat pumps in the UK have provided some evidence that women are less likely to engage with heat pump controls, with Bell *et al.* (2015: 11) noting that older women were the most 'alienated and troubled users' in the 18 households they interviewed. Similarly, a Finnish study of heat pump users (including air-to-water and air-to-air systems) suggested that those tinkering with heat

pump technology were almost all middle-aged men, with 76% of the 22 respondents having a technical education (Hyysalo *et al.* 2013a). This is supported by Australian and Danish studies on smart homes—incorporating appliances such as hybrid and electric heat pumps—which argue that men are more likely to install and/or engage with the energy-monitoring systems (Strengers & Nicholls 2018; Strengers *et al.* 2021; Aagaard & Madsen 2022). Shirani *et al.* (2022) give three case studies of women who all expressed a desire for more information about the operation of their heat pumps and other aspects of their smart homes. This is potentially important given that smart home technologies (including heating controls) are often subtly marketed towards men (Strengers & Nicholls 2018). Despite this, it has been suggested that women become the 'everyday experts' in determining the operating time and temperature of heating systems (Offenberger & Nentwich 2010), and that women might be at the forefront of adapting their household practices to meet demand flexibility requirements as energy systems decarbonise (Johnson 2020).

4.4 RELATIONAL DYNAMICS: HARMONY AND HOSPITALITY

Although relational dynamics was brought up the least often amongst Mallaband & Lipson's (2020) participants, research indicates that care for others is a factor in the adoption and use of heat pumps. This is often considered at the household level and, in the studies analysed, both male and female participants expressed concern for household members, particularly around bathing practices, when determining how to operate a heat pump. However, there is some evidence of differences, with Elnakat & Gomez (2015: 175) finding that differences in thermal set points related to 'cooking and water heating requirements for bathing, washing dishes and doing laundry' led to higher gas consumption in female-dominated households, although this was not specific to heat pumps. In heat pump homes, a female participant in Shirani *et al.* (2022) reported taking quick 'barely lukewarm' showers after the children had bathed and her partner had showered, whilst another has reported 'boosting' the hot water for children's showers and baths (Reid & Ellsworth-Krebs 2021: 6). Although not explicitly disaggregated by gender, several studies have identified interaction between a new heat pump and laundry practices. For example, in qualitative UK studies, female participants have noted that the heat pump 'dries the washing beautifully' (Bell *et al.* 2015: 11) and that they are able to dry laundry more quickly because of the more constant operation of the system (Parrish *et al.* 2021). There is also some evidence of heat pump installers and service mechanics expressing gendered understandings of laundry practices. For example, one surveyor in Owen *et al.*'s (2013: 828) qualitative UK study of heat pump installation commented that:

> the loss of an airing cupboard [because of the installation of a new hot water tank, is] often the principle concern of the woman in the house.

Further research could explore how heat pumps intersect with concerns for the care of others; while there is limited evidence that these concerns are gender dependent, cultural stereotypes may lead them to be disregarded as women's concerns.

There could also be potentially gendered dynamics when it comes to conflict within households, particularly around the control of heat pumps. Sovacool *et al.* (2020: 7) find that conflict between spouses or partners was 'the most prevalent and recurring' in their study of contestations around controls for traditional heating systems in 100 UK homes. Where disagreement around temperature settings exists, women are less likely to initiate negotiation, instead adapting through hot drinks, moving around and adding clothing layers (Sintov *et al.* 2019; Carlsson-Kanyama & Lindén 2007). Using this evidence, it has been suggested that there is:

> a gender bias in house-wide thermal comfort settings, whereby home thermal environments do not cater to women's preferences.
>
> (Sintov *et al.* 2019: 12)

For example, Nyborg (2015) describes a situation in which a male partner's fiddling with heat pump settings for economy does not satisfy his female partner's thermal comfort and preferred hot water temperature. More recent qualitative evidence (Shirani *et al.* 2022) provides a mixed view of

gendered interactions with heat pump controls in Wales, with one participant finding the control simple and sharing the operation with her child, whilst others note that their (male) partners usually manage the heating settings and make adjustments. The more constant operation of heat pumps may mean less tinkering and conflict, whilst shifts towards smart heating controls could also see the outsourcing of autonomy (Sadowski *et al.* 2021). Research is therefore needed on whether heat pumps change existing conflicts within households, and if, as previous research has shown, there continues to be gender bias in thermal control.

5. DISCUSSION AND RECOMMENDATIONS

Bringing Mallaband & Lipson's (2020) heating needs framework together with understandings of gendered household concerns as well as how heat pumps work sheds light on how women's heating needs might interact with heat pump systems. Narratives such as that developed here are not benign or neutral (Moezzi *et al.* 2017). This paper set out with the intention to highlight a currently overlooked group in the heat pump transition. Such narrative reviews can miss relevant research or place excessive reliance on individual studies (Sovacool *et al.* 2018), but the approach was necessary here because of the lack of studies specifically focusing on heat pumps and gender. Instead, this synthesis has drawn together insights from technical, physiological and social research.

