

Article

Exploring Barriers to Residential Heat Pump Adoption: A UK Case Study of User Behaviour

Lin Gao , Philip Naylor , Abdelrahman Hegab and Pericles Pilidis *

Centre for Centre for Aeronautics, Propulsion & Power, Faculty of Engineering and Applied Science (FEAS), Cranfield University, Bedford MK43 0AL, UK; philip.naylor@cranfield.ac.uk (P.N.); a.hegab@cranfield.ac.uk (A.H.)

* Correspondence: lin.gao@energybridgeresearch.com (L.G.); p.pilidis@cranfield.ac.uk (P.P.)

Abstract

With heat pump adoption falling behind expectations, the UK faces a strategic challenge in meeting residential decarbonisation targets. This study investigates the barriers hindering adoption through an in-depth case analysis of a complete household heat pump adoption journey in a pre-Second World War family home in the UK. Combining an autoethnographic approach with quantitative analysis of 4.7 years of household data, it provides a rare, detailed examination of consumer experience in the UK. The analysis applies both rational and relational perspectives, showing that relational factors, such as trust and social networks, are particularly influential in early-stage markets. Key challenges are identified in retrofit system complexity, social engagement, installer capability and electricity pricing. Although the initial assessment found the heat pump was uneconomic, post-installation results showed an annual SPF of 3.22, a 59% reduction in energy demand and a 12% reduction in costs compared with a gas boiler. Behavioural adaptation contributed to demand reduction and lowered the effective electricity price by ~3 pence/kWh. However, a further 7 pence/kWh reduction is required to reach cost parity with a gas boiler, implying an electricity-to-gas price ratio of 2.3. The findings highlight important areas for policy intervention.

Keywords: heat pump; gas boiler; residential heating; buildings; adopter decision-making; seasonal performance factor; energy efficiency; decarbonisation; energy policy

1. Introduction

Following the legalisation of the net-zero commitment in 2019 [1], the United Kingdom (UK) published its Heat and Buildings Strategy (“the Strategy”) [2], outlining plans to decarbonise the buildings sector—the country’s second-largest source of greenhouse emissions. A central objective of the Strategy is to develop a market capable of delivering a minimum of 600 thousand hydronic heat pump installations annually by 2028. To support this target, a government subsidy of up to £7500 per household was allocated in England and Wales to incentivise consumer (this study uses users, consumers, adopters, and homeowners interchangeably.) adoption [3]. Milestones were set to demonstrate the government’s commitment to this transition. Example commitments and the measures proposed to achieve them are described in Table 1.



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Table 1. Example commitments for heat pump implementation in the UK Government’s 2021 Heat and Buildings Strategy [2] and their progress by 2025.

Commitment	Measure	2025 Status
Phase out the installation of new natural gas boilers from 2035		Deadline to be removed [4]
Significantly grow the supply chain to reach a minimum market capacity of 600 thousand installations per year by 2028 and 1.7 million per year by 2035	<ul style="list-style-type: none"> • Grow the heat pump market by providing incentives for early adopters through the Boiler Upgrade Scheme • Introduce a market-based regulation on manufacturers to accelerate market growth • Grow UK-manufactured technology and capability 	The highest annual installation was 51,886 in 2024 [5] ¹
Reduce costs of installing a heat pump by 25–50% by 2025 and achieve a price parity with gas boilers by 2030	<ul style="list-style-type: none"> • Work with the industry 	No evidence of significant cost reduction
Rebalance energy prices to ensure that heat pumps are no more expensive to buy and run than gas	<ul style="list-style-type: none"> • Rebalance energy levies to shift policy costs from electricity to gas in the 2020s • Expand carbon pricing and remove costs from electricity bills • Make decisions in 2022 	No progress until April 2026, when some green levies will be removed from both electricity and gas prices, marginally reducing the price difference by ~3 pence/kWh [6]
Ensure all new buildings in England are ready for net zero from 2025	<ul style="list-style-type: none"> • Introduce Future Home Standard 	Still under discussion [7]
Phase out the installation of fossil fuel heating systems in properties not connected to the gas grid	<ul style="list-style-type: none"> • Consult on ending the installation of high-carbon fossil fuels to heat homes that are not connected to the gas grid in England from 2026 and non-domestic buildings not connected to the gas grid from 2024 	No progress to the consultation launched in 2021 [8]

¹ Full year 2025 data has not been released as at the date of this paper.

Although heat pumps represent a mature technology that has been widely deployed in countries such as Finland and Sweden [9], their uptake in the UK significantly lags behind the target set out in the Strategy. By 2025, only approximately 197 thousand heat pumps had been installed across the UK [10], representing 0.7% of the nation’s housing stock [11] (Figure 1). The peak annual installation rate to date, recorded in 2025, is close to 52 thousand units, falling significantly below the target level of 600 thousand.

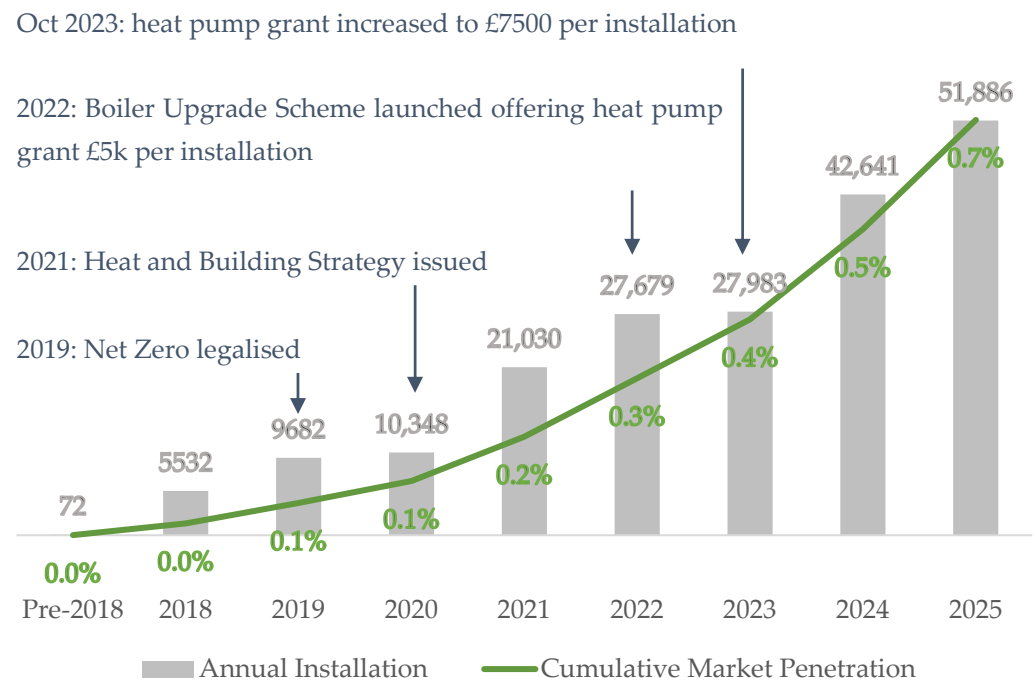


Figure 1. Residential heat pump installations in the UK. Data are sourced from UK Government reports [10,11]. By 2025, approximately 0.7% of the UK's housing stock had installed heat pumps, with annual installation peaking that year at 51,886 units.

Moreover, measures introduced in the Strategy to stimulate the heat pump market have faced delays or re-evaluation, as summarised in Table 1. Amid growing calls to address the climate emergency [12] and given the critical role of heat pumps in achieving net zero through energy demand reduction [13,14], it is essential to investigate the key barriers to residential heat pump adoption in the UK.

The fundamental barrier lies in the conditions of the UK's housing stock. The UK has the oldest housing stock in Europe and, most likely, in the world [15]. Around 35% of the housing stock (~10 million homes) were built before the Second World War. Around 48% (~13 million dwellings) have uninsulated walls. In the UK, the energy efficiency of a property is assessed through an Energy Performance Certificate (EPC). For a heat pump installation to operate effectively, a minimum rating of band C is recommended to be eligible for the grant. However, over 60% of properties fall below this threshold [15].

These housing conditions indicate that the majority of UK homes require substantial retrofit measures to provide suitable operating conditions for heat pumps [16]. These measures, such as improved insulation, upgraded radiators or underfloor heating, may require significant investment, time and effort from homeowners, creating both economic and behavioural barriers to heat pump adoption [16,17]. Energy policies are therefore designed to help homeowners overcome these barriers and promote adoption. However, limited progress suggests that the Strategy should be examined for any potential misalignment between the policy design and homeowner behaviour.

The Strategy made five commitments directly to consumers: (1) phasing out new gas boilers by 2035, based on the assumption of a 15-year product life cycle; (2) reducing installation costs by 25–50% by 2025 and achieving cost parity between heat pumps and gas boilers by 2030; (3) investing in product R&D to improve consumer experience in installation and operation; (4) providing grants to incentivise adoption; and (5) rebalancing electricity and gas prices to ensure heat pumps have cheaper operating costs than gas boilers. Focusing on either technological characteristics or economic incentives, this policy design reflects the rational perspective. This perspective assumes that individuals make

decisions rationally by seeking to maximise their preferences within given constraints and is drawn heavily from scientific and economic evidence [18].

In Diffusion of Innovations (DoI) theory [19], technology attributes, such as technical performance and economics, are the primary criteria evaluated by users in the adoption process, with the preferred option offering greater relative advantages over competing alternatives [20,21]. Barnes and Bhagavathy [22] compared the economic viability of heat pumps with gas boilers in the UK. The study concludes that higher heat pump efficiency ratios, measured by Seasonal Performance Factors (SPFs), lower upfront installation costs and smaller price differentials between electricity and gas, are critical in improving the cost competitiveness of heat pumps relative to gas boilers. Based on the 2024 electricity-to-gas price ratios, Qayyum et al. [23] estimated that heat pumps could incur nearly double the running costs of gas boilers in the UK. Mersch et al. [24] further demonstrated that the capability of heat pumps to shift electricity use from peak to off-peak hours significantly enhanced their cost effectiveness. In addition, higher gas prices and government subsidies for heat pumps were found to increase heat pump deployment.

