Imperial College London

Accelerating the transition to heat pumps: measuring real-world performance and enabling peer-to-peer learning

An Energy Futures Lab Briefing Paper

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Table of Contents

List of acronyms and abbreviations

ASHP	Air source heat pump
BEIS	Department for Business, Energy and Industrial Strategy
BRE	Building Research Establishment
BRP	Building Renovation/Retrofit Passport
BUS	Boiler Upgrade Scheme is the new name for the Clean Heat Grant, which replaced the dRHI in March 2022.
CAD	Consumer Access Device – a household device that allows highly granular consumption data to be collected from the smart meter via the Home Area Network (HAN) and sent by broadband directly to the cloud and shared, thereby entirely bypassing the DCC.
CCC	Climate Change Committee
COP	Coefficient of Performance is the efficiency of a heat pump at any given time or over a defined period of time. COP = Heat output divided by electricity input. For example, a COP of 3 is 300% efficiency and so uses 1 kWh of electric energy to generate 3kWh of heat energy.
CPD	Continuing professional development
DAHPSE	Domestic Annual Heat Pump System Efficiency (BRE methodology for calculating heat pump performance)
DCC	Data Communications Company – provides a secure network for authorised users to access smart meter data
DCT	Digital Comparison tool, e.g. price comparison site
DoI	Diffusion of Innovation Theory
DHW	Domestic hot water
dRHI	Domestic Renewable Heat Incentive
EPC	Energy Performance Certificate. SAP EPC for newbuilds or Reduced Data SAP (RdSAP) EPC for existing buildings.
eWOM	Electronic word-of-mouth
GB	Great Britain (England, Scotland & Wales)
GCH	Gas central heating
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas Emissions
GSHP	Ground Source Heat Pump
HaaS	Heat-as-a-Service
HP	Heat pump
HPSPE	Heat Pump System Performance Estimate
HTC	Heat Transfer Coefficient (HTC), the widely recognised metric for building heat loss, which expresses the time averaged rate at which heat is lost per degree Kelvin temperature difference between the inside and outside of a building. Expressed in units of Watts/Kelvin (W/K). It includes the heat loss through the fabric and by ventilation and infiltration. A lower HTC demonstrates a lower average rate of heat loss and therefore better thermal performance.
HWC	Hot water cylinder
LPG	Liquid petroleum gas
MCS	Microgeneration Certification Scheme
MES	Metered energy savings

MHCLG	Ministry of Housing, Communities and Local Government
MIS 3005	The MCS Microgeneration Installation Standard for heat pump systems.
MMSP	Metering and Monitoring Service Package
Ofgem	The Office of Gas and Electricity Markets. The government regulator for the electricity and downstream natural gas markets in Great Britain.
PAS 2035	Publicly Available Specification (PAS) 2035:2019, is an over-arching British Standards Institute (BSI) document in the retrofit standards framework. It provides best practice guidance for what is called 'whole-house' retrofit of domestic buildings, which takes into account the requirements of the entire building to eliminate problems with defects, shallow retrofit, accountability, poor design and performance gap.
P2P	Peer-to-peer
RdSAP	Reduced Data Standard Assessment Procedure (RdSAP EPC) has been developed by government to generate the EPC for an *existing* dwelling based on a site survey of the property.
RECC	Renewable Energy Consumer Code that sets out consumer protection standards for the sale or lease of renewable energy generation systems to domestic consumers.
RHI	Renewable heat incentive or dRHI (domestic Renewable Heat Incentive). Closed to new applications on 31 March 2022.
RHPP	Renewable Heat Premium Payment
SAP	The Standard Assessment Procedure (SAP) - the methodology used to produce the certificate for new build homes. See also RdSAP.
SCOP	Seasonal Coefficient of Performance. The anticipated efficiency of a heat pump *product* based on factory-based tests and aggregated over a year using standard climate data. It does not number of factors that may affect the performance of a heat pump system as installed in a home.
SEPEMO	SEasonal PErformance factor and MOnitoring (SEPEMO) system boundaries.
SmartHTC	Actual measured HTC.
SMETER	Smart Meter Enabled Thermal Efficiency Ratings. A collective term for products or methods that use smart meter and other data to improve the accuracy of the SAP calculation and the resulting EPC rating. A BEIS-funded project of the same name supported their development.
SPF	Seasonal Performance Factor - the actual achieved Coefficient of Performance (CoP) of an installed heat pump *system* operating in a specific location and averaged over the full heating season. It is the measured annual efficiency but can also be estimated using factory-based tests with a range of adjustments. SPF (or annual efficiency) may use different system boundaries (e.g. including or excluding electrical energy needed for different heat pump system components) but often uses the SEPEMO "SPF H4" system boundary. Comparisons are difficult unless the system boundaries for these electricity inputs and heat outputs are specified and shared.
TPP	Third Party Providers
UPRN	Unique Property Reference Number