A major finding is that empirical evidence on how gendered household concerns interact with heat pumps is currently lacking in all three domains. First, there are very few large-scale technical monitoring studies of heat pumps in use; more of this work would provide firmer physical evidence of the thermal conditions they create. Second, physiological studies of thermal comfort primarily take place in experimental chambers away from the home; no research considers the physiology of thermal or homely comfort *within* heat pump homes. Third, the majority of available evidence on women's experiences with heat pumps is drawn from qualitative studies that report evidence from female participants, but do not explicitly seek to analyse this group. Also a significant dearth of social survey studies seek to quantify and statistically evaluate potentially gendered perceptions of heat pumps, their adoption or use. This review has also collated evidence of heating industry professionals' perceptions of gendered engagement with heat pumps. As there is a persistent gender imbalance in male-dominated energy professions (Aagaard & Madsen 2022) and the heating industry (Wade *et al.* 2016), there is a need to explore what implications this has for the deployment of heat pumps in more detail.

The main recommendation is therefore to carry out more research in this area. Significant research questions emerging from this review are included in Table 4.

Table 4 Suggested research questions on potentially gendered heating needs and heat pumps

CATEGORY	RESEARCH QUESTIONS
Overall	• What are different gendered expectations regarding heating systems (including getting a new heating system) and how well do heat pumps satisfy them? What are the priorities for heat pump/heating system technical research to address such expectations? • How might an individual's engagement in the selection and use of heat pumps impact on overall satisfaction? • What is the role of heat pump designers and installers as mediators in the uptake and use of heat pumps? How does a masculine-dominated heating industry consider and address potentially gendered heat pump concerns? • How might various intersecting identities create differences in heat pump uptake and use?
Wellbeing	• How do internal conditions change following heat pump installation? For whom does this lead to improved thermal comfort? • How do heat pumps interact with ideas of homely and thermal comfort that have traditionally been constructed in a gendered way?

(Contd.)

CATEGORY	RESEARCH QUESTIONS
Resources	• How is willingness to pay for a heat pump affected by gendered concerns and interests, and why? • What role might cost-spreading schemes such as heat-as-a-service play in supporting the transition to heat pumps? How might perceptions and uptake of such schemes be gendered?
Ease of use	• How do women perceive controllability of a heat pump in space and time, and does this match with their expectations and of where and when heat is required? How do future ways of running heat pumps, *e.g.* according to flexible time of use tariffs, intersect with these expectations? • How do heat pumps interact with gendered understandings of domestic labour?
Relational dynamics	• How do heat pumps intersect with concerns about hot water provision? Are those concerns gendered? • Are interactions with heat pump controls gendered? Does the operation and control of heat pumps mitigate or create conflict within households?

Furthermore, a fuller incorporation of gendered concerns will require changes in how heating research is carried out. All the studies cited in this synthesis assume a binary delineation between male and female (when referring to both gender and sex). A more complete picture could be gained from acknowledging these categories as heterogeneous and fluid over time and recognising transgender, intersex and non-binary identities (Bradshaw 2018). The *Buildings & Cities* special issue on 'Energy, Emerging Technologies and Gender in Homes' highlights that energy technologies can also disrupt existing gender identities, roles and relations (Hargreaves & Sharma 2023); whether heat pumps act as such disruptive technologies could also be considered.

This review is not intended to reinforce existing gendered ideas of the home or minimise the diversity of women or households. However, in part because of the limitations of available research, it has not considered the intersection of identities in experiences with heat pumps. It is therefore necessary to undertake 'more "multi-focal" approaches that actively combine queer, decolonial, feminist, and anti-racist critiques' (Hargreaves & Sharma 2023: n.p.). It is possible that different gender roles could be captured by research that takes such intersectionality into consideration; this would offer the opportunity for a more nuanced understanding of how heat pumps interact with gendered concerns in different contexts. Research could also consider experiences amongst different housing sectors and income groups. The need to study intersections between gender, age and heat pump use could also be important. Older people seek to avoid age stigma by adopting varied strategies for managing winter cold (Day & Hitchings 2011), but it is unclear how and whether such strategies might vary with heat pump installation. For example, tenants in the social and private rented sectors can have little choice over the heating technologies installed in their homes (Calver *et al.* 2022), and there is a particular lack of studies on the uptake of heat pumps in private rented properties (Ahmad 2023). All are needed to ensure an inclusive and just energy transition.

6. CONCLUSIONS

The rollout of heat pumps in moderate and cold climates is anticipated to affect millions of households and include all genders, yet is progressing slowly. This article has examined how key differences between heat pumps and incumbent heating systems could have differently gendered impacts, using a framework of heating needs. While there are indications that heat pumps could be particularly beneficial for realising women's thermal comfort (wellbeing) needs, empirical research is lacking, and research that gives fuller consideration of resource, ease of use and relational dynamics is needed. This review has highlighted the need to consider and involve women in realising the heating transition, including in choosing to install a heat pump, anticipating its thermal comfort advantages and disadvantages, and tailoring its operation to work for themselves and their household.

