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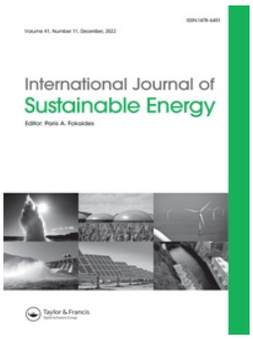

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Household heat pump adoption and user behaviours: a systematic review of drivers and barriers

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ABSTRACT

This systematic literature review synthesises the literature on socio-psychological drivers and barriers to heat pump adoption and efficient use in households, drawing from the 16 research articles available. The review reveals mixed findings: variables were found influential in some studies but not in others. In addition to financial considerations, negative expectations regarding comfort and performance also hinder adoption. The literature on user behaviours suggests that comfort, knowledge, and home characteristics influence how heat pumps are operated, including temperature settings, heating area, and ventilation behaviour. A key research gap is the insufficient study of variables relating to the individual, such as psychological and socio-demographic factors. Based on the findings, we recommend public awareness campaigns to emphasise non-financial benefits of heat pumps, particularly comfort, which users often experience as an advantage. To optimise user behaviour, we recommend offering technical support services, simplifying system interfaces, and providing actionable feedback information on energy consumption.

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household; energy transition; heat pump; adoption; user behaviour

1. Introduction

1.1. Decarbonising residential heating

Space and water heating in homes accounts for roughly half of the energy consumed for heat, and as of yet, it is mostly produced with fossil fuels (International Energy Agency 2023). The combustion of fossil fuels contributes to global warming with catastrophic consequences for the planet (Intergovernmental Panel on Climate Change 2023). To mitigate climate change, it is crucial to decarbonise the residential sector (Kieft, Harmsen, and Hekkert 2021). The transition from fossil fuel-based heating systems to more sustainable alternatives is, however, challenging because it requires changes not only in buildings and infrastructure but also in human behaviour.

Heat pumps can effectively reduce carbon emissions in the residential sector (Bianco, Scarpa, and Tagliafico 2017) and contribute to energy security by decreasing reliance on imported fuels, supporting demand response strategies, and lowering overall heating costs. Therefore, heat

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pumps are a key component in climate policy in many countries and regions, including the United States, the European Union, Japan, and Korea. Currently, heat pump sales are strongly growing, especially in Europe and the United States (International Energy Agency 2023).

A deeper understanding of what drives or hinders households to adopt a heat pump and use it efficiently can help policymakers address relevant factors to accelerate the transition to sustainable heating while ensuring affordability and user satisfaction. Therefore, this research aims to synthesise the available research by exploring the following question: what socio-psychological drivers and barriers to household adoption and use of heat pumps have been studied in the literature?

1.2. Existing heat pump reviews

Existing reviews of heat pump literature provide insights regarding the efficiency of heat pumps under different control or climatic conditions (Adebayo et al. 2024; Beccali et al. 2022), economic feasibility of heat pumps compared to other heating options (Amirkhizi and Jensen 2020; Mitterrutzner et al. 2023), and the role of heat pumps in demand-side flexibility (Golmohamadi et al. 2024). The reviews identify several drivers and barriers influencing the transition to heat pumps across technical, economic, environmental, and policy domains. Cost-effectiveness (Mitterrutzner et al. 2023), decarbonisation targets (Adebayo et al. 2024; Amirkhizi and Jensen 2020; Beccali et al. 2022; Golmohamadi et al. 2024; Mitterrutzner et al. 2023), and the need for flexible energy loads (Amirkhizi and Jensen 2020; Beccali et al. 2022; Golmohamadi et al. 2024) are highlighted as drivers of the transition to (hybrid) heat pumps.

However, several barriers remain, such as high upfront investment costs (Mitterrutzner et al. 2023), the required expansion of the power grid (Amirkhizi and Jensen 2020), and performance limitations in extremely cold climates (Adebayo et al. 2024). Collectively, the reviews highlight the potential of heat pumps as a sustainable heating and cooling technology while emphasising the challenges that need to be addressed to accelerate their integration into energy systems.

Missing from the body of heat pump literature reviews is a systematic analysis of the behavioural factors that influence the transition to heat pumps. While technical, economic, and policy-related factors are crucial aspects of the transition, human behaviour is an important dimension that tends to be overlooked or simplified. A recent review by Rao, Siam, and Bond (2025) has begun to address this gap by exploring modelling and social science literature on heat pump adoption. Moreover, a review by Gaur, Fitiwi, and Curtis (2021) identifies public acceptance and awareness issues as a barrier to heat pump adoption.

Our review differs in that we analyze specific drivers and barriers not only to the adoption of heat pumps but also to their use, which is an aspect that has not been reviewed from a social science perspective before. Additionally, we quantify the findings where possible and provide systematic mappings clarifying which studies examined each factor. This approach reveals key knowledge gaps and identifies relevant factors to address in policy interventions to support the transition to heat pumps.

1.3. Adoption and use of heat pumps

The adoption of heat pumps can be understood as an occasional act that is deliberative or planned. This type of behaviour requires cognitive effort and tends to be informed by careful consideration of the information available to the individual (Kahneman 2011). Nevertheless, the decision to adopt a heat pump can be significantly influenced by socio-psychological factors, which may lead to decisions that are not always economically rational. For example, households may be motivated to adopt a heat pump because it confirms their identity as an environmental person, or they may resist it because they have an aversion to change.

Another behavioural interaction with heat pumps that may not be entirely rational is the use of heat pumps, which is more of a habitual type of behaviour. Habits involve low cognitive effort and

are often triggered by context cues. These behaviours are generally resistant to change (Wood 2017). Since heat pumps require a different operation strategy than traditional heating systems, persistent habits in heating practices can decrease heat pump performance and energy savings.

1.4. Existing reviews of renewable energy technology adoption and use

Literature reviews on the adoption of renewable energy technologies have demonstrated the importance of studying socio-psychological factors. For instance, the financial costs and various socio-demographic variables appear to be important factors (Freyre et al. 2021; Heiskanen and Matschoss 2017; Peñaloza et al. 2022). Some findings indicate that income and age are positively related to the willingness to adopt, while others suggest that this relationship is not linear or that lower-income households are, in fact, more willing to invest in energy technologies if resulting in bill savings. Education levels seem more consistently related to an increased likelihood of adopting renewable energy technologies (Heiskanen and Matschoss 2017). Other drivers and barriers that the reviews identified include, among others, the availability of information (Heiskanen and Matschoss 2017; Peñaloza et al. 2022), recommendations from peers (Heiskanen and Matschoss 2017), and the expected hassle of installation (Freyre et al. 2021; Heiskanen and Matschoss 2017).

The reviews on the adoption of renewable energy technologies provide useful insights but do not exclusively address heat pumps, as few studies were specific to this relatively new technology. Heat pumps are distinct from other renewable technologies in cost, functionality, and installation requirements. Moreover, there are no reviews yet that synthesise the literature on the use of renewable heating systems. Considering that inefficient user behaviour reduces the potential of heat pumps to realise predicted energy savings and contribute to meeting climate goals, a review of the available literature is necessary to reveal what we do and do not yet know about households' use of heat pumps. Given the major role of heat pumps in decarbonising the residential sector, a specific understanding of the factors influencing their adoption and use is needed to support the design of effective policies for the transition to sustainable heating and cooling of homes. For instance, governmental incentives can be tailored to behavioural factors influencing adoption most strongly.

1.5. Research aim and scope

This systematic review synthesises the available research on heat pump adoption and use, and points to knowledge gaps that require further research. Stakeholders across the spectrum can benefit from a deepened understanding of the factors influencing household adoption and use of heat pumps. The findings can inform the development of policies that aim to stimulate heat pump uptake and tailor educational campaigns that inform households about the correct use of heat pumps. Moreover, greater knowledge of the barriers that households experience to adopting a heat pump can support market development and help businesses identify potential growth areas.

The scope of actors considered in this review is limited to households, which includes homeowners, renters in the private sector or social housing, and residents of a building with shared ownership. The findings of this review are, however, likely most applicable to homeowners who can decide to adopt a heat pump independently and have full authority over the use of their heat pump. The decision-making processes differ for tenants or residents living in buildings with shared ownership. The adoption of a heat pump might be unattractive for landlords due to the high upfront costs and the benefits of energy bill savings being distributed to tenants instead (März, Stelk, and Stelzer 2022). Residents sharing a building are required to make decisions in agreement with each other, and in some cases, heating is organised centrally, which complicates the switch to a heat pump.