Executive Summary

Space heating and domestic hot water together account for 80% of a typical UK household's total energy use (Palmer & Cooper, 2013) and around 31% of its carbon emissions (Energy Systems Catapult, 2019c). Collectively, this contributes 17% to the UK's total national emissions (BEIS, 2021e). Decarbonising heat is recognised as perhaps the greatest challenge for the UK achieving its legally binding Net Zero target by 2050 (CCC, 2019a) and has been described as a 'wicked problem' (Morris *et al.*, 2022). It is widely accepted that a transition to the electrification of heat with heat pumps (HPs) will play a dominant role and the UK Government aims to reach 600,000 heat pump installations per year by 2028 (HM Government, 2020). The Climate Change Committee suggests 19 million heat pumps are needed to meet UK net zero goals (CCC, 2019b) but at present rates of adoption it would take over 700 years to reach this target (Rosenow *et al.*, 2020).

A transition to heat pumps will require a massive shift in behaviour among householders and landlords choosing to buy HPs instead of familiar, trusted and cheaper heating appliances, notably gas boilers. But for each new low-carbon heating system going into homes, more than 120 gas boilers are still being installed (Rosenow & Thomas, 2020). Consumer confidence and trust in HP technologies and installers is low. There is open debate and controversy in the mass media about if, and for which homes, heat pumps are a cost-effective choice. Householders and landlords considering installing a heat pump system are faced with complexity, uncertainty and a list of potential concerns, doubts and questions: What will it cost to run? Will it keep my home warm? How much disruption will it involve? Will it be noisy? Which installer should I use? Should I improve building fabric first? Should I replace radiators and plumbing? What would be the best combination of technologies, tariffs and controls? These complexities and uncertainties are major barriers to adoption that will not be addressed by a broad-brush approach of raising consumer 'awareness' of HPs.

A rapid transition to heat pumps (HPs) will require supporting faster and better-informed adoption and maximising positive outcomes in terms of reliable, affordable and flexible low-carbon heat and improved building efficiency. But there is a lack of data and evidence to support consumers' adoption decisions and to inform policy decisions. Policymakers risk 'flying blind' into the transition at a time when extraordinary volatility in gas and oil prices has thrown the topics of heating bills, energy security and the affordability of net zero policy goals under intense scrutiny. There is now a pressing need for well-informed policy that offers appropriate support and advice on heating options to households while also providing value-for-money to the public purse.

The UK and Scottish Governments' heat and buildings strategies (BEIS, 2021e; Scottish Government, 2021c) recognise the need for better information, advice and support to equip the public to make decisions best suited to their needs. However, detail on how to do this is scant and support for building efficiency and flexibility in electric heating loads are both unclear. This work also acknowledges an installer skills gap as a bottleneck for a heat pump transition.

This Energy Futures Lab briefing paper attempts to address some of these key outstanding questions, including:

- How can consumer confidence and informed adoption decisions be supported to accelerate the heat pump transition and provide warm and affordable homes?
- How can installer up-skilling and new heat pump industry offerings be supported?

- How can policymakers fill evidence gaps about heat pump performance, affordability and important related issues of building efficiency and flexibility?
- Where will the data and learning come from to support consumers, policymakers and installers?

The paper explores, in some detail, one approach that might contribute substantially to resolving many of these challenges for a HP transition. Previous work (Carmichael, 2019) has proposed leveraging early adopters by *measuring* heat pump installation outcomes and *sharing* these as case studies on a public database. Exploring the potential impacts and feasibility of this suggestion has required a review and discussion of several topics and innovation areas including: the role of advice and support in the heat pump adoption customer journey; methods of assessing HP and building performance; the potential stakeholder benefits of sharing data; and the technical, cultural, policy and regulatory contexts for implementing these recommendations.

Advice and support on the heat pump adoption customer journey

It is widely recognised that detailed information and tailored advice is vital for public awareness, consumer confidence and informed adoption choices of energy products and services. Households considering more complex and unfamiliar solutions need *more detailed* advice and guidance (Bonfield, 2016), such as precise information and paired comparisons that enable reflective customer choices (Nolting, Steiger, & Praktiknjo, 2018). However, policy has not yet grasped the nettle of how to provide this support for heat pump adoption decisions and the information that is available is not helping. Crucially, the actual real-world performance of buildings and heat pumps are not being measured.