These studies use quantitative modelling, and their findings support the commitments in the Strategy. The rational perspective literature, however, does not address consumer behaviour during adoption. This area remains underexplored partly due to limited user awareness of their own influence and researchers' restricted access to the relevant data [9]. Generalising nearly 50 years of heat pump penetration in Finland, Hyysalo and Juntunen [9] theorised the role of adopters in driving social–technological evolution. User roles include adoption, adaptation, championing and community building in the early market stage. These activities can scale to accelerate diffusion and enable mass adoption. However, the study focuses on broader market movements rather than individual consumer decision-making processes. Individual-level studies are particularly needed to evaluate the Strategy but remain limited due to the greater requirements for user engagement.

Behavioural research, grounded in psychology and sociology, often incorporates qualitative methodologies to examine how psychological or social factors influence decision-making in technology adoption. Consumer attitudes can significantly shape energy-related behaviour. Such attitudes include a belief in the cost-saving potential of heat pumps [17] and a willingness to adopt lower indoor temperatures [25] or to adapt to smaller living spaces [26]. Perceived control also affects adoption, as external constraints—such as a shortage of skilled installers—may reduce the consumer's sense of control over installation [16]. In addition, socio-demographic factors, such as education [27], environmental awareness [28], age [29], wealth [27,30], living locations [30] and culture [28], all influence adoption decisions. Social norms, shaped through collective user activities, further affect adoption patterns [9].

The aforementioned literature suggests a comprehensive examination of consumer decision-making should incorporate technical, economic, behavioural and social factors. Understanding how these factors interact can provide critical insights about adoption barriers. When combined with post-installation performance evidence, such insights can inform robust policy recommendations. However, studies covering the full end-to-end process remain rare. Addressing this gap requires in-depth user engagement and longitudinal data spanning multiple years. This is particularly challenging for UK-based research, as the heat pump market is at an early stage and retrofit cases are limited. Researchers lack sufficient data for performance analysis and therefore tend to use estimation models to generate theoretical values [22,23,31]. These values have yet to be validated against actual performance.

An emerging body of research is further developing behavioural and social lenses into a relational perspective within the context of building energy retrofits and advocating

the application of this perspective in energy policy design [32,33]. These studies argue that consumer decisions are shaped by their social context (class, gender, race, community, etc.), their connection with advisors and the quality of their interactions. Consumers have limited access to advisory support and are less likely to engage with green policy initiatives. Therefore, energy policy cannot adopt a one-size-fits-all approach. Rather, it should aim to foster stronger social networks and ensure greater transparency and accessibility of information. Middlemiss et al. [32] attributed the failure of the UK's "Green Deal", a retrofit energy policy, to its reliance on rational choice logic through payback models.

Brown et al. [33] proposed a six-stage approach to examine a consumer adoption journey. These stages include trigger point, advice, specification, contractor procurement, finance and installation. Based on 30 interviews, the authors identified evidence of the relational approach in consumer decision-making, including adoption triggered by household life-cycle events, reliance on community influence, and the prioritisation of non-economic factors. A lack of good quality information on energy efficiency measures was perceived as a key adoption barrier. The authors proposed incorporating the relational perspective into rational framework-based policy design to improve its effectiveness. Despite providing valuable insights, the relational approach requires further empirical examination to inform policy recommendations.

The proceeding discussion presents three research gaps: limited in-depth exploration of consumer adoption barriers, a lack of end-to-end analysis linking decision-making with performance evaluation, and insufficient comparative assessment of rational and relational perspectives. This study addresses these gaps by examining a complete homeowner adoption journey in a pre-Second World War UK family home. This housing type represents the most challenging yet common category, exhibiting more complex retrofit barriers than new dwellings. Research in this category remains underexplored. The study pursues the following objectives:

1. To explore how technical, economic, behavioural and social factors interact in homeowner heat pump adoption decisions, and to identify barriers encountered throughout the process;
2. To examine post-installation heat pump performance and compare it with gas boiler performance and with pre-installation design expectations;
3. To assess how household behavioural adaptation affects heat pump performance;
4. To assess the rational and relational perspectives in the adoption process.

A mixed-methods approach is employed, combining qualitative autoethnographic reflection on the adoption experience with quantitative technical and economic assessment. A single, in-depth case study provides a high-resolution examination of an underexplored and complex area.

To the authors' knowledge, this study presents the first comprehensive, empirically grounded account of heat pump adoption in the UK's most challenging housing category. It contributes to energy policy and advances both the relational energy literature and the DoI framework by documenting adopter behaviour in the early stages of technology diffusion supported by multi-year performance assessment.

The remainder of the paper is structured as follows: Section 2 presents the methods, Section 3 describes the case study and findings, Section 4 provides a discussion of the findings, and Section 5 outlines the conclusions and policy recommendations.

2. Methods and Data

2.1. Methods

This study adopts a mixed-methods case study design and focuses on a family house constructed before the Second World War with an initial EPC rating below band C, thereby

representing the original characteristics of this housing category. Such dwellings are associated with high heat loss and require substantial building upgrades to enable heat pumps to operate efficiently. Actual installation cases are few in the UK, and identifying research participants with multiple-year data covering both pre- and post-installation periods is a significant challenge. To address this gap, the authors participated in this research and employed an autoethnographic approach, systematically examining their own experiences as homeowners undergoing the adoption process.

2.1.1. Autoethnographic Approach

Autoethnography is a qualitative research method that uses the researcher's own experience as a primary source of data in order to understand broader social, behavioural and technological phenomena [34]. In this study, the researchers document and reflect upon the decision-making process leading to heat pump installation, including motivations, information sources, social contexts, uncertainties and perceived barriers.

The six-stage consumer journey model by Brown et al. [33] is used to structure the process, with an additional seventh stage introduced to capture the post-installation phase. The presence of the rational and relational perspectives is examined across the first six stages by mapping data from the autoethnographic records to Table 2. This table summarises the existing literature [9,20,22,33,35] and provides a guideline for distinguishing between the two perspectives.

Table 2. Comparison of the rational and relational perspectives across the consumer journey of heat pump installation. The six-stage model is proposed by Brown et al. [33].

Stage	Rational Perspective	Relational Perspective
Trigger point	Individuals are primarily motivated by cost savings. Accordingly, the Strategy and marketing efforts tend to emphasise the financial benefits of heat pump adoption, e.g., a £7500 grant per household.	Energy retrofit projects are often part of broader home renovation [33]. Therefore, incentives and marketing efforts should be aligned with key moments in a household's life cycle, such as moving home or undertaking major renovations.
Advice	Information asymmetry exists in a market, and accurate product information and objective assessment of available options are provided to consumers through professional channels such as manufacturers, approved installers, and trained advisors. For example, a home heat survey conducted by a qualified heating engineer is required before assessing eligibility for the grant from the Boiler Upgrade Scheme [36].	Information is frequently shared through informal social networks, among family, friends and community members. People often rely on past experiences or shared knowledge within their social circles, and adoption decisions may be shaped by these relational dynamics rather than formal technical advice.
Specification	Individuals seek the best economic return or the shortest payback period. Product life-cycle economic assessment is therefore central to evaluate available options. As a result, grant eligibility often prioritises more efficient homes, requiring a minimum EPC rating of band C. The heat loss survey calculates the heating demand for each room based on radiator sizes. Homeowners are advised to upgrade radiators if they are undersized and considered insufficient to meet the calculated demand.	Economic return is often assessed at a whole-house level rather than focusing solely on the heat pump installation. Decision-making is also influenced by lifestyle preferences and desired comfort levels, particularly among social groups that have secured financing.

Table 2. Cont.

Stage	Rational Perspective	Relational Perspective
Contractor procurement	Competitive market bidding is used to select contractors. Obtaining multiple quotations ensures the selection of contractors with the best technical capability and customer service to deliver a project effectively.	Trust is often more important to consumers. As a result, homeowners tend to select contractors based on word-of-mouth recommendations. Furthermore, many consumers lack the technical expertise to evaluate contractor's capabilities, making trust a key factor in decision-making.
Finance	All capital is treated equally by consumers, regardless of its source or intended use.	Consumers often earmark certain funds, such as gifts or inheritance, for specific purposes like home renovation and are generally averse to using debt to finance green initiatives [37].
Installation	Information asymmetry exists between installers and consumers. To ensure consumer protection and provide quality assurance, UK heat pump installers are required to obtain MSC certification and register with a NICEIC-approved contractor scheme to demonstrate compliance with industry standards and apply for a grant [38,39].	The interpersonal dynamics between contractors and homeowners matter. Past experience shapes consumers' future expectations [32]. Consequently, contractors are motivated to deliver high-quality work in order to build a positive reputation and secure future business [40].

The post-installation stage includes a qualitative description of the homeowners' behavioural adaptation to optimise the performance of the heat pump system. The effect of the adaptation is assessed by a quantitative analysis.

A narrative style is used to describe the adoption process and present the results. This approach aligns with the autoethnographic nature of the research, as it preserves the authenticity and depth of the lived experience. It enabled the researchers to critically reflect on their own biases, assumptions and learning processes while also highlighting key turning points and challenges, thereby enhancing transparency and reflexivity in the analysis. By presenting the installation journey as a coherent story, the study also helps readers to better understand the complexities involved in heat pump installation as well as providing insights that are valuable for policymakers.

2.1.2. Quantitative Analysis

The study incorporates quantitative analysis of heating system performance, energy consumption and costs to evaluate the technological and economic factors influencing heat pump adoption as well as providing performance verification. In the pre-installation period, the investment appraisal of a heat pump system uses Levelised Cost of Heat (LCOH) [31] to compare the economics of a heat pump system with a gas boiler system. LCOH is expressed in Equation (1):

$$LCOH_i = \frac{\text{Capital Cost}_i + \sum_t \frac{\text{Operating Cost}_t}{(1+r)^t}}{\sum_t \text{Heat Output}_t} \quad (1)$$

where i is the technology, r represents the annual discount rate and t denotes the year.