Section 2 describes how the literature review was carried out. Section 3 presents the findings: first, the drivers and barriers to heat pump adoption, and then the user behaviours that influence

heat pump performance, along with the factors that drive these behaviours. In Sections 4 and 5, the findings are interpreted and situated in social science research on renewable energy technologies, and recommendations are provided for the development of policy and market incentives.

2. Methods

2.1. Literature search strategy

The literature review of heat pump adoption and user behaviours was guided by the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) framework (Page et al. 2021). The search query was developed with a scoping exercise and includes search terms targeting households, heat pumps, adoption and user behaviours, and socio-psychological factors (Table 1). The search query comprised three blocks of search terms that were combined with the Boolean operator 'AND', namely: households, heat pumps, and (behaviours + factors). Within each block, search terms were combined with the Boolean operator 'OR'. The search did not specify a geographical scope to enable a review of the globally available literature.

2.2. Identification of studies

The search string was applied to Scopus on October 2nd 2023 and yielded 106 papers, of which the title and abstract were screened for inclusion (Figure 1). Papers were only included if they met the following inclusion criteria: (1) the technological focus was on heat pumps, (2) households were considered as the target group, (3) adoption or user behaviours were studied, and (4) the research was empirical. Based on this screening, 69 papers were excluded because they did not meet one or multiple of the inclusion criteria or because papers were not accessible. Many papers were excluded because the studies did not explore what households experience as drivers or barriers to adopting or using heat pumps. Especially in studies of heat pump use, user behaviour was mainly considered as one of many factors influencing the energy performance of a house, and often, it was simulated in a model rather than empirically studied. After screening, 35 papers were found eligible for a full-text assessment.

The same four inclusion criteria were applied as defined above for a full-text assessment of the remaining papers. More papers were excluded because they did not meet the inclusion criteria. In fifteen papers, user behaviour was not measured empirically but simulated in a model and thus provided little information about the factors that drive user behaviours. In two papers, the research focus appeared not to be on households. Another paper used the same dataset as another paper that was included; thus, we decided to include only one. One more paper was excluded because it was not a research article. After this full-text assessment, 16 papers remained for inclusion (Appendix A).

Table 1. Search query applied to scopus.

	Query
Search within	TITLE-ABS-KEY (
Population	(home OR occupant* OR apartment* OR house* OR domestic* OR dwelling* OR resident*)
Technology	AND '*heat pump*'
Behaviour	AND ((adoption OR diffusion OR uptake) AND (driver* OR determinant* OR 'psychological variable*' OR (factor W/2 psycholog*) OR 'situational factor*' OR barrier* OR 'behavior* change')) OR ('use* behavior*' OR 'occupan* behavior*' OR 'household behavior*' OR 'people's uses')))

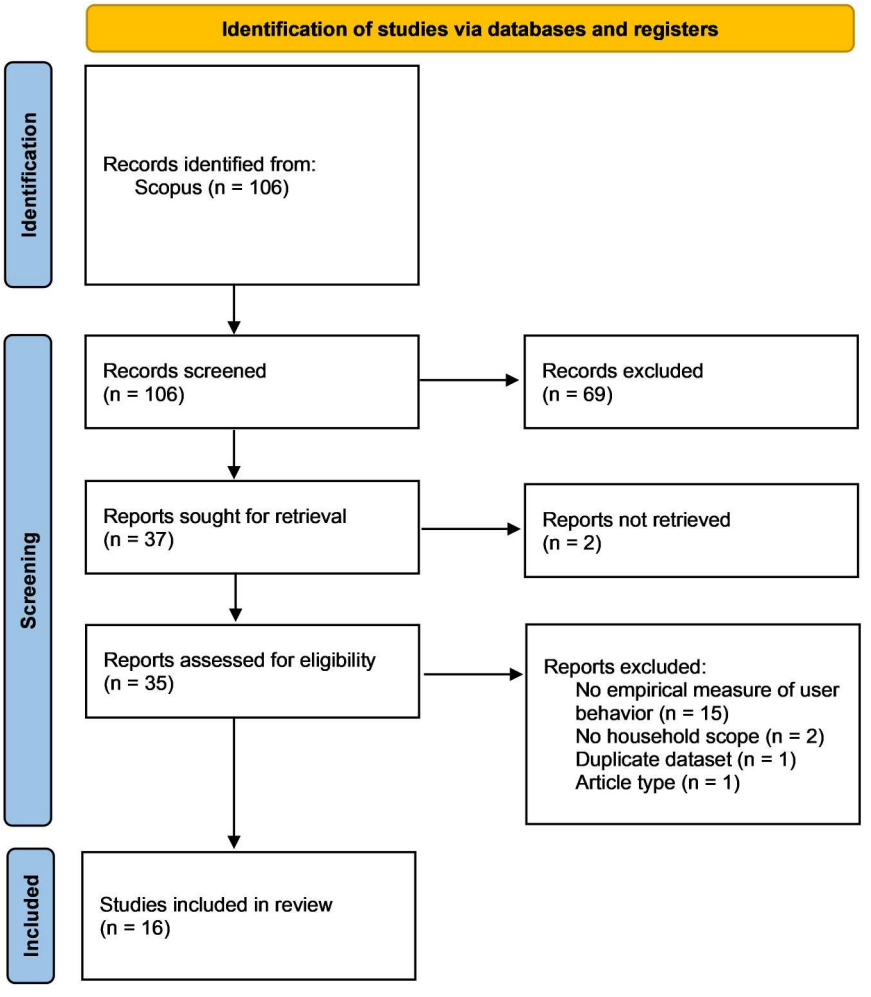

Figure 1. Screening and selection process adapted from PRISMA Framework.

The remaining 16 papers were coded with a coding scheme (Appendix B). For each paper that studied adoption behaviour, it was coded which variables were measured and which were found important for adoption behaviour according to the results. The type of behaviour and its drivers were identified for papers that study use behaviours. Besides coding the target behaviours and factors, it was documented when a socio-psychological theory was applied. In addition, the geographical location of the studies was coded to document the context in which the studies were performed.

To be transparent about the quality of the included studies, self-reported limitations were documented in Appendix C. The studies indicated some limitations related to the research design and methodology that may have introduced biases into the findings. For example, the use of surveys creates room for biases such as the social desirability bias, where participants may provide answers that they perceive as socially desirable rather than truthful, or a sampling bias, where individuals with certain characteristics, like a pre-existing interest in the topic, are more likely to participate, skewing the results.

Additionally, some studies reported biases in the data itself, because data was collected before major system changes or because current data only reflects relevant drivers and barriers in the early stages of the transition to heat pumps. As a result, the findings may primarily reflect the

perceptions of early adopters, which could differ from those of late adopters. For example, early adopters may have more higher financial resources, making heat pumps seem more affordable, and therefore perceive heat pumps as more affordable, or they may be more environmentally conscious, which could have influenced their decision to adopt.

2.3. Categorisation and coding of studies and variables

The identified studies were categorised as studies examining adoption behaviour, user behaviour, or both. Studies exploring factors influencing households' intention or past adoption of heat pumps were categorised as adoption behaviour studies. Papers studying heat pump use and the factors influencing this behaviour were categorised as user behaviour studies. Some studies looked into both adoption and user behaviours and were thus categorised as such.

For each paper, the factors studied and those found to influence adoption and user behaviours were identified. In the rest of this paper, 'factors' and 'variables' are used interchangeably.

Many of the variables studied in the reviewed papers are latent constructs that represent psychological or social factors that cannot be directly observed. For example, attitudes towards heat pumps are a mental state and must be inferred through surveys or other techniques. In surveys, latent variables are measured with a group of related statements or questions. The individual statements or questions are referred to as items, and a group of related items forms a scale.

To ensure precision in our analysis, we coded the individual statements and questions, where possible, rather than the variable names when reviewing studies that used surveys. This approach captures what was actually measured in each study rather than relying on potentially inconsistent variable labels. The items and variables were often presented in tables and figures, enabling a systematic coding approach. In studies without such structured overviews, a content analysis was conducted using a structured manual process to extract relevant variables. This approach was primarily necessary for studies on user behaviours. First, the user behaviours studied in the papers were identified. Then, any passages reporting on factors influencing these user behaviours were coded.

Next, we merged items in overarching variables representing well-known concepts in social psychology. This categorisation of items was performed in a session with two of the authors, both behavioural experts, who compared the wording of items across studies to identify common constructs and cluster similar items together. In cases of disagreement, the final categorisation was determined by consulting the research team. Appendix D shows how items were merged in overarching variables. Because we extracted a wide range of survey items from the reviewed studies, each overarching variable represents a broad concept encompassing multiple related variables.