Building energy performance certificates (EPCs) are the main source of guidance for householders about the energy efficiency of their home and future measures that would make sense for them. But EPC ratings and cost-based metrics discredit heat pumps and their recommended actions consistently deter households from adopting them. The EPC Reduced Data Standard Assessment Procedure (RdSAP) methodology relies on assumptions and modelled estimates of energy efficiency within the home that are not accurate or reliable enough. The Climate Change Committee (CCC), Environmental Audit Committee (EAC), Scottish Government and others have strongly criticised EPCs and advocated their reform with much greater measurement and use of real-world outcomes in order to better drive change to low-carbon heating, flexible demand and building efficiency.

The financial value case for installing a heat pump is highly sensitive to heat pump efficiency (Meek, 2021) but the flawed SAP methodology is used for HP sizing calculations and in-situ performance is estimated not measured. The Heat Pump System Performance Estimates (HPSPE) that customers receive from installers have been found to have little correlation with the actual in-situ performance and running costs of the heating system.

For buildings, signs of potential movement away from estimation to greater *measurement-based* assessment of performance are apparent in work on Smart Meter Enabled Thermal Efficiency Ratings for homes (SMETERs), Building Renovation Passports (BRPs), and Metered Energy Savings (MES). SMETER technologies have successfully demonstrated the feasibility of using data from smart meters and sensors to calculate building heat loss (as Heat Transfer Coefficients/HTCs) with greater accuracy than an expert RdSAP calculation (SMETER Project, 2021a) and more reliability than typical EPCs. Work on Building Renovation Passports and Metered Energy Savings (MES) suggests they could improve on EPCs by using measured energy performance and indicates potential for data to unlock finance for retrofit (GFI, 2020). This work has also highlighted some common issues for implementing measurement-based assessment, but it is unclear exactly how they would support consumers' decisions about retrofit measures.

For heat pumps, policy commitment to measuring real-world in-situ performance has retreated. Under the Domestic Renewable Heat Incentive (dRHI), HPs were metered for payment and or performance, demonstrating that the in-situ performance of HPs can be measured using electricity meters, temperature sensors and heat meters. But since the introduction of the Boiler Upgrade Scheme (BUS), in April 2022, there are no requirements to meter new HP installations.

Householders and landlords considering installing a heat pump system are still faced with complexity, uncertainty and a list of potential concerns, doubts and questions. The impact of heat pump online forums in Finland, and word-of-mouth (WoM) more broadly, strongly suggest that peer-to-peer (P2P) learning could play an important role in normalising, 'policing' and driving heat pump transitions (Martiskainen *et al*., 2021). This is missing in the UK: consumers are passive and policy has not focussed on fostering networks or supporting P2P learning for heat pumps. The Energy Saving Trust Scotland's Green Homes Network is a laudable exception but much greater detail and data ('*numbers*, not adjectives') are needed for case studies to effectively support the HP transition.

Figure A, below, depicts a simplified version of the customer journey for heat pump adoption and shows improvements to the journey from *measuring* performance and outcomes and *sharing* them widely. The existing customer journey for adoption is shown in light blue. Current barriers include: a skills gap and varied competence among installers; low consumer trust in HP technology and installers; the complexity of decision-making about viable or optimal combinations of technologies and services for a particular home (including building fabric improvements, storage, automation and flexibility services); low 'trialability' and 'observability' in HP adoption; and reliance on estimations of building and HP performance. A move to making measurement mainstream during installations would deliver some immediate benefits. Sharing data from the installation, along with other case studies, could deliver many more stakeholder benefits for accelerating the HP transition.

Measure real-world outcomes routinely

Shown in green in Fig. A, pre-installation *measurement-based assessment of building performance* would provide more accurate heat loss data for heating system design (including HP sizing) and forecasts of HP performance and costs given to the consumer ('1' in Fig. A). After installation, *ex-post assessment of HP system in-situ performance* (including the Seasonal Performance Factor/SPF) would allow a check on the installer forecasts given to customers ('2'). Anticipation of this check should provide reassurance to the prospective adopter that their system will perform as predicted. Data on outcomes could also support installer learning-by-doing, CPD and monitoring of competence by MCS and RECC.