Significant research gaps need addressing across multiple disciplines to increase the evidence base around how gender matters in heating transitions. The most pressing recommendation for policy and industry is to fund research to fill the knowledge gaps exposed in this article and summarised in Table 4. With a firmer evidence base, it will become possible to more fully consider and engage women in heat policy. This could include considering how heat pumps are discussed with women, developing information campaigns which incorporate their preferences and experiences, and evaluating how advice and support services are tailored to their needs. Ultimately, it is necessary to include as many groups as possible to more fully guarantee the success of policy for heating transitions.

NOTES

1 Carbon emissions from a heat pump depend on the carbon intensity of the electricity used to power it, thus heat pumps are only a decarbonisation solution if the electricity used is decarbonised.

2 For the papers in the special issue 'Energy, Emerging Technologies and Gender in Homes', see https://journal-buildingscities.org/collections/gender-in-homes/.

3 Heat pumps are sized according to space heating demand under certain design conditions (DECC 2013) and are typically in the range 5–12 kW heat output for UK dwellings. By comparison, gas boilers are usually sized according to either hot water demand for combi boilers, typically 25–35 kW, or a combination of space heating and hot water for system boilers where the domestic hot water is stored in a cylinder. Thus, boilers can deliver heat at up to 8.5 times the rate required for space heating (Bennett *et al.* 2016).

4 For example, for data from a cold snap in mid-December 2022, see https://heatpumpmonitor.org/.

5 Sex is used to describe biological differences, *e.g.* the classification of individuals as male and female based on biological criteria such as hormones, reproductive organs and chromosomes. Sex is often used to disaggregate data and inform energy initiatives (Bradshaw 2018); however, distinctions based on sex provide little insight into the gendered roles of men and women and how they are expected to act (Bradshaw *et al.* 2015). The physiological studies on thermal comfort cited are presumably with cisgender women—this has not been made clear in the existing literature.

ACKNOWLEDGEMENTS

This paper was checked by the editor of D. Scott Edits who has expertise in the use of conscious language. The authors thank D. Scott Edits for their thorough and insightful work, as well as the UKRI Centre for Research into Energy Demand Solutions for funding this edit. We also thank the journal's two anonymous reviewers for their careful reading of the paper and constructive comments.

AUTHOR AFFILIATIONS

Jenny Crawley orcid.org/0000-0001-6352-2226
UCL Energy Institute, University College London, Central House, 14 Upper Woburn Place, London WC1H 0NN, UK

Faye Wade orcid.org/0000-0003-4590-652X
School of Social and Political Science, University of Edinburgh, Edinburgh, UK

Mandy de Wilde orcid.org/0000-0001-8695-6406
Institute for Cultural Anthropology and Development Sociology, Leiden University, Leiden, NL

AUTHOR CONTRIBUTIONS

All authors contributed to the literature review and to the writing and editing of this manuscript.

COMPETING INTERESTS

The authors have no competing interests to declare.

FUNDING

The Centre for Research into Energy Demand Solutions funded the conscious language review and the publication fees of this article (grant number EP/R035288/1).

REFERENCES

Aagaard, L. K., & **Madsen, L. V.** (2022). Technological fascination and reluctance: Gendered practices in the smart home. *Buildings & Cities*, 3(1). DOI: https://doi.org/10.5334/bc.205

Ahmad, S. (2023). *Motivations and barriers associated with adopting domestic heat pumps in the UK*. UK Collaborative Centre for Housing Evidence.

Akrich, M. (1994). The de-scription of technical objects. In W. E. Bijker & J. Law (Eds.), *Shaping technology/building society. Studies in sociotechnical change* (pp. 205–224). Massachusetts Institute of Technology.

Arapostathis, S., Carlsson-Hyslop, A., Pearson, P. J., Thornton, J., Gradillas, M., Laczay, S., & **Wallis, S.** (2013). Governing transitions: Cases and insights from two periods in the history of the UK gas industry. *Energy Policy*, 52, 25–44. DOI: https://doi.org/10.1016/j.enpol.2012.08.016

Bartelink, M. L., De Wit, A., Wollersheim, H., Theeuwes, A., & **Thien, T.** (1993). Skin vascular reactivity in healthy subjects: Influence of hormonal status. *Journal of Applied Physiology*, 74(2), 727–732. DOI: https://doi.org/10.1152/jappl.1993.74.2.727

Barty-King, H. (1984). *New flame*. Graphmitre.