2.4. Challenges in coding the literature

Merging items in overarching variables was a challenging task as in many cases, studies differed in their methods to measure adoption intentions and user behaviours, some conducted surveys while others used interviews or discrete choice experiments. In the case of surveys, there was no consistency in the scales used to measure variables, making it difficult to compare what was measured. Instead of reusing scales to facilitate comparison of findings, the studies developed new scales to fit their research focus or population. Moreover, the names used to refer to the variables measured with those scales often differed or were not made explicit, which made it difficult to know if studies were measuring the same variables.

As measurement scales were not reused, different interpretations of variables were measured. For instance, Michelsen and Madlener (2016) measured the perceived compatibility of a heat pump with existing habits and norms, while Karytsas (2018) measured the perceived compatibility of a heat pump with people's lifestyles, and Corbett et al. (2023) assessed the influence of having a

technology – or environmental-oriented lifestyle in heat pump adoption intentions. Moreover, variables were operationalised differently even when they seemed conceptually similar.

Besides varying methodologies and measurement scales, there were also vast differences in terms of analyses of the results. Some studies tested the significance of effect sizes, and others reported the percentage of participants that deemed a factor important in their decision to adopt a heat pump. A factor was coded as influential when (a) the effect size was significant or (b) the article explicitly referred to a factor as important in cases where no significance level was reported.

3. Results

3.1. General findings

3.1.1. Studied behaviours

First, the general findings of the systematic literature review are presented, including the application of theoretical frameworks in the reviewed studies. Then, we delve into specific drivers and barriers to heat pump adoption, followed by the factors influencing heat pump use. Descriptive statistics of the reviewed literature can be found in Appendix E, which shows the distribution of publication years, publication journals, and countries where the studies were performed.

Overall, it was observed that the body of research studying factors that influence the adoption or use of heat pumps is small: we found 16 research articles that met our inclusion criteria. Here follows a brief analysis of the reviewed studies, with the number of studies indicated in brackets using the letter 'N'. Of the available research, most articles studied only the adoption of heat pumps by households (N = 11), some articles studied both adoption and use (N = 3), and few studied only the use of heat pumps (N = 2).

Among adoption behaviours, the purchasing (N = 12) and leasing (N = 1) of a heat pump were studied, and the co-adoption of multiple technologies (N = 1) (Table 2). In terms of user behaviours that affect the performance of a heat pump and its energy consumption, temperature setting (N = 5), continuous/intermittent operation (N = 5), enlarging the heating area (N = 3), and window/door opening (N = 2) were studied.

Interestingly, many studies measured households' intention or willingness to adopt a heat pump and their preferences for different heating systems rather than studying actual adoption behaviour. This is likely a result of the challenges to tracking human behaviour, such as studying participants without invading and thereby changing their behaviour, and the costs associated with tracking real-time behaviour. Throughout the findings, we use the term 'adoption behavior' for simplicity; however, it is important to note that many of the results specifically pertain to adoption intentions rather than actual behaviour.

Most adoption studies collected self-report data on households' perceptions of heat pumps, their local environment, and themselves. For example, Corbett et al. (2023) did not present survey

Table 2. Heat pump adoption and user behaviours in the literature with frequencies.

Behaviour	Frequency
Adoption	14
Purchase	12
Lease	1
Co-adoption	1
Use	5
Temperature setting	5
Continuous/intermittent operation	5
Heating area enlargement	3
Window/door opening	2

Note: Articles studying adoption exclusively focused on a single type of behaviour, whereas articles studying the use of heat pumps explored multiple types of behaviour.

participants with the actual heat pump costs but measured whether perceiving heat pumps as too expensive to purchase influenced households' willingness to adopt.

3.1.2. Application of theoretical frameworks

Only five articles (N = 5) used a theoretical framework to study adoption or user behaviour. The frameworks used are the (random) utility theory, the Theory of Planned Behavior (Ajzen 1991), the Innovation Diffusion Theory (Rogers 2003), the Attitude-Behavior-Context (ABC) theory (Stern 2000), the practice theory, and combinations thereof.

Côté and Pons-Seres de Brauwer (2023) applied random utility theory to measure homeowner preferences for leasing or purchasing a heat pump. With discrete choice experiments, individual levels of utility associated with product and service attributes were measured.

Meles, Ryan, and Mukherjee (2022) measured heat pump adoption intentions with survey questions based on constructs of the Theory of Planned Behavior: attitude, subjective norm, and perceived behavioural control. Meles, Ryan, and Mukherjee (2022) also applied utility theory by using discrete choice experiments to measure preference for different attributes of new heating systems.

Corbett et al. (2023) employed the ABC theory to explore the role of policy awareness in heat pump adoption. According to the ABC theory, attitudinal, contextual, personal capability, and habitual characteristics influence pro-environmental behaviour. This study used the categorisation of the ABC theory to identify and organise relevant variables to measure in their study.

Owen, Mitchell, and Unsworth (2013) developed a conceptual model of adoption and user behaviour by integrating the Theory of Planned Behavior with the Innovation Diffusion Theory. The integrated conceptual model considers how technology, user, place, and installation factors influence adoption intention, adoption, and use and this framework was used to interpret the findings from interviews.

Winther and Wilhite (2015) applied a theoretical framework, namely practice theory, to understand user behaviour. Practice theory understands consumption patterns, such as home energy consumption, as a result of past actions at the societal and individual levels. Winther and Wilhite (2015) applied practice theory to understand how heat pumps change practice with special attention to comfort practices and how this may result in rebound effects.

3.2. Drivers and barriers to heat pump adoption

Here we present the findings of the reviewed literature on drivers and barriers to household adoption of heat pumps. In Section 3.2.1., we explore what variables were studied in the literature and which were found to influence adoption. Then, the main drivers and barriers to heat pump adoption are briefly discussed in Section 3.2.2. Next, in Section 3.2.3., we zoom in on each of these factors in the order of the most to least frequently identified factors.

3.2.1. Studied variables

The reviewed studies reported mixed findings about the influence that variables have on adoption: some studies identified an effect, while others did not. In other words, while many variables were analyzed for their impact on adoption, only some were found to be influential. Figure 2 shows two different findings: (1) the coloured bar shows how often the overarching variable was found to influence heat pump adoption, and (2) the white bar shows how often the variable was found not to influence heat pump adoption. For improved clarity, the variables are categorised into three clusters: heat pump-specific variables, variables related to the local environment, and variables relating to the individual.

Inconsistencies in the findings across studies suggest that the role of several factors may be context-dependent or require further investigation. Below Figure 2, some examples are given for

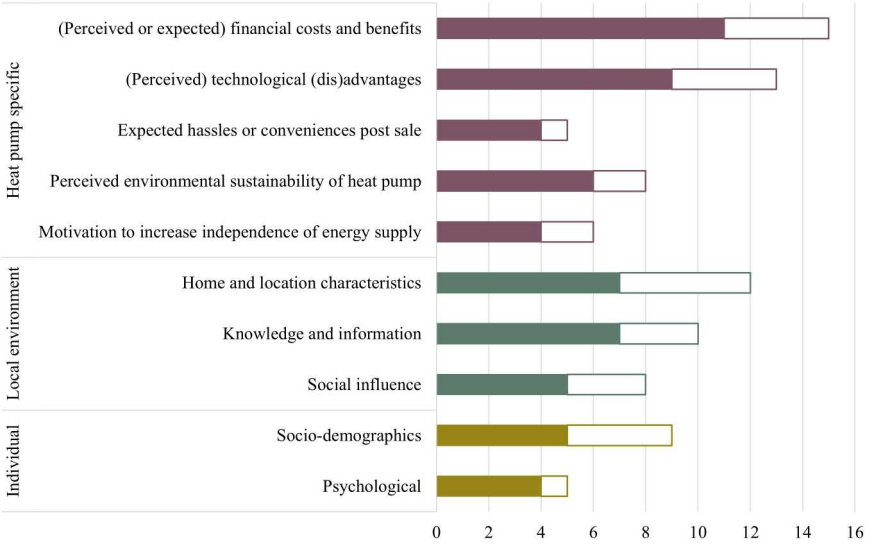

Figure 2. Variables found to (not) influence the adoption of heat pumps by households.