This ex-post assessment could also provide a performance guarantee to unlock finance options ('3' in Fig. A), as noted by work on Building Renovation Passports (BRP) and Metered Energy Savings (MES) (GFI, 2020; Rathmell *et al*., 2021). Ongoing monitoring could, furthermore, support fault detection and optimisation of HP system performance ('4').

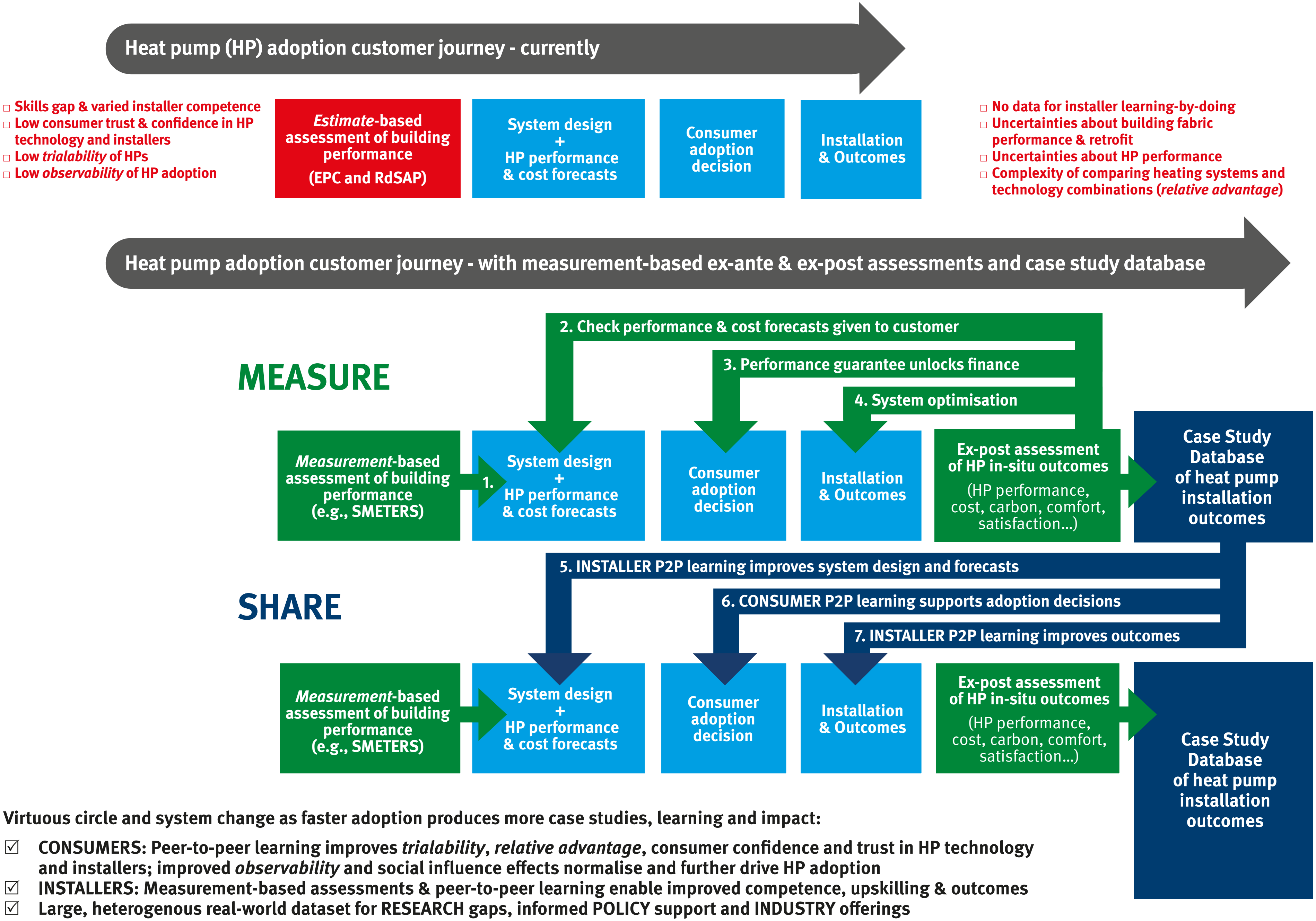


Figure A The customer journey for heat pump adoption: benefits of measurement-based assessment and case studies database

Share outcomes widely for peer-to-peer learning and system-wide benefits

Sharing HP installation outcomes through a database of case studies could deliver further important benefits (shown in dark blue in Fig. A). Such a database could kick-start and 'supercharge' P2P learning among both consumers and installers, allowing both communities to take much more active roles in accelerating the diffusion-of-innovation cycle for heat pumps, which is languishing in the 'Innovator' adoption phase.