BEIS. (2022). *Public attitudes tracker: Net zero and climate change winter 2022, UK*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1140683/BEIS_PAT_Winter_2022_Net_Zero_and_Climate_Change.pdf

Bell, S., Capova, K. A., Barteczko-Hibbert, C., Matthews, P. C., Wardle, R., Bulkeley, H. A., ... & **Powells, G.** (2015). *High level summary of learning: Heat pump customers* (Technical Report). Northern Powergrid (Northeast). https://dro.dur.ac.uk/16651/

Bennett, G., Elwell, C., Lowe, R., & **Oreszczyn, T.** (2016). The importance of heating system transient response in domestic energy labelling. *Buildings*, 6(3), 29. DOI: https://doi.org/10.3390/buildings6030029

Bradshaw, S. (2018). Sex disaggregation alone will not energize equality. *Nature Energy*, 3(10), 813–815. DOI: https://doi.org/10.1038/s41560-018-0247-4

Bradshaw, S., Linneker, B., Nussey, C., & **Sanders-McDonagh, E.** (2015). *Gender evidence synthesis research award (ESRA)* (Report as part of the ESRC-DFID Joint Fund for Poverty Alleviation Research). https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/12108. DOI: https://doi.org/10.35648/20.500.12413/11781/ii216

Building Performance Centre. (2011). *Acoustic noise measurements of air source heat pumps*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48204/3307-acoustic-noise-air-source-heat-pumps-1.pdf

Caird, S., Roy, R., & **Potter, S.** (2012). Domestic heat pumps in the UK: User behaviour, satisfaction and performance. *Energy Efficiency*, 5, 283–301. DOI: https://doi.org/10.1007/s12053-012-9146-x

Calver, P., Mander, S., & **Abi Ghanem, D.** (2022). Low carbon system innovation through an energy justice lens: Exploring domestic heat pump adoption with direct load control in the United Kingdom. *Energy Research & Social Science*, 83, 102299. DOI: https://doi.org/10.1016/j.erss.2021.102299

Carlsson-Hyslop, A. (2016). Past management of energy demand: Promotion and adoption of electric heating in Britain 1945–1964. *Environment and History*, 22, 75–102. DOI: https://doi.org/10.3197/096734016X14497391602242

Carlsson-Kanyama, A., & **Lindén, A.-L.** (2007). Energy efficiency in residences—Challenges for women and men in the North. *Energy Policy*, 35(4), 2163–2172. DOI: https://doi.org/10.1016/j.enpol.2006.06.018

Castellani, J. W., & **Young, A. J.** (2016). Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure. *Autonomic Neuroscience*, 196, 63–74. DOI: https://doi.org/10.1016/j.autneu.2016.02.009

CCC. (2020). *The sixth carbon budget: Buildings*. Climate Change Committee (CCC). https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Buildings.pdf

Clendinning, A. (2000). 'Deft fingers' and 'persuasive eloquence': The 'lady demons' of the English gas industry, 1888–1918. *Women's History Review*, 9(3), 501–537. DOI: https://doi.org/10.1080/09612020000200254

Climate Watch. (2023). *Net zero tracker*. https://www.climatewatchdata.org/net-zero-tracker

Day, R., & **Hitchings, R.** (2011). 'Only old ladies would do that': Age stigma and older people's strategies for dealing with winter cold. *Health & Place*, 17, 885–894. DOI: https://doi.org/10.1016/j.healthplace.2011.04.011

De Wilde, M. (2019). *Wie beïnvloedt wie? Een inkijk in de besluitvorming over energiemaatregelen binnen het gezin* [Who influences whom? Insights into the family decision-making process for energy saving measures] (Report). Wageningen University & Research. https://projecten.topsectorenergie.nl/storage/app/uploads/public/5ee/879/94c/5ee87994c3b29528093165.pdf

De Wilde, M. (2021). 'A heat pump needs a bit of care': On maintainability and repairing gender–technology relations. *Science, Technology, & Human Values*, 46(6), 1261–1285. DOI: https://doi.org/10.1177/0162243920978301

De Wilde, M., & **Parry, S.** (2022). Feminised concern or feminist care? Reclaiming gender normativities in zero waste living. *Sociological Review*, 70(3), 526–546. DOI: https://doi.org/10.1177/00380261221080110

DECC. (2013). *Microgeneration installation standard: MIS 3005, Issue 5.0*. Department of Energy and Climate Change (DECC). https://mcscertified.com/wp-content/uploads/2019/08/MIS-3005.pdf

Durham Energy Institute & **Element Energy.** (2015). *Insight report: Domestic heat pumps*. http://www.networkrevolution.co.uk/wp-content/uploads/2015/01/CLNR-L091-Insight-Report-Domestic-Heat-Pumps.pdf

Ellsworth-Krebs, K., Reid, L., & **Hunter, C. J.** (2019). Integrated framework of home comfort: Relaxation, companionship and control. *Building Research & Information*, 47(2), 202–218. DOI: https://doi.org/10.1080/09613218.2017.1410375