Note: The coloured portion of the bars indicates how often the overarching variable was found to influence heat pump adoption. The white portion of the bars shows how often the variable was found not to influence heat pump adoption. For example, if a study found that an item categorised under social influence influenced adoption, it was added to the coloured portion of that bar. Conversely, if a study examined an item categorised under social influence but found no effect, it was included in the white portion. If the same study found an item categorised in social influence to have an effect, while another item of social influence had no effect, both findings were counted separately, meaning the same study could contribute to both the coloured and white portions of the bar.

overarching variables with frequent mixed findings. Overarching variables be recognised by their *italic* print.

Contradicting findings were particularly evident for the *(perceived or expected) financial costs and benefits*. The reviewed articles generally found that the investment costs of heat pumps were perceived as a barrier to adoption, but some findings challenge this view. For instance, Michelsen and Madlener (2016) and Côté and Pons-Seres de Brauwer (2023) did not find an influence of the perceived total costs, lack of tax benefits, or the availability of grants on adoption. Relatedly, the influence of operation and maintenance costs remains unclear. Michelsen and Madlener (2016) found maintenance costs to have an effect, while other studies reported no effect regardless of whether the operation and maintenance costs were framed to be high or low (Balcombe, Rigby, and Azapagic 2014; Corbett et al. 2023; Côté and Pons-Seres de Brauwer 2023).

Several papers found that *home and location characteristics* influenced the decision to adopt a heat pump, but there were also several items that were not found to be influential. Michelsen and Madlener (2016) found that constraints related to the property were an influential factor, whereas infrastructural constraints were not. Conversely, Balcombe, Rigby, and Azapagic (2014) report that the home not being suitable for a heat pump did not affect adoption. Furthermore, Winther and Wilhite (2015) found that a major home renovation can be a driver for heat pump adoption, while Corbett et al. (2023) and Michelsen and Madlener (2016) indicate that a parallel major retrofit of the home or an energy retrofit had no influence.

Regarding the influence of *socio-demographic* factors, the findings across studies are mostly inconsistent for gender and income. Only Karytsas (2018) found that gender affects heat pump adoption, while other studies report this factor having no influence (Corbett et al. 2023; Michelsen and Madlener 2016; Räihä and Ruokamo 2021). Similarly, research on income was divided, with an equal number of studies finding an effect as those finding none.

Table 3. Drivers and barriers of heat pump adoption in the reviewed studies.

Study	Hass	Home/ Loc	Know/ Info	Ind Ener	Env Sust	Fin	Tech	Psy	Soc In	Soc-dem
Balcombe, Rigby, and Azapagic (2014)			✓	✓	✓	✓	✓			
Corbett et al. (2023)				✓	✓	✓	✓	✓	✓	✓
Côté and Pons-Seres de Brauwer (2023)				✓	✓	✓	✓			
Gram-Hanssen, Christensen, and Petersen (2012)						✓	✓			
Hafner, Elmes, and Read (2019)			✓						✓	
Karytsas (2018)			✓			✓	✓	✓	✓	✓
Lagomarsino et al. (2023)										
Meles, Ryan, and Mukherjee (2022)	✓	✓			✓	✓	✓	✓	✓	
Michelsen and Madlener (2016)	✓	✓	✓	✓	✓	✓	✓			✓
Owen, Mitchell, and Unsworth (2013)	✓	✓	✓			✓			✓	
Poblete-Cazenave and Rao (2023)		✓				✓				✓
Räihä and Ruokamo (2021)		✓	✓				✓			✓
Snape, Boait, and Rylatt (2015)	✓	✓				✓				
Winther and Wilhite (2015)		✓			✓	✓	✓	✓		

Note: Abbreviations: Hass = Expected hassle or convenience post-sale; Home/Loc = Home and location characteristics; Know/Info = Knowledge and information; Ind Ener = Motivation to increase independence of energy supply; Env Sust = Perceived environmental sustainability; Fin = (Perceived or expected) financial costs and benefits; Tech = (Perceived) technological (dis)advantages; Psy = Psychological; Soc In = Social influence; Soc-dem = Socio-demographics.

3.2.2. Influential variables

Table 3 displays the variables that were found to influence households' adoption of heat pumps in the reviewed studies. Variables related to the *perceived financial costs and benefits* and the *perceived technological advantages and disadvantages* of the heat pump were most often found to drive or hinder adoption. Households' adoption intentions were also often influenced by the *characteristics of their home and its location*.

The findings suggest that the adoption of heat pumps largely depends on the attractiveness of the technology itself and its suitability in the home. Based on the findings, it seems like households were least often influenced by *psychological* variables and *socio-demographics* when considering adopting a heat pump. However, it should be noted that few individual factors were studied, and therefore, it can be misleading to draw conclusions about the influence of these variables.

We compiled an overview of the quantitative findings in Appendix F. Since the full overview is too extensive for the main text, Table 4 presents an excerpt focusing on the quantitative findings for the *motivation to increase independence of energy supply*. The findings in this table are interpreted in section 3.2.3.5.

It was not feasible to fully synthesise the quantitative findings because many studies either did not quantify their findings or did so in non-comparable ways. Some studies provide insights on the effect sizes that factors have on adoption behaviour with standardised beta coefficients or average marginal effects, while others report on the percentages of their study sample who scored a factor as important in influencing their behaviour, or divide the study sample into sub-classes based on their likelihood of agreeing or disagreeing with survey questions.

To interpret the quantitative findings of the reviewed studies, the overview was sorted first by overarching factor and then by study-specific factor (or item). This grouped similar variables together, facilitating comparison across studies. The next section follows a detailed discussion of the influence of each variable on heat pump adoption across the reviewed studies. In the discussion here, we mainly focus on the direction of the influence (positive/negative), since different measurement scales make it impossible to fully compare all effect strengths.

3.2.2.1. Heat pump-specific variables

3.2.2.1.1. (Perceived or expected) financial costs and benefits. The *(perceived or expected) financial costs and benefits* of heat pumps were most often found to influence the adoption of heat pumps

Table 4. Excerpt of Appendix F: Overview of the available quantitative findings in the reviewed studies.

Study	Adoption type	Heat pump type	Effect type	Overarching factor	Factor	Sub-sample (if any)	Statistical details
Côté and Pons-Seres de Brauwer (2023)	Adoption intention	HP	Three most important drivers/barriers influencing heat pump installation for each sub-sample in %	Motivation to increase independence of energy supply	Decreased dependence on foreign energy sources	French German Swiss	44.1 60.7 49.8
Corbett et al. (2023)	Adoption intention	ASHP	Standardised beta coefficient (SE)[1]	Motivation to increase independence of energy supply	Functional characteristics[2]		0.365*** (0.025)
Côté and Pons-Seres de Brauwer (2023)	Adoption intention	HP	Three most important drivers/barriers influencing heat pump installation for each sub-sample in %	Motivation to increase independence of energy supply	Hedging against potential energy price increases	German Swiss	48.4 37.3
Balcombe, Rigby, and Azapagic (2014)	Adoption and adoption intention	Microgeneration	Hierarchical Bayes Estimation: mean (SE), only for the factors mentioned in-text	Motivation to increase independence of energy supply	Make the household more self sufficient	Adopters Considerers Rejectors	23.6 (1.04) 27.7 (0.93) 26.3 (0.82)
					Protect against future higher energy costs	Adopters Considerers Rejectors	24.1 (0.76) 23.1 (1.04) 26.05 (0.64)
Michelsen and Madlener (2016)	Adoption	Renewable heating system	Average marginal effect (SE)	Motivation to increase independence of energy supply	Reactions to external threats		0.285*** (0.010)
Corbett et al. (2023)	Adoption intention	GSHP	Standardised beta coefficient (SE)	Motivation to increase independence of energy supply	Societal-functional characteristics[3]		0.055* (0.037)

Note. [1]The notation (SE) is used to refer to Standard Error values. [2]Functional characteristics is a compound variable of the following items: be effective in heating your home, be effective in cooling your home, be easy to use, be easy to maintain, help to fight climate change, be an effective way to improve indoor air quality, be an effective way to improve outdoor air quality, help reduce our dependence on oil and natural gas. [3]Societal-functional characteristics is a compound variable of the following items: increase your quality of life, help to fight climate change, be an effective way to improve indoor air quality, be an effective way to improve outdoor air quality, help reduce our dependence on oil and natural gas.

(N = 11). Several studies found that the upfront investment costs were a major barrier to heat pump adoption (Balcombe, Rigby, and Azapagic 2014; Côté and Pons-Seres de Brauwer 2023; Michelsen and Madlener 2016; Räihä and Ruokamo 2021). Another financial barrier was the prospect of losing money when moving homes.