SPF is a key metric for assessing heat pump performance [22,31]. A theoretical SPF is used in the system design and investment appraisal to estimate electricity consumption for a given heat demand. Performance verification requires the calculation of an actual SPF, as expressed in Equation (2):

$$SPF_t = \frac{\text{Heat Output}_t}{\text{Electricity Consumption}_t} \quad (2)$$

Separate SPFs are reported for space heating and water heating to reflect differences in system efficiency under varying operating conditions.

In addition to SPFs, performance assessment includes comparing energy consumption and bills between the heat pump and the replaced gas boiler system using two approaches. First, the post-installation phase, i.e., the heat pump phase, is directly compared with the pre-installation phase, i.e., the gas boiler phase, using actual consumption and costs data. However, this approach is affected by weather or lifestyle differences over different periods. To address this limitation, a second approach is used in which the post-installation energy demand is assumed to be met by a gas boiler system equivalent to that used prior to installation. This approach assumes the continuation of the gas boiler system in the post-installation period and is used as a benchmark scenario to compare the actual heat pump performance. Under this scenario, the proportion of gas and electricity consumption is assumed to remain consistent with the pre-installation pattern, and the energy tariff is assumed to be unchanged, but the prices in the post-installation period are used. This method provides a more controlled basis for comparison by accounting for differences in the weather and energy usage across the two periods.

Quantitative analysis is also used to demonstrate the outcome of post-installation behavioural adaptation by illustrating the daily energy consumption patterns before and after installation. It is further used to compare the actual annual energy demand with both the design assumptions and the historical annual average to reflect the household adjustment to the lower living temperature. The design demand represents a theoretical comfortable living condition, while the historical average during the gas boiler phase reflects previous living habits. A lower actual heat demand than both the design and the historical demand suggests household adaptation to cooler living temperatures.

2.2. Data Sources

Data sources include (1) homeowners' autoethnographic records, such as correspondence with energy suppliers and installers, installer quotations, design information, event logs, decision-making records, and observation notes; (2) property information from the Land Registry; (3) EPC reports from the UK Government; (4) home heat loss survey reports from a surveyor; (5) hourly household energy consumption data and monthly gas and electricity bills from the energy supplier—the data selection criteria include one complete year of post-installation data and maximise the availability of pre-installation data, resulting in a study period from January 2021 to August 2024; (6) heat pump operation data downloaded from the user portal maintained by the heat pump manufacturer—the dataset includes ambient and indoor temperatures, heat output and the electricity consumption of the heat pump; (7) other household information provided by the homeowners; and (8) Octopus Energy's Flexible Tariff data from AgileBuddy [41]. Household-specific data (item 1–6) were provided by homeowners. Aggregated and anonymised versions of these data, together with the tariff data (item 8), are deposited for public access.

3. Case Study

3.1. Context

3.1.1. Consumer Demographics

The consumers are a household comprised of two adults and two school-age children. The homeowners hold university degrees in engineering and finance, have work experience in the energy and banking sector, and possess strong awareness of energy efficiency technologies and environmental issues. They are accustomed to quantitative and rational approaches to decision-making.

The home is a four-bedroom, two-storey detached house located in the middle of England, where the mean annual temperature is approximately 10 °C [42]. Winter temperatures occasionally fall to −7 °C, although −3 °C has been more common in recent years.

Since the shift to hybrid working in 2020, the home has been occupied for most of the day, resulting in consistently high daytime heating demand. In addition, daily evening meal preparation further contributes to energy use during national peak hours between 5 pm and 7 pm.

Gas consumption was mostly for space and water heating, with a negligible amount used for cooking using a gas hob. Annual gas consumption was around 87% of the total energy use from 2021 to 2023.

3.1.2. Building Characteristics

Constructed in the 1930s using a brick structure and thin cavity walls, the property falls within the 35% of UK housing stock built before 1945. The total heated floor area is approximately 160 m². An EPC assessment carried out prior to 2010 rated the dwelling as band E, recommending improvements to the building fabric and heating and hot water systems. The property underwent extensive phased upgrades over 10 years, ultimately achieving an EPC rating of band C in 2022.

The floors in the three living rooms on the ground level were suspended timber floors, i.e., wooden floorboards laid above timber joists, creating an underfloor void. The kitchen floor was primarily a thin concrete slab laid directly onto the soil, contributing to significant heat loss in colder months.

3.2. Installation Decision-Making and Barriers

The narrative of the homeowners' experience follows the approach described in Table 2.

3.2.1. Trigger Point

Beginning in 2022, the homeowners planned a further upgrade, including underfloor heating in the two coldest ground floor rooms—the kitchen and a living room—and refurbishment of the kitchen and family bathroom. The plan also involved relocating the loft-based water storage system to the ground floor, requiring pipework reconfiguration. Installers advised that the existing gas boiler, although modern and with working life remaining, would need replacement with a larger-capacity unit to support the underfloor heating system. Given the interconnected nature of the works across multiple rooms and the level of disruption expected, a holistic approach was deemed more efficient and cost-effective than a series of isolated interventions. Motivated by environmental concerns and a belief in long-term cost savings, the homeowners sought to electrify their home despite limited knowledge of heat pumps.

3.2.2. Advice

In the absence of peer recommendations, the homeowners initially relied on installers for guidance, as they had during previous gas boiler installations.

In September 2022, they reached out to their energy supplier, who had been advertising heat pump installations. However, the response they received was:

“...With the launch of the government's Boiler Upgrade Scheme, we're ramping up installations now. We want to tell you upfront that it'll likely be at least 6 months before you can get a heat pump from us. Right now, we're generally focusing on two to four bedroom, well-insulated homes under 200 m², built since the 1930s. Based on the information you gave us, your property is a bit different... If you're desperate to get a heat pump sooner, here are some trusted installers who can help.”

Nevertheless, communication with their energy supplier and two companies from its list of trusted installers helped the homeowners develop a better understanding of available products, grant eligibility and installation requirements. This improved familiarity prompted them to carry out further research into more installer profiles and technologies through online searches. Over the span of a year, the homeowners shortlisted ten installers offering five different brands, with only one manufactured in the UK. Excluded from the shortlist were companies that operated primarily as online platforms acting as intermediaries. While such business models were common in the gas boiler market, they were considered premature for emerging technologies like heat pumps in the UK. Sales representatives from these intermediary companies tended to rely heavily on repeating information available on government websites and were unable to engage in in-depth discussions. This limited engagement failed to build confidence among the homeowners.

Engagement with the installers revealed several issues that led the homeowners to reconsider their immediate plan to install a heat pump. The challenges encountered are summarised in Table 3. First, there was a shortage of installers with the capability to offer integrated retrofit services including a heat pump system and underfloor heating. Second, most installer businesses were small with a limited number of key technical personnel, who were typically overloaded. Third, there was a lack of practical experience to address technical questions that extended beyond the guidance published by government sources. This gap was more problematic in retrofit contexts, where each project has unique constraints and requirements. Fourth, pricing transparency was limited. All companies quoted the upper cost estimates in the government grant scheme. Notably, after the grant value increased by £2500 in October 2023, total quoted costs rose by a similar amount, effectively absorbing the additional funding rather than reducing costs for the consumer.

Table 3. Installer Engagement Report from September 2022 to February 2024.

Outcome	Reason for Not Proceeding	Large Business Count	Medium Business Count	Small or Micro Businesses Count	Total Count
Contract winner	N/A		1		1
Property visit followed by a quotation	Unable to support non-standard design options, such as a phased upgrade of a water tank and heat pump			1	1
	Unable to provide underfloor heating installation			2	2
Property visit without a quotation	Lack of a suitable product	1			1
	No communication			1	1
	Technical staff shortage			1	1
A quotation provided without a property visit	Unable to support non-standard underfloor heating products, such as pipe-to-pipe distance narrower than 150 mm			1	1
No response after initial information exchange via email	N/A			2	2
		1	1	8	10

Additionally, none of the prospective building contractors had experience with heat pump integration, leaving the homeowners responsible for coordinating the installation with broader building work.

Design concerns were partially alleviated through peer advice from a hybrid heat pump user in a similar property, who recommended 100 mm pipe spacing for underfloor heating, closer than the standard 150 mm, to enhance thermal output at the lower flow temperatures typical of heat pump systems.

3.2.3. Contractor Procurement

Following the peer-recommended pipe spacing advice, the homeowners expanded their supplier search to nationwide underfloor heating suppliers and eventually located a supplier who referred them to a commercial renewable energy installer with residential retrofit experience. This medium-sized company had the technical capacity to provide design solutions tailored to the homeowners' needs.

3.2.4. Specification

Two installation options were considered during the procurement stage: (1) a full upgrade including heat pump and hot water storage, or (2) a phased approach starting with hot water storage, followed by heat pump installation at a later stage. While installer quotations indicated that the second option would be cheaper while running on a gas boiler, it would require the engagement of two separate installers, i.e., one for the gas boiler upgrade and the other for future heat pump installation. This approach also involved the risk of additional heating system or house modifications being needed later to accommodate the heat pump. As a result, the homeowners chose the first option, as it offered the least interruption to the building and reduced the likelihood of future work.

Radiators were another point of consideration. While some quotations bundled the replacement of seven radiators into the heat pump system costs, citing government recommendation, others offered the option to separate radiator work from the heat pump installation. Although delaying radiator upgrades might appear less energy efficient from a technical perspective, the homeowners chose to align the replacements with future room redecoration plans. They also noted that the location and usage of certain rooms meant that radiator upgrades could be deferred, if necessary.

The economic return analysis, summarised in Table 4, was based on the heat pump system design calculation conducted by the installer following an on-site heat loss survey. The system was specified to maintain the indoor room temperature between 18 °C and 22 °C, with an external design temperature of −2.4 °C and a system flow temperature of 50 °C, indicative of the property's high heat loss. The projected annual heat demand was 27,312 kWh. Despite high efficiency, consuming only 31% of the energy used by a gas boiler (Table 4), the financial statistics were worse than for the latter.