For prospective buyers, heat pump systems are unfamiliar and uncommon, and 'try-before-you buy' is not possible. This unfamiliarity and low 'trialability' (Rogers, 2003) could be mitigated by enabling buyers to learn from the experiences of those who have already installed HPs before they commit to an expensive purchase. Case studies could present detailed and accurate assessments of building performance, heating system energy use, costs, carbon and consumer satisfaction before and after the installation of the heat pump (and any other retrofit measures). This would help to clarify the value case for getting a HP and provide much-needed support for adoption choices. A standardised format for case studies and a searchable and filterable database would allow easy comparisons of technologies and installers. Such peer-to-peer learning among consumers - through browsing, searching and comparing case studies - would reduce the time, effort, complexity and uncertainty in adopter decision-making and increase consumer confidence ('6' in Fig. A).

Information provision is sometimes criticised for being an individualistic approach to behaviour change that assumes consumers act as an overly-rational *Homo economicus*, or "Economic Man", but case studies would also leverage powerful social dimensions of adoption by fostering social networks and harnessing peer effects. The case study database would increase the 'observability' of HP adoption, which is associated with more rapid diffusion of innovation (Rogers, 2003): being able to see that more and more households are installing HPs could help to turn social influence effects (both *informational* and *normative* social influence) from an inhibitor to a driver that normalises and accelerates HP adoption through social contagion (Frank, 2020). Clarity about the HP value case and occupant experiences could also help householders, landlords and tenants reach agreement and avoid conflict where adoption decisions and impacts are shared.

For installers, case studies would provide a rich resource to support upskilling via peer-to-peer learning, thereby improving heating system design decisions, HPSPE performance forecasts and, potentially, best practice guidelines ('5' in Fig. A) - ultimately delivering improved outcomes for the consumer ('7'). The database would also provide transparency in outcomes that would incentivise and reward installer excellence and weed out poor installers - thereby further helping to close the skills gap and improve the HP industry reputation. Supporting transparency and excellence would, moreover, provide more proactive and effective consumer protection than current approaches that are based on compliance with minimum standards and redress after-the-fact.

A holistic approach: stakeholder coordination and systemic change

Beyond the consumer adoption journey and installer upskilling, measuring and sharing HP installation outcomes could deliver wider stakeholder benefits (see Fig. B). A large and diverse dataset of case studies, that better reflects real-world contexts and outcomes, would be valuable to researchers, policymakers and industry to fill evidence gaps and better understand how HP systems (including high-temperature HPs and hybrid HPs) perform (on consumption, cost, carbon, flexibility and customer satisfaction) across a range of buildings and occupants. This could help to inform industry practices, technology development, market offerings, business models and help policymakers design and monitor support for fast and fair uptake of technologies, services and building fabric improvement.

This broad range of stakeholder benefits would provide the *holistic approach and coordination between stakeholders* that have been identified as particularly important for facilitating an effective large-scale HP rollout (BEIS, 2021e). While data and learnings from HP field trials and demonstration projects have value, their datasets are constrained and removed from real-world market activities: they are unlikely to impact transparency, accountability or learning in the day-to-day practices of installers or give peace-of-mind to individual householders about their choice of installer, the quality of their installation or the performance of their HP.

Impacts from measuring and sharing installation outcomes could also support self-reinforcing positive feedback effects and wider system change for a HP transition. A virtuous circle would be expected as the database drives stronger demand and installer competence, thereby increasing adoption and growing the number of case studies in the database; this in turn produces a burgeoning impact through social influence and the value of the data for industry and policy support, further accelerating demand, supply and adoption (see Fig. B).

Data sharing and consent

There are many ongoing Smart Data and open data initiatives which aim to facilitate data sharing. However, activity to date has tended to focus on organisational and commercial users while consumer-focussed use cases have centred on supporting consumer choice of services such as energy tariffs. Consumers also need support for making decisions on adopting low-carbon *technologies* such as heat pumps.

Households sharing their data in a public case study database presents greater data privacy issues than households sharing their smart meter data with selected third parties (such as price comparison services) or organisations accessing anonymised or aggregated smart meter data for public interest purposes. Informed *opt-in* consent would be required for households to share this wider set of data with a wider set of users in a format which is at best pseudonymised. But the public's strong support and sense of citizenship towards a clean energy transformation, the opportunity to participate more actively in the energy transition, and consumers' willingness to share their experiences, could outweigh privacy concerns for many, as evidenced by participation in the Green Homes Network, online forums and online product reviews more generally.