Côté and Pons-Seres de Brauwer (2023) explored how heat pump leasing can lower the financial barriers to heat pump adoption and showed that at least a third of homeowners favoured leasing over purchasing a heat pump. The leasing of heat pumps could possibly lower these financial barriers for households.

In terms of financial benefits, the reviewed papers found that households are driven to adopt a heat pump by expected savings on their energy bill. Related to bill savings are fuel prices, which were perceived as both a driver and barrier to adoption depending on the fuel considered and the actual prices of the fuel at the time of conducting the study. For example, Michelsen and Madlener (2016) showed that households perceived electricity prices as a barrier to adoption and Poblete-Cazenave and Rao (2023) found that the attractiveness of heat pumps was positively related to gas prices. Furthermore, Karytsas (2018) found that adoption is more likely when future fuel price expectations are not a concern, whereas Michelsen and Madlener (2016) showed that having expectations about future fuel prices reduces the likelihood of adoption.

Several of the reviewed studies showed that access to subsidies positively influenced households' intentions to adopt a heat pump (Balcombe, Rigby, and Azapagic 2014; Côté and Pons-Seres de Brauwer 2023; Owen, Mitchell, and Unsworth 2013; Poblete-Cazenave and Rao 2023), although Snape, Boait, and Rylatt (2015) found that this variable interacts with the hassle associated with adopting a heat pump. Adoption stagnated despite financial incentives past a certain threshold of hassle (Snape, Boait, and Rylatt 2015).

3.2.2.1.2. (Perceived) technological (dis)advantages. The *(perceived) technological (dis)advantages* were also often found important to the adoption of heat pumps (N = 9). Concerns about the uncertain performance of heat pumps were found as one of the main barriers to adoption in a sub-sample of the study by Côté and Pons-Seres de Brauwer (2023), and such concerns were lower for adopters than rejectors of heat pump adoption in Balcombe, Rigby, and Azapagic (2014).

Households who did not find the compatibility of a heat pump with their lifestyle important, or those with a technology-oriented lifestyle were found more likely to adopt (Corbett et al. 2023; Karytsas 2018). When asked about the perceived compatibility of a heat pump with existing habits, norms, understandability, and ease of use, this was actually found to decrease the likelihood of adoption (Michelsen and Madlener 2016).

Mixed findings were observed for the influence of comfort on adoption, as Gram-Hanssen, Christensen, and Petersen (2012) found that improving comfort was one of the main reasons for households to purchase a heat pump, whereas Michelsen and Madlener showed that a higher preference for comfort makes home-owners more likely to keep their fossil fuel-based heating system and Karytsas (2018) found that households are more likely to adopt a heat pump if they do not find thermal comfort important.

3.2.2.1.3. Expected hassle or convenience post-sale. Few studies found that the *expected hassle or convenience post-sale* influences household adoption of heat pumps (N = 4). Households were mostly concerned with the expected hassle of installing, operating, and maintaining a heat pump and these function as a barrier to adoption. The installation of a heat pump can be perceived as a hassle that can take several days to complete. In the case of a ground-source heat pump, the installation requires digging trenches in the garden, which can be disruptive.

In their study of households' willingness to lease a heat pump, Michelsen and Madlener (2016) found that all-inclusive leasing packages that cover installation, maintenance, and repair activities were favoured over basic packages that do not include any services. Such all-inclusive leasing packages may remove the expected hassles post-sale.

3.2.2.1.4. Perceived environmental sustainability. The results of the reviewed studies consistently showed that perceiving a heat pump as good for the environment increases the likelihood of

adoption. Notably, the *perceived environmental sustainability* (N = 6) appeared to be a differentiating factor between those who adopt or reject a heat pump (Balcombe, Rigby, and Azapagic 2014). Balcombe, Rigby, and Azapagic (2014) found that helping improve the environment is more important for adopters than for rejectors in their decision to install microgeneration.

Besides the perceived importance of helping the environment, it was the perceived efficacy of heat pumps in addressing environmental issues that was found to drive adoption decisions. For example, Meles, Ryan, and Mukherjee (2022) found that nearly everyone in the pro-heat pump class agreed that a heat pump would be good for the environment, whereas in the against-heat pump class, more than a third disagreed with this statement. Relatedly, Corbett et al. (2023) showed that the perception that heat pumps are effective in improving indoor and outdoor air quality increased households' willingness to adopt a heat pump.

3.2.2.1.5. Motivations to increase their independence of energy supply. The ability of heat pumps to *increase their independence of energy supply* was found to positively influence adoption (N = 4), in particular when the heat pump was perceived to make the household more self-sufficient and decrease dependence on utility companies (Balcombe, Rigby, and Azapagic 2014), oil and gas (Corbett et al. 2023), and foreign energy sources (Côté and Pons-Seres de Brauwer 2023). Another motivation to increase self-sufficiency was to protect oneself against future higher energy costs according to the findings of Côté and Pons-Seres de Brauwer (2023). Balcombe, Rigby, and Azapagic (2014) also found this to be an important motivation for households to adopt a microgeneration technology such as a heat pump.

3.2.2.2. Local environment

3.2.2.2.1. Home and location characteristics. Home and location characteristics were found to be a key factor influencing heat pump adoption intentions of households (N = 7). The perceived compatibility of the home infrastructure played a key role in adoption intentions. Most households intending to adopt agreed that their home infrastructure was compatible, while roughly half of those opposed to adoption disagreed (Meles, Ryan, and Mukherjee 2022). Similarly, Michelsen and Madlener (2016) found that constraints related to the property were an important factor for not adopting a heat pump.

Besides the compatibility of the home, home age and size were also influential factors. Households were more willing to adopt a heat pump when living in a larger home (Lagomarsino et al. 2023). Mixed results were found for the influence of the age of the home, as Corbett et al. (2023) found a positive influence on adoption, while Räihä and Ruokamo (2021) found a negative influence.

In terms of characteristics related to the location, the region and the climate in which the home is located were key factors influencing adoption. Since the reviewed studies were conducted in different countries, it was difficult to identify a pattern for the influence of living regions and climate on adoption. For example, Räihä and Ruokamo (2021) found that not living near a coastal region is a driver of heat pump adoption, Corbett et al. (2023) report that living in any region of Canada other than the Atlantic provinces was a barrier to adoption, and Poblete-Cazenave and Rao (2023) found that urban households are more likely to adopt.

Another relevant factor in terms of location is the availability of alternative heating systems. Living in an area where no gas network is available increased the likelihood of adopting a heat pump (Karytsas 2018) and conversely, living in a district heating network area reduced the likelihood of adopting a heat pump as a supplementary heating system (Räihä and Ruokamo 2021).

3.2.2.2.2. Knowledge and information. Another key factor that was found to influence households' adoption is *knowledge and information* (N = 7). Different types of knowledge were measured across studies, including knowledge of renewable heating systems, experience with low-carbon technologies, and knowledge of one's energy bill (Karytsas 2018; Lagomarsino et al. 2023; Michelsen and Madlener 2016). Information was found to both function as a driver and a barrier, depending on the source. For example, Räihä and Ruokamo (2021) showed that literature as an information

source positively influenced adoption, while information from friends negatively influenced adoption.

3.2.2.2.3. Social influence. Notably, *social influence* was found to influence heat pump adoption in some studies (N = 5). Different types of social influence were studied, such as knowing a heat pump owner and living with someone whose occupation or studies are related to the environment, technology, or engineering (Corbett et al. 2023; Karytsas 2018).

3.2.2.3. Individual variables

3.2.2.3.1. Socio-demographics. Some studies found that *socio-demographics* (N = 5) influence adoption. The reviewed studies consistently found that older individuals are less likely to adopt a heat pump (Corbett et al. 2023; Michelsen and Madlener 2016; Räihä and Ruokamo 2021). The influence of education level on adoption was also consistent across studies. Both Räihä and Ruokamo (2021) and Michelsen and Madlener (2016) found that individuals with a university education are less likely to adopt a heat pump, and Karytsas (2018) showed that graduates of practical education were more likely to do so. Mixed results were found for the influence of income as Karytsas (2018) and Corbett et al. (2023) found that a higher income increased heat pump adoption, while Räihä and Ruokamo (2021) report that income was negatively related to adoption.

3.2.2.3.2. Psychological variables. Few studies assessed the influence of *psychological* variables (N = 4). The psychological variables that were found important include values (Corbett et al. 2023), the perceived behavioural control to make heating system decisions (Räihä and Ruokamo 2021), households' environmental awareness (Karytsas 2018), awareness and support for environmental policies (Corbett et al. 2023), environmental identity (Gram-Hanssen, Christensen, and Petersen 2012), and the extent to which they feel a responsibility to contribute to the energy transition (Lagomarsino et al. 2023) were studied and found important in some papers.