The LCOH for the heat pump system over a 20-year period was 33% higher than that of a gas boiler (Table 4). This was mainly driven by the high electricity-to-gas ratio (3.84 in Table 4), significantly higher capital costs even after a £7500 subsidy, and higher annual service costs. The assessment included VAT savings from installing underfloor heating at 0% instead of the standard 20% when combined with a heat pump. Excluding these incentives, the LCOH difference was 54%. The financial analysis highlights a significant barrier to adoption. Cost parity with a gas boiler would require the electricity-to-gas price ratio to fall below 2.7, assuming all other variables remain constant.

Ultimately, the decision to proceed with the heat pump installation was not driven solely by the financial analysis of the standalone system but by a combination of factors, including environmental concerns, expectations of a future decline in the electricity-to-gas

price ratio, and the opportunity to integrate the installation with other planned building works. The homeowners considered that undertaking projects in stages would significantly increase building and other enabling system costs, which far exceeded the costs of the heat pump systems themselves. This decision highlights the complex interplay between financial considerations, practical implementation challenges and consumer behaviours in residential retrofit projects.

Table 4. Cost comparison of a heat pump and gas boiler during design in January 2024. All prices presented in 2024 real terms.

	Unit	Heat Pump	Gas Boiler	Heat Pump to Gas Boiler
Equipment life	Year	20	15	
Energy consumption				
Space-heating demand	kWh/year	22,517	22,517	
Space-heating SPF	%	366%	94%	
Energy consumption	kWh/year	6152	23,954	
Water-heating demand	kWh/year	4795	4795	
Water-heating SPF	%	175%	94%	
Energy consumption	kWh/year	2740	5101	
Immersion heater energy consumption	kWh/year	78	N/A	
Total heating demand	kWh/year	27,312	27,312	
Total energy consumption	kWh/year	8970	29,055	0.31
Heat pump combined SPF	%	304%		
Costs				
Energy unit cost	pence/kWh	28.0	7.3	3.84
Annual energy cost	GBP/kWh	2512	2121	1.18
Equipment and installation ¹	GBP	10,200	4000	2.55
Underfloor heating VAT savings ²	GBP	756	N/A	
Annual servicing	GBP/year	330	100	3.30
LCOH (20-year) ³	p/kWh	9.6	7.2	1.33

¹ Heat pump costs are net of the £7500 grant. ² Only eligible when installing together with a heat pump.

³ Assuming an annual discount rate of 3.5% and like-for-like replacement of gas boilers after 15 years.

Among the heat pump options recommended by the installer, the homeowners chose a well-established UK-based brand to support local businesses and ensure easier access to maintenance. The system mainly comprises a 12 kW heat pump paired with a 300-litre hot-water cylinder, a 45-litre buffer vessel and two expansion vessels.

3.2.5. Finance

The heat pump installation was financed through the family's house renovation fund. The homeowners did not consider debt financing a viable option, believing that the high prevailing interest rates would further weaken the economic case compared to gas boilers.

3.2.6. Installation

The installation required two weeks, with a further two weeks needed to resolve initial operational issues. The company's professionalism, quality of work and customer

services left the homeowners highly satisfied. The installer managed the entire grant application process, making it simple and stress-free for the homeowners. As a result, a strong sense of trust was established. The same company was later invited back to carry out annual servicing of the heat pumps, which was also completed to a high standard. The homeowners went on to recommend the installer within their local community.

The heat pump installation also generated notable community effects, as the technology was perceived as uncommon by many, including builders, neighbours and friends. The builder for the homeowners, initially sceptical, gained a deeper understanding through collaboration with the installer and subsequently began sharing this knowledge with their professional networks, marketing their experience in heat pump-enabling building work. Community interest increased, with multiple enquires and site visits from neighbours and friends. One visitor proceeded to install a heat pump, indicating signs of peer influence.

3.3. Post-Installation Behavioural Adaptation

The household initiated several behavioural adaptations to optimise heat pump performance. Firstly, they enrolled in a time-of-use electricity tariff, with three off-peak periods (4–7 am, 1–4 pm, 10 pm–12 am) offering rates 50% lower than the standard rate and a peak period (4–7 pm) at a 50% higher cost. Electricity-intensive activities such as washing, drying and oven-cooking were rescheduled to off-peak time.

Secondly, the flow temperature was reduced to 45 °C from the previous 70 °C for space heating and 60 °C for water heating. Once a week, during an off-peak period, the flow temperature was raised to 60 °C to allow the hot water cylinder to perform a legionella protection cycle. This setting enabled load shifting and reduced electricity usage and costs.

Thirdly, the space-heating schedule was also adjusted to maximise underfloor heating operation, which provided higher comfort at lower electricity demand than radiators. Heating for the radiator zones was reduced to 15 °C during the peak period, relying on heat from adjacent underfloor heating areas or residual heat from earlier periods. After nearly a year, the household reported high satisfaction with the underfloor heating performance although with reduced comfort in radiator-heated zones. Underfloor heating was regarded central to the improved thermal experience.

These behavioural adaptations are evidenced using the post-installation energy consumption and costs in Section 3.4.3.

3.4. Performance Assessment

3.4.1. Actual SPF

The actual SPFs are calculated using Equation (2) from the heat pump operation data. The data show that the annual average ambient temperature was 10 °C, with a minimum of −2.7 °C on 11 January 2025. The underfloor heating zone averaged 18 °C, and the hot water tank averaged 42 °C. In the radiator-heated areas, the target temperature was set at 18–20 °C during off-peak periods, 17 °C from 7 am to 1 pm and 15 °C during the remaining hours.

The overall SPF for the one-year assessment period was 3.22, outperforming the design target of 3.05 reported in Table 4, indicating higher heat earned and reduced electricity consumption. The annual SPF for space heating was 3.21, slightly below the design value of 3.66 (Table 4), while the SPF for water heating reached 3.26, significantly exceeding the design value of 1.75 (Table 4). It should be noted that the homeowners set the flow temperatures to 45 °C, lower than the design value of 50 °C. As heat pump performance is also influenced by outdoor temperatures, the study subsequently examines outdoor temperature conditions.

Figure 2 reveals a strong correlation between outdoor temperatures and indoor heat demand. Monthly SPF values were generally above 3, with a minimum performance ratio of 2.27 recorded on the coldest day, 11 January 2025 (-2.7°C). Notably, the low SPF (0.59) observed for space heating in July corresponded to heat waves in that month, during which indoor temperatures exceeded the target setpoint. Consequently, the heat pump was switched off on those days, reducing heat earned and lowering the efficiency ratio. These extreme weather conditions were considered anomalies relative to the design assumptions.

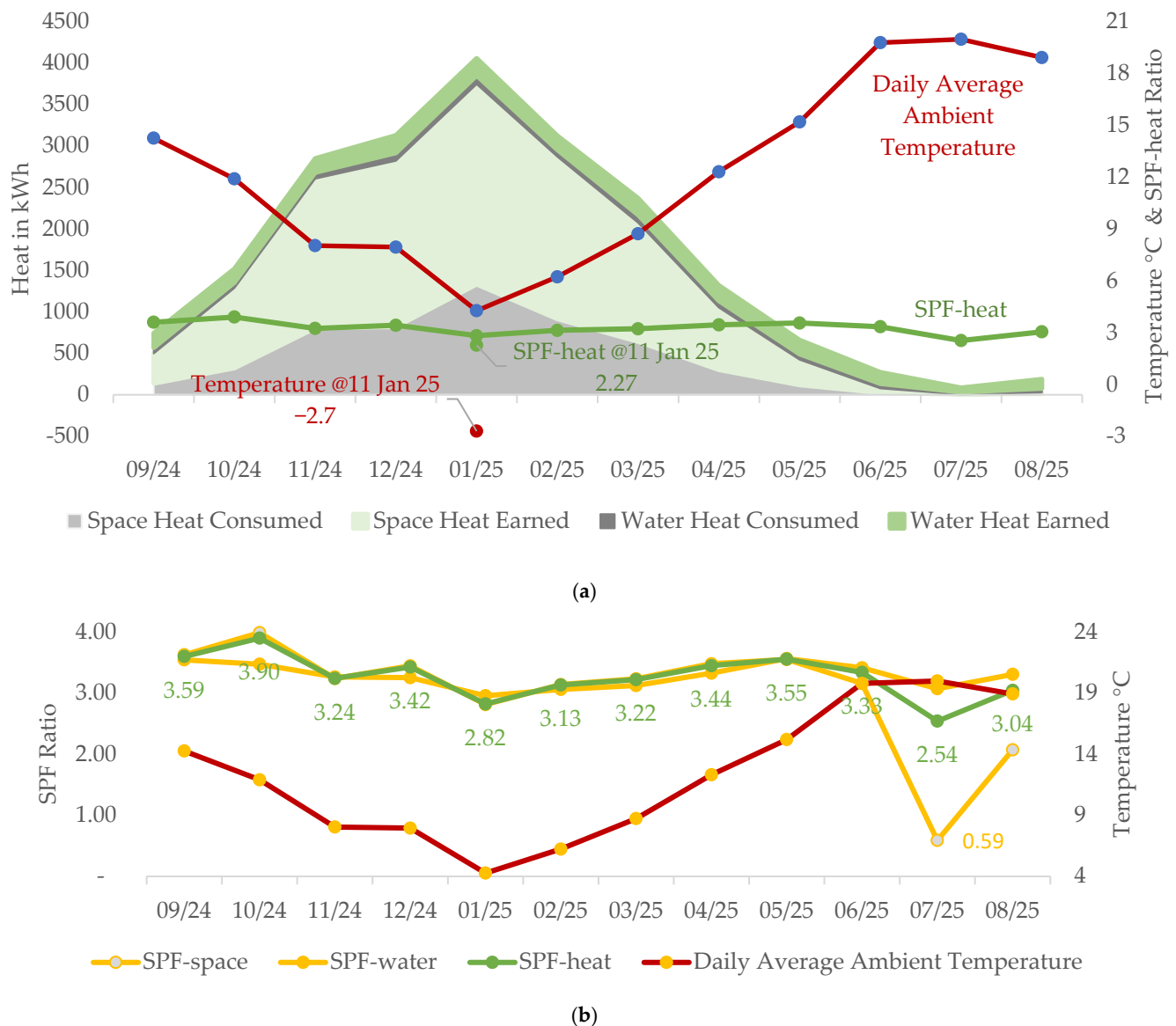


Figure 2. Heat pump performance with temperature change. (a) Heat demand, heat pump SPFs and ambient temperatures; (b) heat pump SPFs, space-heating SPFs and water-heating SPFs. Monthly space-heating SPFs are below the design target of 3.66 in all months except October, while monthly water-heating SPFs exceed the design target of 1.75 in all months. Combined SPFs exceed the design target of 3.05 in all months except January, July and August.