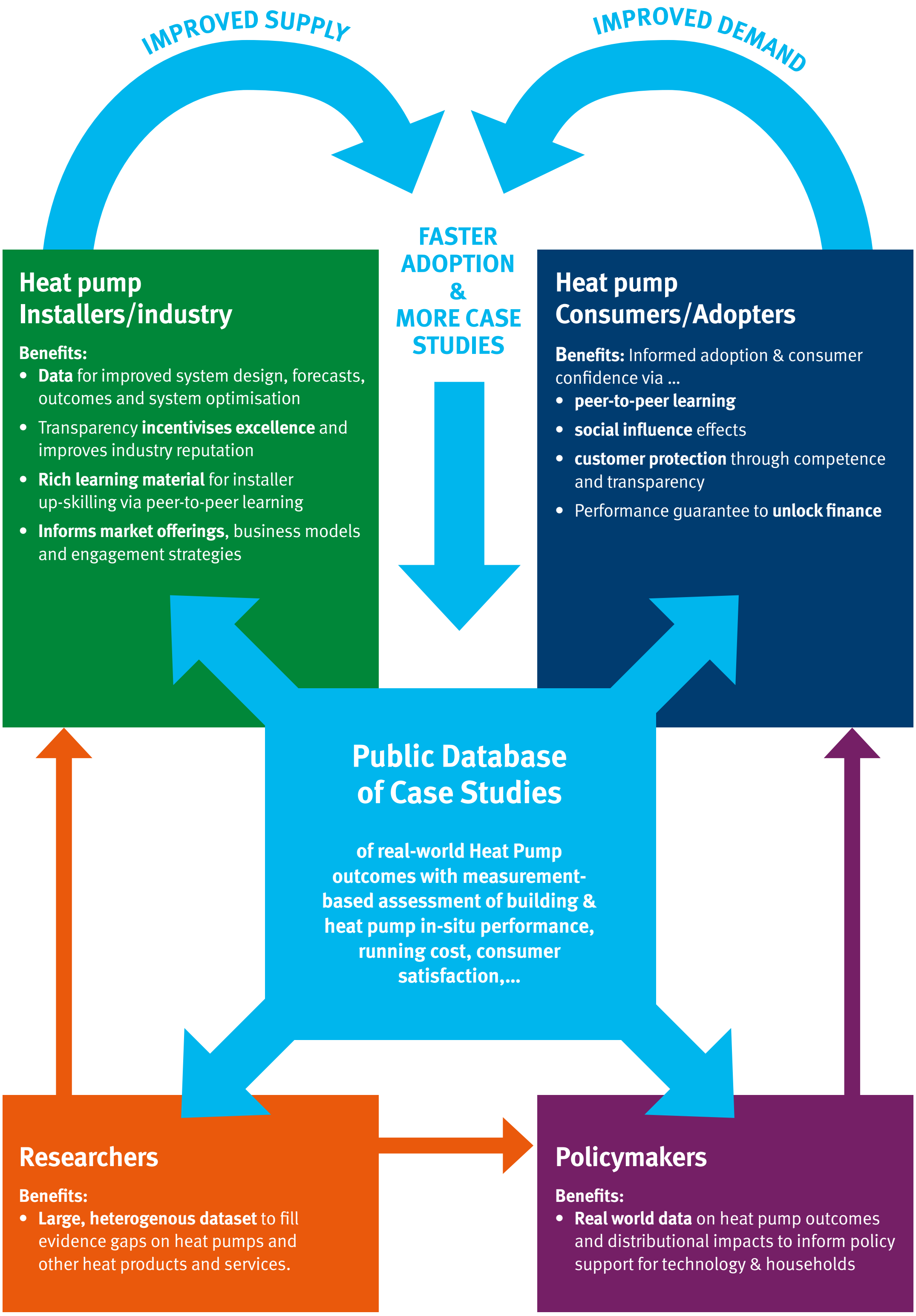


Figure B A public database of case studies of heat pump installation outcomes: multiple stakeholder benefits and positive feedback loops

Recommendations for Government

1. Support the development of standardised procedures for measuring the in-situ performance of buildings and heat pumps.

These protocols should:

a. Be affordable and suitable for rapid scale-up.

b. Provide data that is accurate and detailed enough for the purposes of heat pump case studies of value to users.

c. Use cost-effective hardware (exploring opportunities to reduce costs of monitoring equipment and operative time).

d. Minimise inconvenience and other concerns for households and installers.