3.3. Drivers and barriers to the efficient use of heat pumps

Here we discuss the factors that influence user behaviours. We begin by identifying various types of user behaviours and the factors that influence them, followed by an overview of the factors across studies. Next, we provide a detailed analysis of how user behaviours are affected by the identified factors. However, it should be noted that the findings on user behaviour are based on a small number of articles, making it more difficult to substantiate observed patterns across studies.

The section on user behaviour follows a reporting format different from section 3.2. on adoption behaviour for three reasons. First, the reviewed articles are discussed in more detail due to the limited studies available on heat pump user behaviour. Second, there are four types of user behaviour that are each associated with different factors. Instead of reviewing the influence of each individual factor, we explore the influence of multiple factors on all types of user behavior. Third, none of the reviewed studies provide quantitative findings on the influence of factors on user behaviours, so we focus mainly on qualitative insights.

3.3.1. Main findings

Four different user behaviours were studied in the literature: the temperature at which a heat pump is set, how it is operated, the heated area, and ventilation behaviour in the form of window and door opening (Figure 3). User behaviours were largely driven by *technological advantages and disadvantages*, such as increased thermal comfort (N = 6) and system complexity (N = 2) were identified. *Knowledge and information* (N = 3), in particular user knowledge and expert advice, was also found to influence user behaviours. Furthermore, *home and location characteristics* (N = 5) influenced the area that was heated with a heat pump, the operation strategy, and temperature settings. Interestingly, few studies identified the *perceived financial costs and benefits* (N = 2) having an influence on user behaviours.

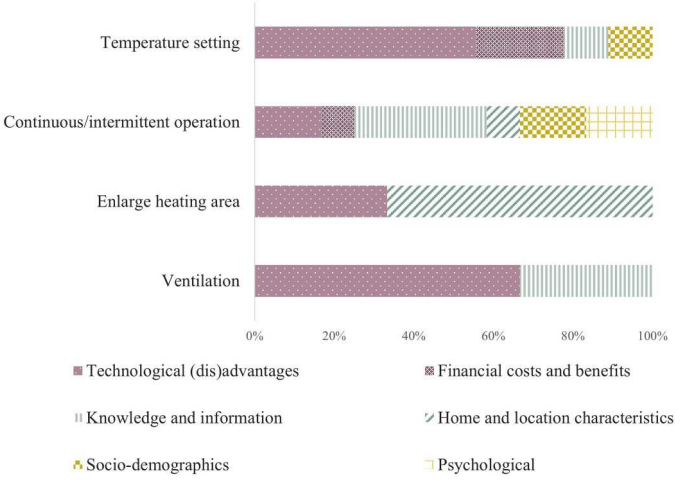

Figure 3. Factors influencing household user behaviours of heat pumps.

Note: The vertical axis of this chart displays the four user behaviours that were studied in the literature. The relative ratio of a factor to all variables is shown in percentages. Similar colours in the labels of the variables reflect that such factors belong to the same category of variables. For example, 50% of the variables that influence temperature setting are related to technological (dis)advantages, while the other 50% is comprised of financial costs and benefits, interpersonal variables, and socio-demographics.

Table 5. Drivers and barriers to the efficient use of heat pumps in the reviewed studies.

Study	Home/Loc	Know/Info	Fin	Tech	Psy	Soc-dem
Caird, Roy, and Potter (2012)	✓	✓		✓	✓	✓
Gram-Hanssen, Christensen, and Petersen (2012)	✓		✓	✓		
Oikonomou et al. (2022)			✓	✓		✓
Owen, Mitchell, and Unsworth (2013)		✓	✓		✓	✓
Winther and Wilhite (2015)	✓	✓		✓		

Note: Abbreviations: Home/Loc = Home and location characteristics; Know/Info = Knowledge and information; Fin = (Perceived or expected) financial costs and benefits; Tech = (Perceived) technological (dis)advantages; Psy = Psychological; Soc-dem = Socio-demographics.

Table 5 specifies which factors influenced the use of heat pumps for each of the reviewed studies. Not all overarching variables that affect adoption behaviour were also found to play a role in user behaviour. These variables are not included in the table, as they were not explicitly identified in the reviewed papers that studied user behaviours. There are no significant differences in how frequently each variable was studied across the reviewed papers. The next section provides a more detailed analysis of how these factors influence different types of user behaviour.

3.3.2. Temperature-setting and operation strategy

Households' operation strategy and temperature-setting behaviour are closely related, as temperature settings are a primary means by which households operate their heat pump. For example, frequent adjustments to the temperature often indicates a more intermittent operation strategy, especially when households adjust the indoor temperature by switching off the heat pump. In the reviewed literature, two types of households can be distinguished concerning temperature-setting behaviour and operation strategy. There is one group of households that did adjust the temperature of their home and one group that refrained from doing so entirely.

This first group of households adjusted the temperature their heat pump provides by using the thermostat to meet their heating needs (Oikonomou et al. 2022). *Technological advantages*, in particular thermal comfort, were key drivers for some households to establish higher temperatures in

their home than before the heat pump was installed (Gram-Hanssen, Christensen, and Petersen 2012).

Besides technological aspects, *financial costs and benefits* influenced the temperature-setting behaviour and operation strategy. When households perceived their electricity bill to be much higher than anticipated, some lowered the temperature or switched it off at night or when away (Oikonomou et al. 2022). Some households used to a boiler perceived it as wasteful and costly to keep the heat pump on at the same temperature, day and night. As a result of this perception, some heating habits may have persisted when their boiler was replaced by a heat pump (Caird, Roy, and Potter 2012; Owen, Mitchell, and Unsworth 2013). However, it is uncertain whether decreasing the temperature or switching the heat pump off will actually reduce electricity consumption because it needs to work harder again when raising the temperature (Oikonomou et al. 2022).

The second group of households refrained from interacting with their heat pump. A key driver of such behaviour was *knowledge and information*, in particular the advice of experts to keep the temperature constant during the heating season and to leave it on continuously unless away for an extended period (more than several days). This advice matched people's preference for even temperatures and constant heat, resulting in increased comfort (Winther and Wilhite 2015). Because of the slow warm-up of heat pumps, running the heat pump continuously at an even temperature prevents the home from being cold in the mornings and early afternoon (Caird, Roy, and Potter 2012). In addition to the expert advice and increased comfort, the system's complexity and uncertainties about the effect of changing the temperature and switching the heat pump on and off did not provide any incentive for households to experiment with the temperature settings of their heat pump (Caird, Roy, and Potter 2012; Winther and Wilhite 2015).

Differences in operation strategy were especially observed across private households and social housing tenants, with the latter achieving lower heat pump system efficiencies. Caird, Roy, and Potter (2012) found that social housing tenants tended to exhibit more intermittent heat pump operation and reported having less knowledge of heat pump systems and more difficulty understanding how best to operate it. However, not all social housing tenants have access to the heat pump controller, as highlighted by Oikonomou et al. (2022). Building characteristics such as insufficient insulation and radiator-based heating distribution systems further exacerbated the achieved system efficiency of heat pumps in social housing.

3.3.3. Heating area and door/window opening

A similar distinction can be made between households that keep doors within the house open versus those who keep them closed. The reviewed literature presents two contrasting narratives regarding best practices for opening and closing doors, both of which influence the area that is being heated. K*nowledge and information* were identified as a driver of either behaviour, as households were often following expert advice.

One narrative posits that heat pumps are most efficient when doors and windows remain closed. One study identified this as a widespread belief, finding that nearly two-thirds of respondents 'rarely or never leave windows and/or doors open with heating on' (Caird, Roy, and Potter 2012, 293). This practice mirrors traditional heating behaviours observed in households with boilers, where closing doors helps retain heat within individual rooms. The same study found that nearly all respondents heated not only the room that they occupied but their entire home; a behaviour driven by *technological advantages*, in particular thermal comfort.

The other narrative emphasises that heat pumps are designed to efficiently distribute hot air across larger spaces (Winther and Wilhite 2015). Unlike Caird, Roy, and Potter (2012), Winther and Wilhite (2015) found that households are more likely to keep doors within the house open after installing a heat pump. This new practice of keeping doors open was established based on the belief that heat pumps are most effective when heat can circulate freely, which was confirmed by experts installing the heat pump.