3.4.2. Heat Pump and Gas Boiler Comparison

The assessment compares two phases: the heat pump phase, including September 2024 to August 2025, and the gas boiler phase, covering January 2021 to July 2024. Figure 3a illustrates the clear reduction in total energy consumption in the heat pump phase compared to the gas boiler phase, reflected by the significantly smaller shaded area—the green area

in the heat pump phase relative to the grey area in the gas boiler phase. However, this reduction is less apparent in cost terms (Figure 3b). Compared with the benchmark scenario, which assumes the continued use of the gas boiler system to meet post-installation energy demand, the heat pump system achieves a 59% reduction in energy consumption, as indicated by the dotted area in Figure 3a. However, the corresponding annual cost saving is only around 12% (Figure 3b). Notably, in January 2025, the coldest month, the heat pump system was £22 more expensive to operate than the gas boiler.

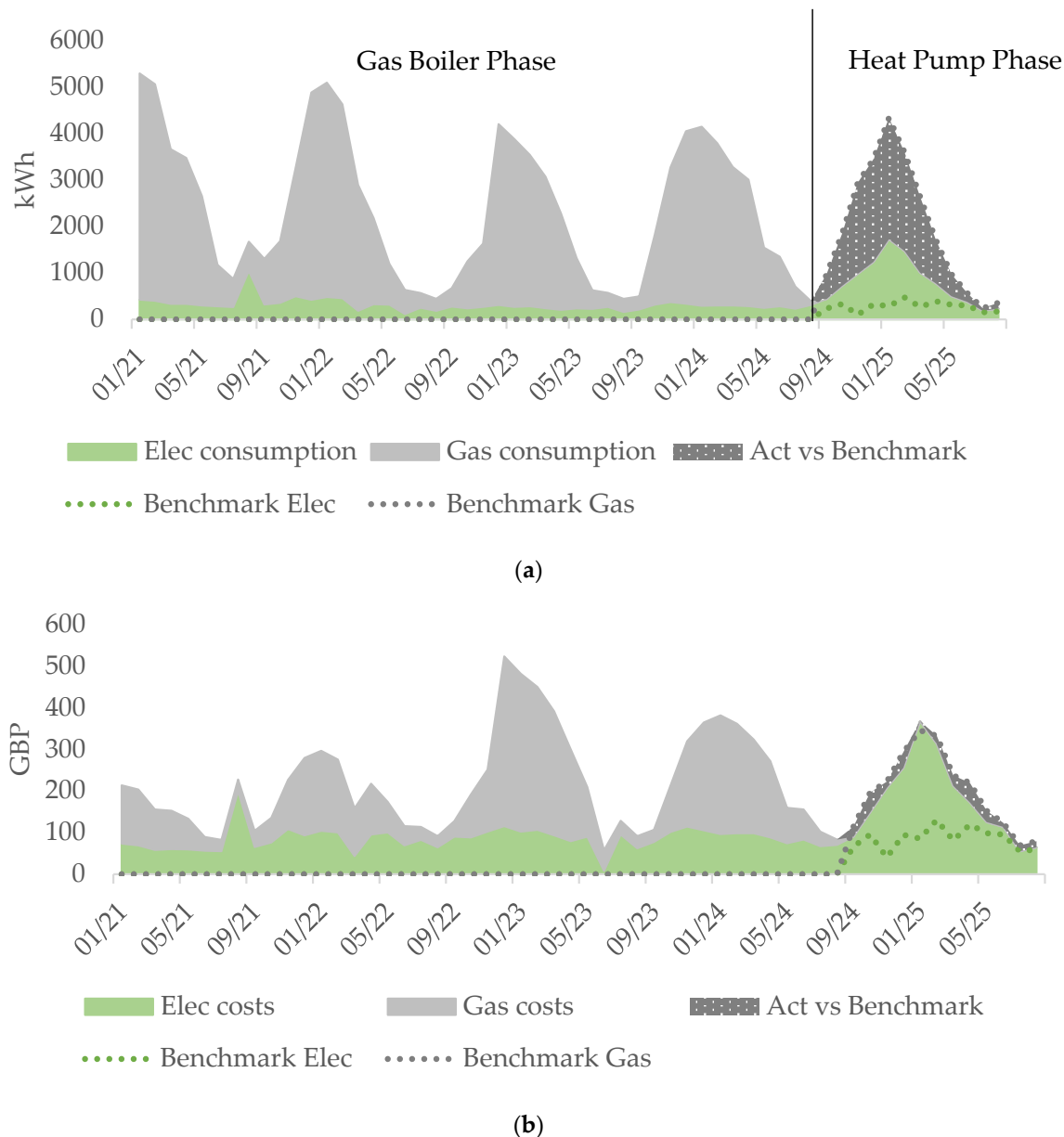


Figure 3. Gas and electricity consumption and costs from January 2021 to August 2025 in stacked charts. (a) Gas and electricity consumption; (b) gas and electricity costs. Elec = Electricity. Gas Boiler Phase: pre-installation period. Heat Pump Phase: post-installation period. Green shaded area: actual electricity consumption or costs. Grey shaded area: actual gas consumption or costs. Green dotted line: theoretical electricity consumption or costs in the benchmark scenario (continuation of the gas boiler system). Grey dotted line: theoretical gas consumption or costs in the benchmark scenario. Dotted area: the difference between the actual consumption/costs and the theoretical consumption/costs. Key finding: the heat pump achieves a 59% reduction in energy consumption relative to the gas boiler benchmark (a), but this translates to only a 12% cost saving (b), illustrating the impact of the high electricity-to-gas price ratio.

3.4.3. Behavioural Adaptation

Figure 4 illustrates the shift in household energy-use patterns following the heat pump installation and with a time-of-use electricity tariff. During the gas boiler phase, electricity usage peaked between 5 and 9 pm, aligned with evening cooking, washing and drying activities and corresponding to typical post-school and post-work routines (Figure 4a). Gas consumption peaked at around 6 am as the boiler initiated to preheat the house before waking hours (Figure 4b), then declined and remained steady until shutdown at 10 pm. Cost patterns mirrored these consumption trends.

In the heat pump phase, electricity consumption peaks coincided with off-peak tariff periods, reflecting the strategic scheduling of heating and appliance use. Notably, demand was lowest during the 4–6 pm peak-price window, as radiator heating was minimised and residual heat from the 1–3 pm period was utilised. A subsequent rise occurred at 7 pm when heating resumed. These patterns reflect deliberate behavioural adjustment to maximise tariff benefits and system efficiency, including prioritising underfloor heating and tolerating cooler temperatures in the radiator zones.

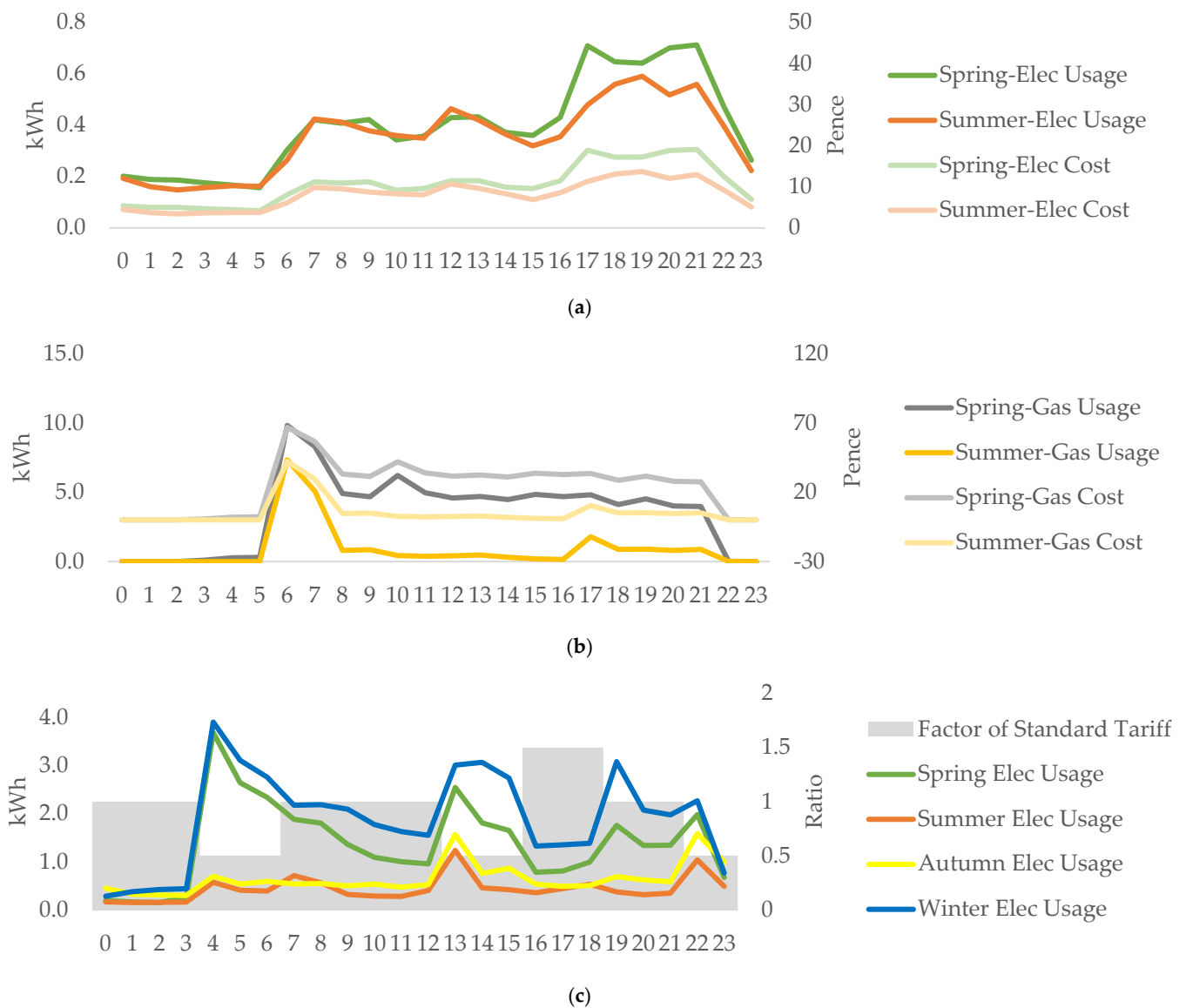


Figure 4. Cont.