Elnakat, A., & **Gomez, J. D.** (2015). Energy engenderment: An industrialized perspective assessing the importance of engaging women in residential energy consumption management. *Energy Policy*, 82, 166–177. DOI: https://doi.org/10.1016/j.enpol.2015.03.014

ESC. (2023). *Electrification of heat: Interim heat pump performance data analysis report*. Energy System Catapult (ESC). https://es.catapult.org.uk/report/electrification-of-heat-interim-heat-pump-performance-data-analysis-report/

Falkus, M. (1988). *Always under pressure: A history of North Thames Gas Since 1949*. MacMillan. DOI: https://doi.org/10.1007/978-1-349-10316-4

Gleeson, C. P. (2016). Residential heat pump installations: The role of vocational education and training. *Building Research & Information*, 44(4), 394–406. DOI: https://doi.org/10.1080/09613218.2015.1082701

Gram-Hanssen, K., Heidenstrøm, N., Vittersø, G., Madsen, L., & **Jacobsen, M.** (2017). Selling and installing heat pumps: Influencing household practices. *Building Research & Information*, 45(4), 359–370. DOI: https://doi.org/10.1080/09613218.2016.1157420

Hanmer, C. (2020). Flexibility of UK home heating demand: An exploration of reactions to algorithmic control (Doctoral dissertation, University College London, London).

Hannon, M. (2015). Raising the temperature of the UK heat pump market: Learning lessons from Finland. *Energy Policy*, 85, 369–375. DOI: https://doi.org/10.1016/j.enpol.2015.06.016

Hansen, A., Madsen, L., Knudsen, H., & **Gram-Hanssen, K.** (2019). Gender, age, and the education differences in the importance of homely comfort in Denmark, *Energy Research & Social Science*, 54, 157–165. DOI: https://doi.org/10.1016/j.erss.2019.04.004

Hargreaves, T., & **Sharma, N.** (2023). Developing an intersectional approach to emerging energy technologies in homes. *Buildings & Cities*, 12 April. https://www.buildingsandcities.org/insights/commentaries/developing-intersectional-approach.html

Harris, H. J. (2008). Conquering winter: US consumers and the cast-iron stove. *Building Research & Information*, 4, 337–335. DOI: https://doi.org/10.1080/09613210802117411

Hashiguchi, N., Feng, Y., & **Tochihara, Y.** (2010). Gender differences in thermal comfort and mental performance at different vertical air temperatures. *European Journal of Applied Physiology*, 109, 41–48. DOI: https://doi.org/10.1007/s00421-009-1158-7

Hyysalo, S., Juntunen, J. K., & **Freeman, S.** (2013a). Internet forums and the rise of the inventive energy user. *Science & Technology Studies*, 26(1), 25–51. DOI: https://doi.org/10.23987/sts.55307

Hyysalo, S., Juntunen, J., & **Freeman, S.** (2013b). User innovation in sustainable home energy technologies. *Energy Policy*, 55, 490–500. DOI: https://doi.org/10.1016/j.enpol.2012.12.038

IEA. (2021). *Net zero by 2050: A roadmap for the global energy sector*. International Energy Agency (IEA). https://iea.blob.core.windows.net/assets/063ae08a-7114-4b58-a34e-39db2112d0a2/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf

Jingchao, Z., Kotani, K., & **Saijo, T.** (2018). Public acceptance of environmentally friendly heating in Beijing: A case of a low temperature air source heat pump. *Energy Policy*, 117, 75–85. DOI: https://doi.org/10.1016/j.enpol.2018.02.041

Johnson, C. (2020). Is demand side response a woman's work? Domestic labour and electricity shifting in low income homes in the United Kingdom. *Energy Research and Social Science*, 68, 101558. DOI: https://doi.org/10.1016/j.erss.2020.101558

Kaikaew, K., van den Beukel, J. C., Neggers, S. J., Themmen, A. P., Visser, J. A., & **Grefhorst, A.** (2018). Sex difference in cold perception and shivering onset upon gradual cold exposure. *Journal of Thermal Biology*, 77, 137–144. DOI: https://doi.org/10.1016/j.jtherbio.2018.08.016

Karjalainen, S. (2007). Gender differences in thermal comfort and use of thermostats in everyday thermal environments. *Building and Environment*, 42(4), 1594–1603. DOI: https://doi.org/10.1016/j.buildenv.2006.01.009

Karjalainen, S. (2012). Thermal comfort and gender: A literature review. *Indoor Air*, 22(2), 96–109. DOI: https://doi.org/10.1111/j.1600-0668.2011.00747.x

Kelly, M. (2016). Sex versus gender categorization. In *The Wiley Blackwell encyclopedia of gender and sexuality studies* (pp. 1–3). DOI: https://doi.org/10.1002/9781118663219.wbegss028