This could draw on outputs from the SMETERs programme as well as insights from the work on Metered Energy Savings (MES) and the Electrification of Heat Demonstration Project. See Appendix, Table 3, for an initial, indicative summary of data requirements and collection methods.

2. Introduce a requirement that all new heat pump installations carry out measurement-based assessment of the actual in-situ performance of the building and heat pump system (according to standardised procedures suggested in Recommendation 1).

Options should be explored for how the costs of pre- and post-installation assessment should be funded, including Government financial support where needed and the possible division of cost between HP client, installer, industry and Government, based on the benefits delivered to these different stakeholders. Financially supporting an extra layer of 'crowdsourced' data collection that piggybacks on installations occurring spontaneously could offer good value for money, especially in view of the multiple stakeholder benefits from sharing case study data.

Also consider introducing a measurement-based assessment for compliance with the minimum heat pump performance requirements within the Boiler Upgrade Scheme (BUS) (now 2.8 COP) rather than efficiency being evidenced through the MCS certificate submitted by the installer (BEIS, 2021c). Such a shift to measurement-based compliance with building energy efficiency standards has been pursued by some cities in the USA (Etude, 2021). Governmental or regulatory support may be required to clarify and define procedures, responsibilities and liabilities in cases where an ex-post assessment reveals that a HP is not performing as forecast and corrective work is needed.

3. Fund the development, operation and oversight of a publicly-accessible database for case studies of heat pump installations.

This database should:

a. Develop relatively frictionless informed opt-in consent procedures for owner-occupiers, landlords and occupants to participate as case studies. Consent should accommodate preferences for levels of openness and privacy - such as what data is shared and which stakeholder groups access their data.

b. Develop and implement procedures for data verification/assurance and data privacy while retaining the value and integrity of pseudonymised case studies.

c. Be trusted by users and those sharing their data. Ongoing work on open data could offer insights to help build stakeholder confidence in how case study data is collected, accessed, used and shared.

d. Be designed with good user experience and inclusion in mind. Use by households with poor digital literacy or access could be supported by customer advice organisations via phone or in person.

Government/developers should consult with the HP industry on risks and the possible need for mitigations. For example, there is a potential risk that a public database will make poor installation outcomes more visible and thereby damage the reputation of some installers or the HP industry. Transparency is, however, needed to incentivise and support upskilling (delivering better outcomes and customer satisfaction) and also as a basis for increasing consumer trust. One way of mitigating this risk could be for case studies to be accessible only to installers and industry for the first 12 months. Staggering access in this way would allow some time for installer upskilling before the database is viewable by the public. Similarly, anonymising or pseudonymising installers in case studies for an initial period could be preferable in order to increase installers' willingness to share and discuss installations with less concern about negative feedback and reputational damage.

This paper focusses on retrofit installation of heat pumps, but the model and recommendations proposed here should, in time, be expanded to include a wider range of innovative energy technologies and services not yet familiar and trusted by consumers and for which there are gaps in skills and data. This could support innovation, adoption and learning across heating systems, building efficiency, micro-generation and storage, and shed light on the most appropriate solutions for different circumstances. The use of smart meter data for measurement-based assessment and P2P learning could also help householders see value in smart meters and the data they provide and so bolster public engagement with the smart metering rollout, now just halfway to completion (BEIS, 2022) and with a deadline of 2025.

Broader still, the 'measure and share' approach advocated here has two further implications for delivering Net Zero generally. Firstly, *enabling currently passive consumers to play more active roles through peer-to-peer learning (exchanging data, knowledge and experiences) could be applied more widely as a model for public engagement* in other areas of UK decarbonisation. Secondly, these proposals also underline the potential to *support positive feedback effects by leveraging what progress has been achieved*: whether this progress is technology adoption, behaviour change or the accrual of co-benefits[1], making these visible and learning from them can build momentum in societal change and system change for Net Zero goals (Carmichael, 2020). The heat pump case studies database discussed here illustrates the potential of data-led digital tools and ICT in this area.

1 See https://ukerc.ac.uk/project/win-window/

1. Introduction

Space heating and domestic hot water together account for 80% of a typical UK household's total energy use (Palmer & Cooper, 2013) and around 31% of their carbon emissions (Energy Systems Catapult, 2019c); collectively this contributes 17% to the UK's total national emissions (BEIS, 2021e). Decarbonising heat is recognised as perhaps the greatest challenge for the UK achieving its legally binding Net Zero target by 2050 (CCC, 2019a) and has been described as a 'wicked problem' (Morris *et al.*, 2022).