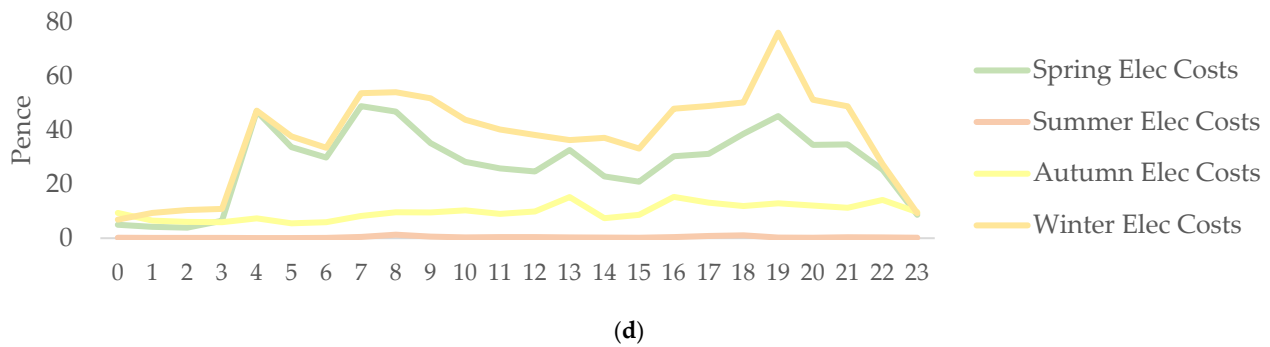


Figure 4. Seasonal hourly energy consumption and cost patterns before and after heat pump installation. (a) Seasonal hourly average electricity consumption and costs in the gas boiler phase; (b) seasonal hourly average gas consumption and costs in the gas boiler phase; (c) seasonal hourly average electricity consumption in the heat pump phase; (d) seasonal hourly average electricity costs in the heat pump phase. Elec = Electricity. The figures exhibit different energy usage patterns before and after heat pump installation. In the gas boiler phase, electricity usage peaked between 5 and 9 pm and gas peaked at around 6 am, while in the heat pump phase, electricity consumption peaks coincided with off-peak tariff periods. Key finding: post-installation energy use shifts decisively away from peak-price periods (4–7 pm), demonstrating effective load-shifting behaviour aligned with the time-of-use tariff.

The daily behavioural adaptation led to annual consumption savings, which is illustrated by comparing the heat pump's actual performance against its design output and the historical performance (Figure 5). The one-year post-installation energy demand, shown by the total height of the third column, is 7010 kWh lower, equivalent to a 26% reduction, than the design output (second column) and 4466 kWh lower, equivalent to a 18% reduction, than the average annual energy consumption over 2021–2023 (first column). The lower actual demand demonstrates the household behavioural adaptations to lower indoor living temperatures. The fourth column shows the heat earned, i.e., heat extracted from outdoors by the heat pump, resulting in actual electricity consumption of only 6309 kWh, equivalent to a 75% reduction compared to the historical annual average.

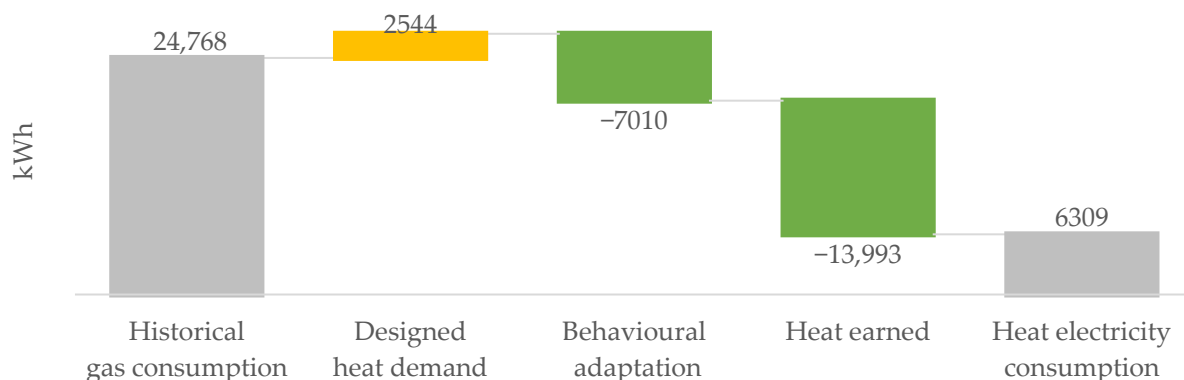


Figure 5. Annual heating consumption movement from the gas boiler phase to the heat pump phase. Historical gas consumption is the average annual energy consumption over 2021–2023. Designed heat demand is the household heating demand assumption used during system design. Heat earned is heat extracted from outdoors by the heat pump. Key finding: actual annual energy demand is 18% below the historical average and 26% below the design assumption, demonstrating measurable household adaptation to lower indoor temperatures.

3.4.4. Heat Pump Investment Case Re-Evaluation

A further analysis was conducted by revisiting the economic return assessment in Table 4, this time using actual energy consumption and tariff data as at August 2025 to

compare the LCOH of the heat pump with that of a gas boiler. The results, presented in Table 5, reveal that electricity-to-gas price ratios significantly affect the economic viability of the heat pump relative to a gas boiler.

Table 5. Post-installation cost comparison of the heat pump and a gas boiler and price parity assessment. Standard: the standard prices of Flexible Tariff. Effective: the actual electricity prices calculated by the usage-weighted sum of standard, off-peak and peak prices, assuming gas prices are the same as the standard prices. Parity: the calculated electricity unit price when the LCOHs of electricity and gas are the same, assuming the gas prices are the same as the standard prices and the same standing charges apply across gas and electricity.

		24 January	25 August		
		Standard	Standard	Effective	Parity
Total energy demand (kWh/year)		27,312	20,302	20,302	20,302
Unit price (pence)	Electricity	28.0	25.1	22.0	14.0
	Gas	7.3	6.2	6.2	6.2
	Electricity-to-gas	3.8	4.0	3.5	2.3
Standing charge (pence)	Electricity	48.7	54.8	45.3	29.4
	Gas	27.5	29.4	29.4	29.4
	Electricity-to-gas	1.8	1.9	1.5	1.0
LCOH (pence/kWh) ¹	Electricity	9.6	9.8	9	7
	Gas	7.2	7.0	7.0	7.0
	Electricity-to-gas	133%	140%	129%	100%

¹ Assuming an annual discount rate of 3.5%, with all prices presented in real terms to remove inflation impact.

Although annual energy demand in August 2025 was lower than that in January 2024, electricity-to-gas ratios under the household's original tariff, Octopus Energy's Flexible Tariff, increased over the same period. Figure 6 shows that the ratio for unit prices was already high at 3.8 in January 2024, rising further to 4.0 by August 2025. Similarly, the ratio for standing charges increased from 1.8 to 1.9. These changes would have raised the LCOH of the heat pump from 33% above that of a gas boiler to 40% (Table 5) if the household remained on the same tariff. Fortunately, the availability of a time-of-use tariff enabled a reduction in effective electricity prices by aligning energy use with different pricing periods.

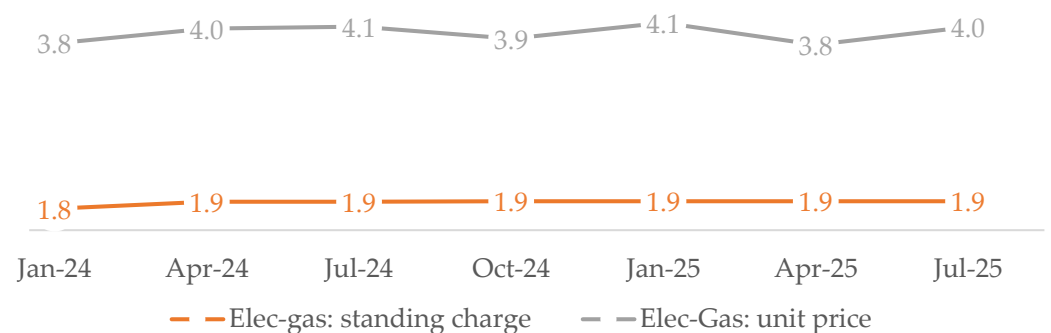


Figure 6. Electricity-gas price ratios: standing charge and unit price from January 2024 to August 2025. Elec-gas = electricity to gas price ratio. Based on Octopus Energy's Flexible Tariff from AgileBuddy [41]. Key finding: the electricity-to-gas unit price ratio rose from 3.8 to 4.0 between January 2024 and August 2025 under the standard tariff, widening the cost disadvantage of the heat pump and reinforcing the need for structural pricing reform.

The household's behavioural adaptation led to an effective electricity unit price of 22 p/kWh, indicating a unit electricity-to-gas ratio of 3.5 (Table 5). As a result, the LCOH differential was improved to 29% (Table 5). This demonstrates a consumer-driven mechanism for rapid electricity price reduction.