Khamati-Njenga, B., & **Clancy, J.** (2002). *Concepts and issues in gender and energy*. ENERGIA. Leusden. https://genderinsite.net/sites/default/files/Energia-gender-energy.pdf

Knobloch, F., Pollitt, H., Chewpreecha, U., Daioglou, V., & **Mercure, J. F.** (2019). Simulating the deep decarbonisation of residential heating for limiting global warming to 1.5°C. *Energy Efficiency*, 12, 521–550. DOI: https://doi.org/10.1007/s12053-018-9710-0

Liu, H., Wu, Y., Lei, D., & **Li, B.** (2018). Gender differences in physiological and psychological responses to the thermal environment with varying clothing ensembles. *Building and Environment*, 141, 45–54. DOI: https://doi.org/10.1016/j.buildenv.2018.05.040

Love, J., Smith, A. Z., Watson, S., Oikonomou, E., Summerfield, A., Gleeson, C., ... & **Lowe, R.** (2017). The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial. *Applied Energy*, 204, 332–342. DOI: https://doi.org/10.1016/j.apenergy.2017.07.026

Lowe, R., & **Oreszczyn, T.** (2020). *Building decarbonisation transition pathways: Initial reflections* (CREDS Policy Briefing). https://www.creds.ac.uk/wp-content/uploads/CREDS-decarb-transitions-brief-2020.pdf. DOI: https://doi.org/10.31224/osf.io/s43zg

Lowe, R., Summerfield, A., Oikonomou, E., Love, J., Biddulph, P., Gleeson, C., ... & **Wingfield, J.** (2017). *Final report on analysis of heat pump data from the renewable heat premium payment (RHPP) scheme*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf

Lowes, R., Rosenow, J., Qadrdan, M., & **Wu, J.** (2020). Hot stuff: Research and policy principles for heat decarbonisation through smart electrification. *Energy Research & Social Science*, 70, 101735. DOI: https://doi.org/10.1016/j.erss.2020.101735

Mallaband, B., & **Lipson, M.** (2020). From health to harmony: Uncovering the range of heating needs in British households. *Energy Research & Social Science*, 69, 101590. DOI: https://doi.org/10.1016/j.erss.2020.101590

Martiskainen, M., Schot, J., & **Sovacool, B.** (2021). User innovation, niche construction and regime destabilization in heat pump transitions. *Environmental Innovation and Societal Transitions*, 39, 119–140. DOI: https://doi.org/10.1016/j.eist.2021.03.001

Mechlenborg, M., & **Gram-Hanssen, K.** (2020). Gendered homes in theories of practice: A framework for research in residential energy consumption. *Energy Research & Social Science*, 67, 101538. DOI: https://doi.org/10.1016/j.erss.2020.101538

Moezzi, M., Janda, K., & **Rotmann, S.** (2017). Using stories, narratives, and storytelling in energy and climate change research. *Energy Research & Social Science*, 31, 1–10. DOI: https://doi.org/10.1016/j.erss.2017.06.034

Mort, H. (2019). *A review of energy and gender research in the global north*. Technical University of Vienna. http://geecco-project.eu/

Myhren, J. A., & **Holmberg, S.** (2008). Flow patterns and thermal comfort in a room with panel, floor and wall heating. *Energy and Buildings*, 40(4), 524–536. DOI: https://doi.org/10.1016/j.enbuild.2007.04.011

National Grid. (2022). *Customer perceptions on unlocking flexibility from heat* (December). https://www.nationalgrid.co.uk/downloads-view-reciteme/620467

Neirotti, F., Noussan, M., & **Simonetti, M.** (2020). Towards the electrification of buildings heating—Real heat pumps electricity mixes based on high resolution operational profiles. *Energy*, 195, 116974. DOI: https://doi.org/10.1016/j.energy.2020.116974

Nesta. (2023). *Heat pumps: A user survey*. Eunomia Research and Consulting & Nesta. https://www.nesta.org.uk/report/heat-pumps-a-user-survey/

Nyborg, S. (2015). Pilot users and their families: Inventing flexible practices in the smart grid. *Science & Technology Studies*, 28(3), 54–80. DOI: https://doi.org/10.23987/sts.55342

Offenberger, U., & **Nentwich, J.C.** (2010). *Intertwined practices of gender and technology: The case of sustainable home heating*. https://www.alexandria.unisg.ch/69108/

Oikonomou, E. (2022). *Understanding the drivers affecting the in-situ performance of domestic heat pumps in the UK* (Doctoral dissertation, University College London).

Owen, A., Mitchell, G., & **Unsworth, R.** (2013). Reducing carbon, tackling fuel poverty: Adoption and performance of air-source heat pumps in East Yorkshire, UK. *Local Environment*, 18(7), 817–833. DOI: https://doi.org/10.1080/13549839.2012.732050

Pan, L., Lian, Z., & **Lan, L.** (2012). Investigation of gender differences in sleeping comfort at different environmental temperatures. *Indoor and Built Environment*, 21(6), 811–820. DOI: https://doi.org/10.1177/1420326X11425967

Parr, J. (1990). *The gender of breadwinners: Women, men, and change in two industrial towns, 1880–1950*. University of Toronto Press.