For some households undergoing renovations, the prospect of installing a heat pump was even an incentive to opt for more open spaces with minimal doors (Winther and Wilhite 2015). By removing doors, open layouts expand the heated area, particularly in homes where closed-off rooms would not have been heated separately. In this case, it were *home and location characteristics* that affected the heating area and opening or removing of doors.

3.4. Literature on adoption and use compared

Similar drivers and barriers emerged from the reviewed literature on adoption and user behaviour, but the frequency with which they were found differed for both behaviours. For example, *financial costs and benefits* were often found to influence adoption behaviour but this variable was scarcely identified as influencing user behaviour in the reviewed literature. For *knowledge and information*, the information source was more diverse for adoption than for user behaviours. Adoption was found to be influenced by family members, friends, and neighbours, while user behaviours were mostly influenced by experts exclusively. Another interesting difference was that the *perceived environmental sustainability* of a heat pump drives the adoption of heat pumps, but the literature on user behaviours did not capture the influence of any environmental factors.

Additionally, methodological differences were observed across articles studying adoption or use. Adoption behaviour was mostly studied with quantitative methods such as surveys or discrete choice experiments. These studies often statistically tested the influence of variables on adoption behaviour. Identifying drivers and barriers to adoption was straightforward because variables were explicitly referred to, for instance in a table. User behaviour, on the other hand, was mainly studied qualitatively with interviews and observational methods. Some reviewed articles complemented qualitative data about user behaviour with quantitative technical data about electricity consumption and heat pump performance. Given the qualitative nature of the data, the coding of drivers and barriers required more effort and interpretation for user behaviours compared to adoption behaviour.

4. Discussion

4.1. Interpretation of the findings

4.1.1. Adoption

This paper reviewed the available literature on drivers and barriers to the adoption and use of heat pumps by households. In the literature, we identified three clusters of variables related to heat pumps, the local environment, and the individual. Heat pump-specific variables were most often found to influence adoption. The importance of this type of variable for adoption behaviour emphasises the relevance of studying drivers and barriers to a specific technology rather than relying on the assumption that similar variables influence energy technologies in general. Without measuring the influence of the subsidies that are available specifically for heat pumps or the influence of the perceived thermal comfort that heat pumps offer, we would be missing out on key variables that explain why households decide to adopt or not adopt a heat pump.

Beyond financial factors, the cluster of heat pump-specific variables includes technological aspects such as the perceived ease of use or performance of heat pumps, as well as the perceived environmental sustainability. The findings of the reviewed studies emphasise that it is key to also recognise the role of non-financial factors in heat pump adoption.

Variables related to the local environment, such as characteristics of the home or social influence, were also often reported as a key factor influencing adoption. In other words, The decision to adopt a heat pump does not occur in a vacuum and is influenced by the environment in which the decision is made. Adoption rates are thus likely to differ across regions and countries because of differences in building age and type, current heating equipment, social norms, and

information sources. Steering the transition to heat pumps might, therefore, benefit from approaches tailored to the specific characteristics of the local environment. Some countries, like the Netherlands, are indeed implementing regional strategies for the energy transition (Poelwijk and Neerhof 2021).

Of all three clusters of variables, individual variables were least often found to influence adoption. However, this finding should be interpreted with caution, as relatively few studies measured the influence of individual variables, making it difficult to draw conclusions about their effect. One possible explanation is that adoption behaviour has mostly been studied from the perspective of social psychology, which involves the study of how an individual is influenced by the presence of others. If adoption behaviour were instead studied from a general psychology perspective, more emphasis would likely be placed on individual variables, such as environmental concern or personality traits.

Roughly a third of the factors studied in the reviewed articles did not influence adoption. This finding raises a critical question for variables that were influential in some cases and not in others: can these variables truly be considered influential in the decision to adopt a heat pump? A potential explanation for the mixed findings across studies is that the behaviour is highly dependent on contextual and temporal factors such as technological advancements or major events in society. Most of the reviewed studies were conducted in Europe, where households experienced an energy crisis following Russia's invasion of Ukraine. Rising gas prices boosted the sale of heat pumps (International Energy Agency 2022). The energy crisis might have influenced what drives households to adopt a heat pump and could, therefore, possibly partly explain the mixed findings across studies. The mixed findings could also be the result of measurement variability and sample characteristics. Different measurement scales might explain why some studies find an influence of a variable while others do not. This stresses the need for reusing measurement scales across studies to reveal which drivers and barriers influence behaviour in different contexts and samples.

4.1.2. Use

The reviewed literature on user behaviour finds distinct operation patterns. Some households operate their heat pump intermittently, switching it on and off and adjusting the temperature as needed, while others maintain a constant temperature and rarely switching it off. Similarly, some households keeps doors within the house closed while others leave them open, often based on expert advice. Even in households that keep doors closed, the heated area was often larger after installing a heat pump because of increased comfort-taking.

User behaviours were primarily driven by technological advantages such as thermal comfort, disadvantages like system complexity, user knowledge and information provided by experts, and characteristics of the home and its location. The literature highlights issues that require measures in both behavioural and technical dimensions to support the energy transition. For example, while comfort-taking requires a behavioural intervention, the system complexity and required knowledge to operate a heat pump call for improvements in the design of heat pumps.

Winther and Wilhite (2015) framed the extended heating periods and enlarged heating areas as temporal and spatial rebound effects, retrospectively. A rebound effect in energy entails a reduction in the expected energy savings from a new technology. This effect occurs when individuals increase their energy consumption after purchasing an energy technology that is more sustainable or cost-efficient than what was used previously (Greening, Greene, and Difiglio 2000). For example, heat pumps may lower heating costs, leading households to maintain higher indoor temperatures, thereby partially offsetting the energy savings. Rebound effects have been found for a variety of technologies, and the findings of this review suggest that they might also be apparent for heat pumps.

If the actual energy savings of a heat pump cannot meet the projected savings, this could potentially slow down the energy transition. Increased electricity demand due to rebound effects might also contribute to net congestion. The possibility of rebound effects occurring in the transition to heat pumps should be considered by policymakers when designing energy programmes. The risk of

disregarding the influence of user behaviour on the energy transition is that energy savings may be overestimated which can lead to inadequate planning for the energy transition.

4.2. Scientific relevance of the findings

The findings of this research align to some extent with previous studies on socio-psychological drivers and barriers to the adoption of renewable energy technologies. Compared to others on energy technology adoption, the key distinction of this review is its emphasis on factors specifically related to heat pumps that are crucial for adoption.

This review highlights that without considering drivers and barriers specifically related to heat pumps, we are missing out on many factors that account for the adoption of heat pumps. For example, several of the reviewed studies found that households are driven to adopt a heat pump because of its expected ease of use and compatibility with their lifestyle (Corbett et al. 2023; Karytsas 2018; Michelsen and Madlener 2016; Räihä and Ruokamo 2021), the expected increased thermal comfort (Gram-Hanssen, Christensen, and Petersen 2012; Karytsas 2018; Meles, Ryan, and Mukherjee 2022; Michelsen and Madlener 2016; Winther and Wilhite 2015), and the ability to increase the self-sufficiency of energy supply (Corbett et al. 2023; Côté and Pons-Seres de Brauwer 2023). Heat pump-specific barriers that households experience include for instance the investment costs (Balcombe, Rigby, and Azapagic 2014; Corbett et al. 2023; Côté and Pons-Seres de Brauwer 2023; Meles, Ryan, and Mukherjee 2022; Michelsen and Madlener 2016; Snape, Boait, and Rylatt 2015).

4.3. Societal relevance of the findings

Current policy incentives largely focus on lowering the financial barriers to heat pump adoption, yet this review highlights a crucial gap: the role of technological aspects as barriers to adoption. While financial considerations are important, the findings suggest that households are also hindered by negative expectations regarding comfort, performance, and other aspects of heat pump use. Notably, the reviewed studies indicate that heat pump owners experience high levels of comfort, suggesting a disconnect between the expectations of non-adopters and the actual experiences of users.

Winther and Wilhite (2015) further illustrate this gap, finding that heat pump suppliers mainly promote energy savings, while users highlight improved comfort as the most significant impact of the heat pump on their daily lives. This presents an opportunity for policymakers to refine their strategies by integrating non-financial benefits, such as improved thermal comfort, into public awareness campaigns. Likewise, businesses can expand their marketing efforts beyond cost and energy savings to emphasise the improved thermal comfort provided by heat pumps.