To achieve cost parity with a gas boiler, electricity prices would need to fall further to approximately 14 p/kWh, assuming all other variables remain constant (Table 5). This would imply an electricity-to-gas ratio of 2.3 (Table 5), a change likely requiring a structural reform in electricity pricing.

4. Discussion

4.1. Interaction of Rational and Relational Perspectives

The case study reflects the presence of both rational and relational perspectives, with the former providing the analytical foundation for assessment and the latter shaping the homeowners' decision-making. Although the homeowners have technical expertise and are accustomed to quantitative analysis, they still relied heavily on their past experience and recommendations from a friend and a familiar energy supplier when selecting installers and deciding key specifications. This reflects the limitations of consumer choice in an early-stage market.

The installation was not primarily driven by the heat pump itself but was instead part of a broader whole-house renovation project, with the heat pump considered as one of several potential solutions. With this in mind, the homeowners began searching for heat pump information online and consulting friends and building contractors. Financing for the heat pump was drawn from a dedicated home renovation fund and was therefore constrained by the overall project budget. A significantly higher price would have rendered this option unfeasible.

A lack of high-quality information from the installers nearly led the homeowners to revert back to a gas boiler. While economic return analysis provided useful insights, the unfavourable cost comparison with gas boilers would typically discourage adoption. However, the homeowners evaluated costs at the whole-house level and sought to avoid future disruption by completing the work in one phase. This whole-system perspective, rather than the standalone economic case for heat pumps, ultimately drove adoption. The selection of the installer and the overall installation process highlight the critical role of trust, reputation, and community influence in low-carbon technology uptake.

To conceptualise the interplay between the rational and relational elements in consumer heat pump adoption, this study presents a rational model (Figure 7), which serves as the analytical foundation, and a relational model (Figure 8), which captures the influence of social dynamics.

Figure 7 illustrates seven technology attributes that consumers evaluate for financial decisions along with their sources, including housing conditions, market actors (e.g., manufacturers and installers), and government policy. These are the factors consumers evaluate for financial decisions. Unlike some technologies that function effectively in isolation, the performance of heat pumps is substantially improved through the integration of complementary systems such as underfloor heating [16]. These enabling technologies are not optional additions but essential components that significantly affect system efficiency and user experience, thereby becoming integral to an adoption decision. The associated installation costs are part of the enabling costs. Also included in the enabling costs are expenditure for housing upgrades and system integration. These costs introduce additional complexity to the financial viability of heat pump adoption [16].

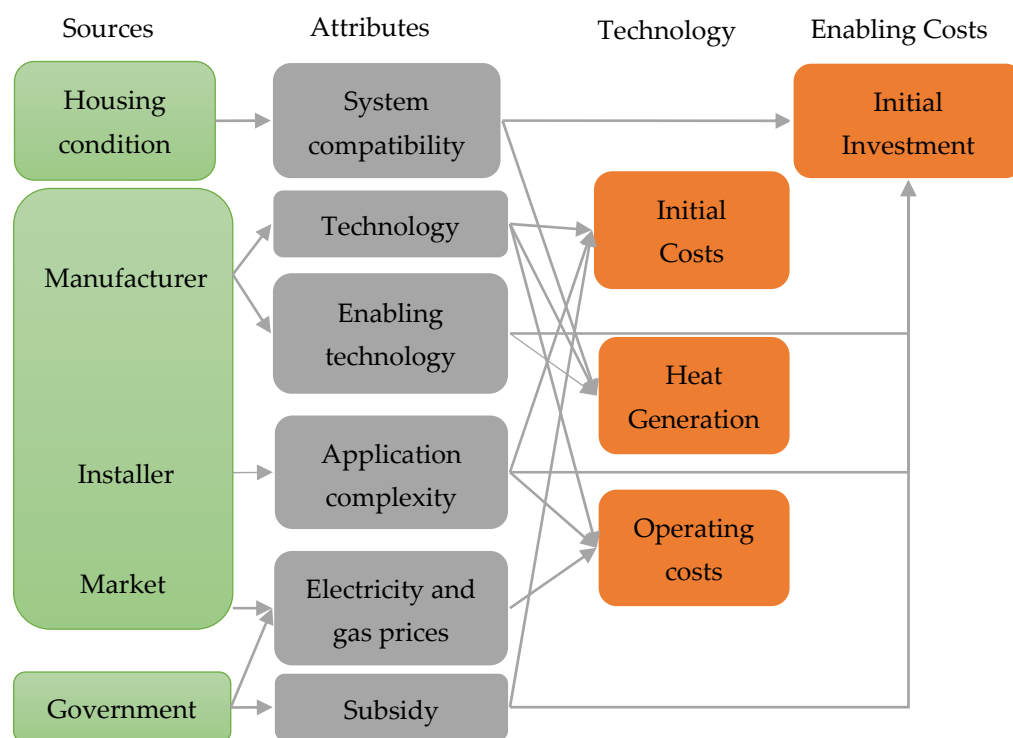


Figure 7. Rational view of consumer decision-making in heat pump adoption.

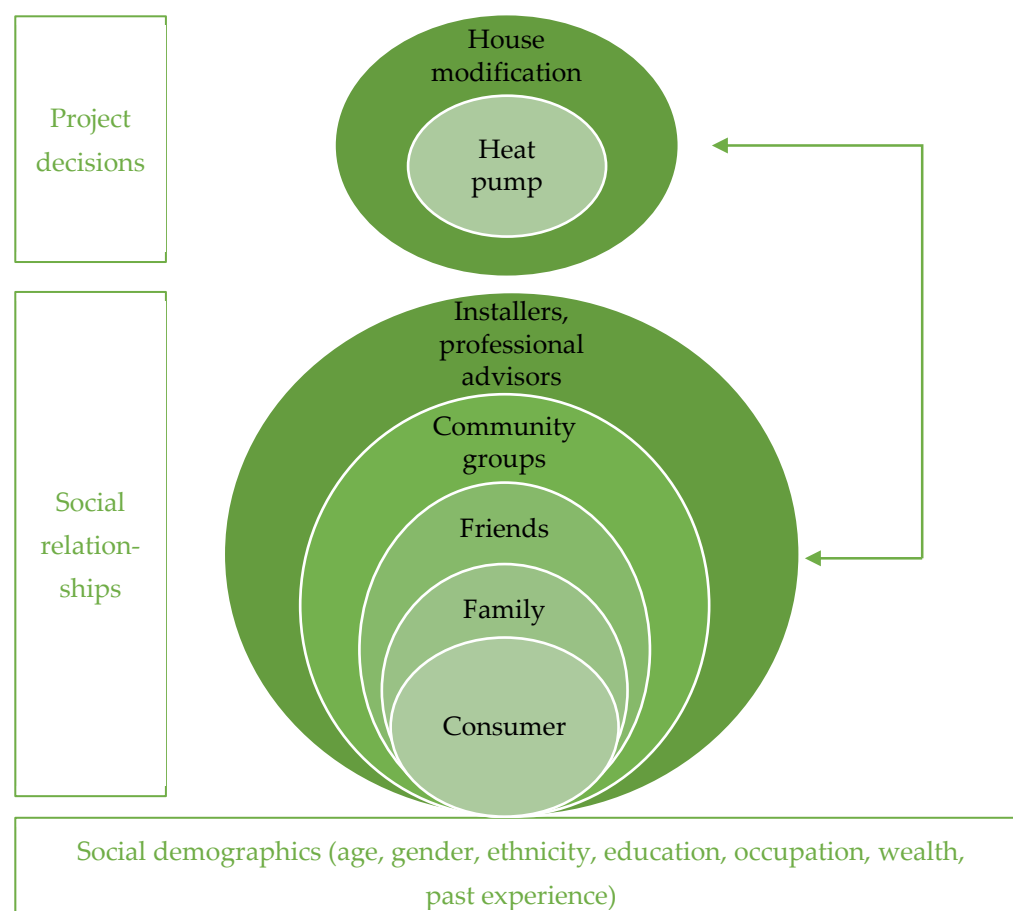


Figure 8. Relational view of consumer decision-making in heat pump adoption.

This rational model not only operationalises the technology attribute evaluation process at the core of DoI theory [19] but extends it to capture the enabling costs and complementary system requirements that are specific to the heat pump retrofit context and absent from the standard DoI framework [19].

Figure 8 illustrates that consumers frequently rely on social relationships to obtain first-hand information when undertaking home improvement projects. Heat pump adoption is typically considered in conjunction with broader home modification, and social networks are often used as a source of recommendations for both general renovation and heat pumps [9]. Post-installation behavioural adaptation, such as load shifting and temperature adjustments, can significantly enhance heat pump performance [24,25]. These processes of adoption and adaptation produce community-level effects, reinforcing social influence. The diffusion of heat pumps is therefore shown to depend heavily on community dynamics [33].

The relational model supplements DoI theory by explicitly incorporating social network dynamics, trust-building processes, and community-level diffusion effects, which Rogers [19] identifies as secondary factors but which, as this case demonstrates, function as primary drivers in an early-stage market with limited information infrastructure.

While both models acknowledge that heat pump adoption is rarely a standalone decision, the dominance of either model depends on the maturity of the market. In an early-stage market like the UK, where the quality and consistency of available information is limited and the number of qualified installers is low, the relational model tends to play a more prominent role. Conversely, in more mature markets with reliable information and established supply chains, the rational model gains prominence and may offer greater efficiency in guiding consumer decisions. This study, therefore, contributes to the relational energy literature [32,33].

4.2. Case Context

This property exhibits characteristics typical of the UK's houses constructed before 1945, which account for ~35% of all dwellings. These properties are typically characterised by brick cavity wall construction, suspended timber ground floors, and an initial EPC rating below band C [15]. Detached houses account for around one fifth of the housing stock [15]. As a detached four-bedroom property with a floor area of approximately 160 m², the dwelling is larger than the average pre-1945 home (~90–110 m²) but within the expected range for detached homes of similar age (average ~158 m²). The average home sizes are based on the English housing survey [43]. England's housing stock accounts for 84% of the UK's housing stock [15]. The survey's floor area definition includes internal partition walls and is therefore slightly higher than that of the case study property.