Parrish, B., Hielscher, S., & **Foxon, T. J.** (2021). Consumers or users? The impact of user learning about smart hybrid heat pumps on policy trajectories for heat decarbonisation. *Energy Policy*, 148. DOI: https://doi.org/10.1016/j.enpol.2020.112006

Reid, L., & **Ellsworth-Krebs, K.** (2021). Demanding expectations: Exploring the experience of distributed heat generation in Europe. *Energy Research & Social Science*, 71, 101821. DOI: https://doi.org/10.1016/j.erss.2020.101821

Reinholdt, L., Kristófersson, J., Zühlsdorf, B., Elmegaard, B., Jensen, J., Ommen, T., & **Jørgensen, P. H.** (2018, June). Heat pump COP, part 1: Generalized method for screening of system integration potentials. Paper presented at the 13th IIR Gustav Lorentzen Conference on Natural Refrigerants (GL2018). International Institute of Refrigeration, Valencia, Spain. https://iifiir.org/en/fridoc/heat-pump-cop-part-1-generalized-method-for-screening-of-system-33637

Rosenow, J., Gibb, D., Nowak, T., & **Lowes, R.** (2022). Heating up the global heat pump market. *Nature Energy*, 7, 901–904. DOI: https://doi.org/10.1038/s41560-022-01104-8

Roy, R., & **Caird, S.** (2013). Diffusion, user experiences and performance of UK domestic heat pumps. *Energy Science and Technology*, 6(2), 14–23. DOI: https://doi.org/10.3968/j.est.1923847920130602.2837

Rupp, R.F., Jungsoo, K., de Dear, R., & **Ghisil, E.** (2018). Associations of occupant demographics, thermal history and obesity variables with their thermal comfort in air-conditioned and mixed-mode ventilation office buildings. *Building and Environment*, 135, 1–9. DOI: https://doi.org/10.1016/j.buildenv.2018.02.049

Sadowski, J., Strengers, Y., & **Kennedy, J.** (2021). More work for big mother: Revaluing care and control in smart homes. *Environment and Planning A: Economy and Space*. DOI: https://doi.org/10.1177/0308518X211022366

Sardjoe Mishre, A. S., Martinez-Tellez, B., Acosta, F. M., Sanchez-Delgado, G., Straat, M. E., Webb, A. G., ... & **Ruiz, J. R.** (2022). Association of shivering threshold time with body composition and brown adipose tissue in young adults. *Journal of Thermal Biology*, 108, 103277. DOI: https://doi.org/10.1016/j.jtherbio.2022.103277

Schwartz Cowan, R. (1983). *More work for mother*: *The ironies of household technology from the open hearth to the microwave*. Basic.

Shah, N., & **Hewitt, N.** (2015, June). High temperature heat pump operational experience as a retrofit technology in domestic sector. Paper presented at the 2015 IEEE International Conference on Engineering, Technology and Innovation/International Technology Management Conference (ICE/ITMC), Belfast, UK. DOI: https://doi.org/10.1109/ICE.2015.7438691

Shahzad, S., & **Rijal, H. B.** (2019). Preferred vs neutral temperatures and their implications on thermal comfort and energy use: Workplaces in Japan, Norway and the UK. *Energy Procedia*, 158, 3113–3118. DOI: https://doi.org/10.1016/j.egypro.2019.01.1007

Shirani, F., O'Sullivan, K., Henwood, K., Hale, R., & **Pidgeon, N.** (2022). Living in an active home: Household dynamics and unintended consequences. *Buildings & Cities*, 3(1), 589–604. DOI: https://doi.org/10.5334/bc.216

Shove, E. (2010). Beyond the ABC: Climate change policy and theories of social change. *Environment and Planning A*, 42, 1273–1285. DOI: https://doi.org/10.1068/a42282

Singh Gaur, A., Fitiwi, D., & **Curtis, J.** (2021). Heat pumps and our low-carbon future: A comprehensive review. *Energy Research & Social Science*, 71, 101764. DOI: https://doi.org/10.1016/j.erss.2020.101764

Sintov, N. D., White, L. V., & **Walpole, H.** (2019). Thermostat wars? The roles of gender and thermal comfort negotiations in household energy use behavior. *PloS One*, 14(11), e0224198. DOI: https://doi.org/10.1371/journal.pone.0224198

Smale, R., Spaargaren, G., & **van Vliet, B.** (2019). Householders co-managing energy systems: Space for collaboration? *Building Research & Information*, 47(5), 585–597. DOI: https://doi.org/10.1080/09613218.2019.1540548