To bridge this gap, governmental or business campaigns could feature testimonials from heat pump users who have experienced greater thermal comfort. To further reshape expectations, the comfort provided by heat pumps could be demonstrated to a large audience by incentivizing the installation of heat pumps in communal spaces, office buildings, or holiday homes. Additionally, concerns about heat pump performance and ease of use should be addressed. This can be achieved by providing guarantees on heat pump performance and offering new heat pump owners technical support to optimise performance.

Our findings show that the environmental benefits of heat pumps and the desire to be more self-sufficient in heating supply are key drivers of adoption. This highlights the importance of aligning governmental campaigns with these motivations. Messages can be tailored to environmentally aware households by emphasising the carbon reductions heat pumps offer. For households motivated by increased self-sufficiency, campaigns could underscore the potential of heat pumps to

decrease dependence on foreign energy sources and utility companies and protect against future energy price fluctuations.

The findings of this review show that increased temperature settings, incorrect operation, enlarged heating areas, and ventilation strategies threaten to compromise heat pumps' performance and potential energy savings. Since households indicate their limited knowledge as a barrier to using their heat pumps efficiently, educational campaigns could be an effective approach to optimising user behaviour. However, generic advice might not benefit households since each home is unique, and there is no 'one-size-fits-all' method to apply (Oikonomou et al. 2022).

More useful than generic instructions would be to offer technical support services upon installation to promote efficient heat pump operation. Caird, Roy, and Potter (2012) suggest that social housing residents, in particular, would benefit from such support and highlight the role that social housing providers could play in facilitating this. Given that the reviewed studies indicate that the information provided by installers is perceived as trustworthy by households, guidance from installers could significantly improve the efficiency of user behaviour. For technical support services to achieve the intended effect, it is crucial that policy efforts are aimed towards enhanced training of installers. Improved training of installers can lead to better advice, ultimately enabling optimal heat pump efficiency.

Since it can be difficult to observe cost reductions from heat pump use, new heating practices are more often driven by comfort preferences rather than cost considerations (Winther and Wilhite 2015). This emphasises the importance of raising awareness of user behaviour through feedback information displayed in user-friendly interfaces. This can help heat pump owners to understand the effects of their behaviour on their electricity consumption and gradually shift towards more efficient heating practices. It could be particularly valuable for households to receive summary reports on how their specific behaviours, such as continuous or intermittent operation or door opening, influence heat pump efficiency (Oikonomou et al. 2022).

In addition to improving household knowledge, enhancing the design and user-friendliness of control systems is key. Reduced system complexity can encourage households to experiment with different settings and behaviours. Furthermore, smart controls can minimise the influence of household behaviour on heat pump performance. For individuals who prefer to retain control, it could be beneficial to highlight the energy savings achieved through the use of smart controls.

4.4. Knowledge gaps and future research

The lack of research on the influence of individual factors on adoption intentions reveals a significant knowledge gap. Existing reviews on the adoption of renewable energy technologies demonstrate the importance of studying (socio-)psychological factors (Bjørnstad 2012; Heiskanen and Matschoss 2017; Karytsas and Theodoropoulou 2014; Sopha and Klöckner 2011). However, our findings indicate that these factors have been overlooked in heat pump adoption research. This gap suggests that future research should explore the role of psychological factors in heat pump adoption. Greater knowledge of the influence of individual factors on adoption can help direct resources towards interventions that target key drivers and barriers. Without this understanding, interventions may fail to address underlying factors, potentially leading to resistance to adoption.

Research on the adoption and use of renewable energy technologies can help determine the most relevant factors to study in the context of heat pumps. Psychological variables that were found to influence renewable energy technology adoption include, among many others, environmental awareness (Niamir et al. 2020), consumer awareness of the technology (Luthra et al. 2015), and the degree to which an individual is novelty-seeking (Elmustapha, Hoppe, and Bressers 2018). For user behaviour, it seems useful to look into factors that influence heating behaviour with traditional heating equipment or energy consumption more generally. Values have, for instance, been shown to affect household gas consumption (Hess, Samuel, and Burger 2018) and routinised energy consumption behaviours (Namazkhan, Albers, and Steg 2020).

To further help identify relevant psychological factors for future research, theoretical frameworks from social psychology can offer guidance. Moreover, theoretical frameworks can help map the relationships between factors and behaviour. In the literature reviewed, the application of such frameworks was limited. Future research on heat pump adoption could benefit from applying additional frameworks like the Value-Belief-Norm theory (Stern 2000), the Technology Acceptance Model (Davis, 1993), or the Self-regulated behaviour change theory (Bamberg 2013), which have been widely applied in studies of household energy behaviour (see Chen, Xu, and Arpan 2017; Guo et al. 2018; Nachreiner et al. 2015; Niamir et al. 2020).

Another research gap is related to the use of heat pumps since this was barely studied from a behavioural perspective. The literature reviewed here highlights that heat pumps may not be used efficiently due to several barriers experienced by households. Future research can apply quantitative methods to study user behaviour, for example, by applying theoretical frameworks to test systematically which factors influence specific user behaviours. This can help to identify the influence of knowledge or the perceived ease of use on heat pump operation.

Additionally, longitudinal studies would be useful to explore the persistence of habits in heating practices before and after a heat pump is installed. Complementing this with short daily surveys on residents' experience of the thermal comfort in their home would provide valuable data on how and when comfort drives heat pump operation.

Informational feedback on energy consumption has been shown to encourage more efficient energy use among households (Faruqui, Sergici, and Sharif 2010; Fischer 2011). Since heat pumps often feature complex systems and experts advise against frequent user adjustments, future research should explore how informational feedback influences heat pump operation. Specifically, research should explore various types of feedback and interface designs to determine the most effective approach for guiding heat pump owners toward optimal heating practices.

Lastly, we have some recommendations related to the methodology of future research. Future behavioural research on heat pumps should aim to reuse established measurement scales to enhance comparability across studies and advance the development of this research field. Applying consistent scales across diverse contexts and samples will enable researchers to draw more robust conclusions about the factors influencing household behaviour. Providing access to supplementary data and materials to facilitate this is crucial, allowing researchers to adapt and refine these scales based on prior studies. More broadly, it is recommended that the influence of these factors on behaviour be tested against a statistical significance level to ensure their importance is easily comparable across studies.

The reviewed papers use various methods, including surveys, interviews, and discrete choice experiments, all of which are valuable for capturing the determinants of behaviour. Given that heat pump adoption and use are influenced by many interacting factors, future research should employ methods capable of capturing this complexity. The field of social simulation provides a range of tools that enable researchers to examine how multiple factors jointly shape behaviour. Additionally, these methods allow researchers to explore the dynamic interplay between individuals' behaviours and their environment and how these relationships change and evolve.

5. Conclusion

This study systematically reviewed the literature on drivers and barriers to heat pump adoption and use by households. We identified what factors were studied in social science literature and which ones influence adoption and user behaviours. Additionally, quantitative findings are presented for studies where such data was available. The body of research on this topic is small and in particular, the number of studies on user behaviour is low.

Beyond the well-known financial barriers, this review shows that expectations about comfort, performance uncertainties, and the broader impact of heat pumps on daily life also play a key role in adoption decisions across the reviewed studies. Given that heat pump owners report

increased comfort levels, governmental and business campaigns should emphasise this to boost adoption. Equally, it is key to remove uncertainties about the performance of heat pumps, for example, by having heat pump suppliers provide performance guarantees or technical support to optimise performance.

While behavioural research on household heat pump use remains limited, the reviewed studies reveal insights into the persistence of heating habits and unclarities regarding optimal behaviours. Some households continue to operate their heat pump like a traditional heating system, adjusting temperatures based on their heating needs and electricity costs, while others avoid interacting with their heat pump. Relatedly, some households keep doors within the house open to optimise air circulation, while others keep them closed to retain, mirroring traditional heating practices. This uncertainty about optimal user behaviour underlines the need for clearer guidance. Providing heat pump owners with technical support and user-friendly feedback on the impact of their behaviour on electricity consumption can help households optimise their behaviour, ensuring both cost and energy savings without compromising thermal comfort.

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Author contributions

Lynn de Jager: Conceptualisation, Methodology, Formal analysis, Writing – Original draft, Writing – Review & Editing, Project administration. **Liesbeth Claassen**: Conceptualisation, Formal analysis, Writing – Review & Editing, Supervision. **Geeske Scholz**: Conceptualisation, Writing – Review & Editing, Supervision. **Emile Chappin**: Conceptualisation, Writing – Review & Editing, Supervision. **Anne van Bruggen**: Writing – Review & Editing, Supervision.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-4 in order to improve the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Data availability statement

The datasets generated for this study can be found in Zenodo at 10.5281/zenodo.13885821.

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