While representing a larger and old housing category, this property differs from the model case in that it underwent a phased retrofit programme over a decade, resulting in an above-average EPC rating of band C at the time of heat pump installation. These differences should be considered when interpreting the heat loss values and the post-installation SPF outcomes, as the starting thermal condition after retrofitting was considerably better than that of the majority of pre-1945 UK homes. The reported SPF of 3.22 should therefore be interpreted in the context of housing characteristics, outdoor temperatures and household behaviour. Together with Foster et al. [44] and Rosenow et al. [45], who examined small-to-average-sized UK dwellings and reported SPF values based on field trials involving short-duration performance monitoring, this study responds to calls for evidence across a broader spectrum of housing types.

While this engagement was conducted within a specific region of England, the challenges identified—including technical staff shortages, limited retrofit integration capability, and pricing opacity—are consistent with structural deficiencies reported at the national

level in UK heat pump market assessments [16], suggesting these are systemic rather than geographically localised constraints. Nevertheless, installer density and capability vary by region, and readers should interpret the case-specific findings in the context of the broader market evidence.

4.3. Empirical Findings

The in-depth analysis of consumer adoption and adaptation behaviour provides strong empirical support for Hyysalo and Juntunen [9], who argue that user activities can actively shape the diffusion of heat pumps in society. The peer advice on pipe spacing, collaboration between the builder and installer, and community interest following installation all demonstrate that users can influence uptake through their practices.

The observed behavioural outcomes align with and extend the findings in the energy demand flexibility literature, particularly in relation to consumer demand management. Mersch et al. [24] modelled the household and whole-system benefits of heat pump deployment in the UK, demonstrating the economic value of load shifting. The present case provides a rare empirical illustration of this mechanism in practice: shifting heating and appliance use outside the 4–7 pm peak window reduced the effective electricity price by approximately 3 pence/kWh, thereby contributing to a lower electricity-to-gas price ratio. The observed 18% reduction in energy demand relative to the pre-installation average further corroborates Levesque et al. [25], who demonstrated the potential for energy savings through lower indoor temperature preferences. Together, these results suggest that behavioural flexibility offers a practical, consumer-driven route to improving heat pump economics that complements, but does not substitute for, structural reform of electricity pricing.

The barrier from high electricity prices is demonstrated via the comparison of consumption and cost reduction ratios. Despite a 59% reduction in annual energy consumption compared to using a gas boiler system, the cost reduction was only around 12%. This large gap highlights the impact of high electricity prices. Although heat pumps are significantly more efficient than gas boilers, the gains from efficiency were offset by electricity's price premium over gas. In August 2025, the electricity-to-gas unit price ratio was 4.0 under the household's standard tariff (Table 4). Consequently, replacing a large volume of low-cost gas with a smaller but higher-cost volume of electricity reduced the overall financial benefits. Behavioural adaptation through time-of-use scheduling reduced the effective electricity-to-gas price ratio to 3.5, contributing to the ~12% cost saving. This illustrates that, under the current UK pricing conditions, even a well-performing heat pump in a well-retrofitted home generates only modest cost benefits despite transformative reductions in energy consumption and carbon emissions. This finding underscores that the key remaining barrier is not the heat pump's technical performance but the high cost of electricity relative to gas—an area where, as Table 1 demonstrates, policy progress has been limited over the study period. While the conclusion is consistent with previous studies [22,23], the real and long-duration household-level data provide compelling evidence.

The case study also highlights the divergence between design-stage performance projections and actual operational outcomes. Divergence analysis is particularly relevant for early-stage markets, where information is limited and system designers and consumers often rely on promotional materials during decision-making. Stanytsina et al. [31] demonstrate, using the Ukraine market, that promotional materials systematically underestimate real-world costs, partly due to discrepancies between assumed and actual system performance. Using the UK data, Rosenow et al. [45] show a substantial performance gap between well-optimised systems (mean SPF 3.86) and those from the broader trial (mean SPF 2.81), attributing this mainly to suboptimal flow temperature settings and control

strategies. In the present case, the actual combined SPF of 3.22 exceeded the design estimate of 3.05, a result attributable to deliberate behavioural adaptation—specifically the reduction in flow temperature to 45 °C and the prioritisation of underfloor heating—rather than to over-optimism in the original design. This suggests that where adopters are actively engaged in system optimisation, actual performance can meet or exceed design expectations in contrast to the pattern observed in systems where adopters are more passive.

4.4. Limitations

The single case study is the main limitation of this paper. While it provides high-resolution data into household behaviour that could be difficult to capture through large-scale studies, the findings are context-specific and should be interpreted with caution when expanded to other households with different socio-economic characteristics, energy-use behaviour or house categories. The findings should therefore be interpreted as exploratory insights that contribute to the growing body of research on the behavioural dimensions of low-carbon heating technologies.

Additionally, although the autoethnographic approach provides detailed insight into decision-making and behavioural adaptation, it introduces subjectivity. As the researchers are also the adopters, two forms of bias deserve explicit acknowledgement. First, retrospective bias: the decision-making narrative is reconstructed from records made during the process, and the framing of earlier decisions is inevitably influenced by knowledge of subsequent outcomes. This was partially mitigated by structuring the analysis using an established customer journey model [33]. Second, selection bias: the household is atypical, comprising highly energy-literate professionals with financial and temporal capacity to engage in extensive research. This may over-emphasise technical and installer-related barriers relative to the broader population. These limitations strengthen the case for future multi-household studies that can test the generalisability of the findings presented here.

Finally, the monitoring period for system performance is limited to the post-installation period available during the study. Heat pump performance can vary across multiple years due to changes in the weather and user behaviour. A longer monitoring period would provide a more comprehensive understanding of long-term operational performance and behavioural adaptation.

5. Conclusions

The UK is currently at a strategic implementation crossroad in delivering its strategy to decarbonise the residential sector. However, heat pump adoption remains significantly below the government target despite policy incentives offered to consumers. This highlights the need for investigation into the barriers hindering adoption. The existing literature identifies technical and economic factors, as well as user behavioural and social factors, as key influencers on technology diffusion in a society. The former are typically associated with the rational perspective, while the latter align with the relational perspective. Understanding consumer experience can provide valuable insights into the dominant factors influencing heat pump adoption in the UK.

However, empirical evidence, including both adoption decision-making and heat pump performance, remains rare and is absent for pre-Second World War homes, which typically have high heat loss and whose owners often face more barriers in installation than those of newer homes. Therefore, research focusing on this segment is of strategic importance for informing policy.

The study addresses the literature gaps and provides an in-depth case analysis of a UK household heat pump adoption journey in a pre-1945 family home. Combining an autoethnographic approach with quantitative analysis of 4.7 years of household data,

the findings reveal a mismatch between the current policy incentives, which focus on technological and economic drivers, and consumer perspectives, which emphasise broader house renovation considerations, installer capability and social network recommendations. The authors argue that the relational perspective tends to dominate in an early-stage heat pump market like the UK.

In addition, the findings provide evidence of household behavioural adaptation, including adjustment to lower living temperatures and the adoption of new daily routines aligned with time-of-use tariff periods. These adaptations contributed up to an 18% reduction in energy demand relative to the three-year pre-installation average and reduced the effective electricity price by approximately 3 pence/kWh, thereby lowering the electricity-to-gas price ratio from 4 to 3.5. Behavioural adaptation can therefore improve the heat pump economics.

The analysis demonstrates improved household energy performance relative to both the design expectations and the pre-installation gas boiler phase. The one-year SPF reached 3.22, exceeding the design value of 3.05. Energy consumption decreased by 75% compared to the three-year pre-installation average and by 59% when compared directly with a gas boiler system over the same period. Despite this substantial reduction in energy consumption, the corresponding annual cost saving was only around 12% in the latter comparison. This limited cost saving is due to the high prices compared to gas, which reduces the economic attractiveness of heat pumps and discourages their adoption. The analysis further suggests that achieving cost parity with gas boiler systems would require an additional reduction in electricity prices of approximately 7 pence/kWh, corresponding to a decrease in the electricity-to-gas price ratio to around 2.3.

The study suggests several policy implications in the following areas:

i. Consumer information and engagement strategies.

It indicates that energy policy may benefit from moving beyond purely techno-economic incentives to include measures that utilise social networks to improve public understanding of, and confidence in, heat pump technologies. Public awareness campaigns could be supported by empirical case studies demonstrating real-world performance. Such initiatives may also help address common concerns related to system integration and building retrofit. Greater emphasis on behavioural adaptation in reducing energy demand may further encourage consumer engagement and ownership.

ii. Pricing and regulatory reforms

The research suggests addressing the electricity–gas price disparity is important in supporting a market-driven transition from gas to electricity. Additionally, policy measures could incentivise replacing gas boilers with heat pumps during key housing life-cycle events, such as new builds, moving house or major renovation.

iii. Market development

The study suggests the need to expand the pool of high-quality installers and to promote greater collaboration between building contractors and heat pump specialists for more integrated retrofit solutions.

While the above recommendations are grounded in the experiences of a single household, they are consistent with and supported by the broader literature on heat pump adoption barriers [9,16,22,24,32,33] and should be understood as directions for further policy development requiring validation across a wider sample of households.

Future research can build on the analytical insights generated by this single case study and extend the analysis to larger and more diverse household samples.

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Data Availability Statement: The aggregated, anonymised household-related data and tariff data used in this study are reported in the paper and in the Cranfield University Research Data (CORD) repository (<https://doi.org/10.57996/cran.ceres-2846> (accessed on 1 September 2025)) for open access. The raw household data remain restricted to protect household privacy.

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Conflicts of Interest: The authors declare that they were both the researchers and participants in this study. While this dual role may introduce subjective perspectives, all data have been reported transparently, and analytical procedures were applied consistently to minimise bias. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

SPF	Seasonal Performance Factor
kWh	kilowatt hour
EPC	Energy Performance Certificate
DoI	Diffusion of Innovations
LCOH	Levelised Cost of Heat

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Gao, Lin; Naylor, Philip; Hegab, Abdelrahman; Pilidis, Pericles

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