Song, M., Shiming D., Chaobin D., Ning M., & **Zhihua W.** (2018). Review on improvement for air source heat pump units during frosting and defrosting. *Applied Energy*, 211, 1150–1170. DOI: https://doi.org/10.1016/j.apenergy.2017.12.022

Sovacool, B., Axsen, J., & **Sorrell, S.** (2018). Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design. *Energy Research & Social Science*, 45, 12–42. DOI: https://doi.org/10.1016/j.erss.2018.07.007

Sovacool, B., Martiskainen, M., Osborn, J., Anaam, A., & **Lipson, M.** (2020). From thermal comfort to conflict: The contested control and usage of domestic smart heating in the United Kingdom. *Energy Research & Social Science*, 69, 101566. DOI: https://doi.org/10.1016/j.erss.2020.101566

Strengers, Y., Dahlgreen, K., Nicholls, L., Pink, S., & **Martin, R.** (2021). *Digital energy futures: Future home life*. https://www.monash.edu/__data/assets/pdf_file/0011/2617157/DEF-Future-Home-Life-Full-Report.pdf

Strengers, Y., Gram-Hanssen, K., Dahlgreen, K., & **Aagaard, L. K.** (2022). Energy, emerging technologies and gender in homes—Editorial. *Buildings & Cities*, 3(1), 842–853. DOI: https://doi.org/10.5334/bc.273

Strengers, Y., & **Nicholls, L.** (2018). Aesthetic pleasures and gendered tech-work in the 21st-century smart home. *Media International Australia*, 166(1), 70–80. DOI: https://doi.org/10.1177/1329878X17737661

Sullivan, O. (2018). The gendered division of household labour. In B. Risman, C. Froyum & W. Scarborough (Eds.), *Handbook of the sociology of gender*. Springer. DOI: https://doi.org/10.1007/978-3-319-76333-0_27

Trust Electric Heating. (2023). *How does electric heating work?* https://www.trustelectricheating.co.uk/news/how_does_electric_heating/

Tunzi, M., Boukhanouf, R., Li, H., Svendsen, S., & **Ianakiev, A.** (2018). Improving thermal performance of an existing UK district heat network: A case for temperature optimization. *Energy and Buildings*, 158, 1576–1585. DOI: https://doi.org/10.1016/j.enbuild.2017.11.049

UKERC. (2023a). *Decarbonising home heating: An evidence review of domestic heat pump installed costs*. UK Energy Research Centre (UKERC). https://ukerc.ac.uk/publications/heat-pump-cost-review/

UKERC. (2023b). *Unlocking the economy wide benefits of heat pumps: The role of electricity and gas prices*. UK Energy Research Centre (UKERC). https://ukerc.ac.uk/publications/benefits-heat-pumps-role-electricity-gas-prices/

Valdorff Madsen, L., & **Gram-Hanssen, K.** (2017). Understanding comfort and senses in social practice theory: Insights from a Danish field study. *Energy Research & Social Science*, 29, 86–94. DOI: https://doi.org/10.1016/j.erss.2017.05.013

Wade, F. (2022). *Pathways to engagement with low carbon heat: An industry perspective*. Scottish and Northern Ireland Plumbers Employer's Federation/Construction Scotland Innovation Centre/Energy Saving Trust.

Wade, F., Hithcings, R., & **Shipworth, M.** (2016). Understanding the missing middlemen of domestic heating: Installers as a community of professional practices in the United Kingdom. *Energy Research & Social Science*, 19, 39–47. DOI: https://doi.org/10.1016/j.erss.2016.05.007

Wang, Z., De Dear, R., Luo, M., Lin, B., He, Y., Ghahramani, A., & **Zhu, Y.** (2018). Individual difference in thermal comfort: A literature review. *Building and Environment*, 138, 181–193. DOI: https://doi.org/10.1016/j.buildenv.2018.04.040

Watson, S. D. (2020). *Predicting the additional GB electricity demand resulting from a widespread uptake of domestic heat pumps* (Dissertation, Loughborough University).

Watson, S. D., Crawley, J., Lomas, K. J., & **Buswell, R. A.** (2023). Predicting future GB heat pump electricity demand. *Energy and Buildings*, 286, 112917. DOI: https://doi.org/10.1016/j.enbuild.2023.112917

Yang, L., Zhao, S., Gao, S., Zhang, H., Arens, E., & **Zhai, Y.** (2021). Gender differences in metabolic rates and thermal comfort in sedentary young males and females at various temperatures. *Energy and Buildings*, 251, 111360. DOI: https://doi.org/10.1016/j.enbuild.2021.111360

TO CITE THIS ARTICLE:
Crawley, J., Wade, F., & de Wilde, M. (2023). Gender and the heat pump transition. *Buildings and Cities*, 4(1), pp. 948–964. DOI: https://doi.org/10.5334/bc.392

Submitted: 05 October 2023
Accepted: 31 October 2023
Published: 13 December 2023

Buildings and Cities is a peer-reviewed open access journal published by Ubiquity Press.