It is widely accepted, however, that a transition to the electrification of heat with heat pumps (HPs) will play a dominant role. The UK Government aims to reach 600,000 heat pump installations per year by 2028 (HM Government, 2020). The Climate Change Committee suggests 19 million heat pumps are needed to meet net zero goals (CCC, 2019b) but at present rates of adoption it would take more than 700 years to reach this target (Rosenow *et al.*, 2020).

A transition to heat pumps will require a massive shift in behaviour among householders and landlords choosing to buy HPs instead of familiar, trusted and cheaper heating appliances, notably gas boilers. But for each new low-carbon heating system going into homes, more than 120 gas boilers are still being installed (Rosenow & Thomas, 2020). Consumer confidence and trust in HP technologies and installers is low. There is open debate and controversy in the mass media about if, and for which homes, heat pumps are a cost-effective choice. Householders and landlords considering installing a heat pump system are faced with complexity, uncertainty and a list of potential concerns, doubts and questions: What will it cost to run? Will it keep my home warm? How much disruption will it involve? Will it be noisy? Which installer should I use? Should I improve building fabric first? Should I replace radiators and plumbing? What would be the best combination of energy storage devices, smart controls and smart tariffs? The recently introduced Boiler Upgrade Scheme (BUS) and a VAT-reduction ease some financial barriers but these complexities and uncertainties are major barriers to adoption that will not be addressed by a broad-brush approach of raising 'awareness' of HPs among consumers.

A rapid transition to heat pumps (HPs) will require supporting faster and better-informed adoption and maximising positive outcomes in terms of reliable, affordable and flexible low-carbon heat and improved building efficiency. But there is a lack of data and evidence to support consumers' adoption decisions and inform policy decisions. Policymakers risk 'flying blind' into the transition at a time when extraordinary volatility in gas and oil prices has thrown the topics of heating bills, energy security and the affordability of net zero policy goals under intense scrutiny. There is now a pressing need for well-informed policy that offers appropriate support and advice on heating options to households while also providing value-for-money to the public purse. The latest IPCC report on mitigation (IPCC, 2022) is another reminder of the need for "urgent, effective and equitable mitigation actions" (p.52) to meet and exceed targets and that more needs to be done.

The UK and Scottish Governments' Heat and Buildings Strategies (BEIS, 2021e) (Scottish Government, 2021c) recognise the need for better advice and support to equip the public to make decisions best suited to their needs and also highlight an installer skills gap as a bottleneck for a heat pump transition. Support for building efficiency and flexibility in electric heating loads are also unclear.

1. Introduction

This briefing paper attempts to address some of these key outstanding questions including:

- How can consumer confidence and informed adoption decisions be supported to accelerate the heat pump transition and provide warm and affordable homes?
- How can installer up-skilling and new heat pump industry offerings be supported?
- How can policymakers fill evidence gaps about heat pump performance, affordability and important related issues of building efficiency and flexibility?
- Where will the data and learning come from to support consumers, policymakers and installers?

This paper explores in some detail one approach that might contribute substantially to resolving many of these challenges for a HP transition. Previous work (Carmichael, 2019) has proposed that *measuring* heat pump installation outcomes and *sharing* them as case studies on a public database could accelerate informed HP adoption. Exploring the potential impacts and feasibility of this suggestion requires discussion of several innovation areas in this longer Energy Futures Lab briefing paper.

Chapter 2 lays out the important role of heat pumps in decarbonising UK domestic heating and the significant challenges and barriers for ramping up the pace of heat pump deployment to the levels needed. It draws particular attention to the importance of providing good information and advice to potential adopters.

Chapter 3 explores the information and advice currently available on the heat pump adoption customer journey and draws out limitations in the collection and use of building and heat pump performance data.

Chapter 4 explores a range of technology and policy initiatives that could support a move towards measurement-based evaluation of the real-world in-situ and in-use performance of buildings and heat pumps.

Chapter 5 considers a wide range of important stakeholder benefits that could be delivered if real-world outcomes from HP installations were shared as case studies on a public database. Some specific issues for the feasibility of collecting and sharing private data at scale are also considered.

Chapter 6 presents conclusions on the opportunity and feasibility of supporting the heat pump transition by crowdsourcing real-world data from early adopters and sharing it widely. It offers some recommendations for realising these benefits for consumers, industry and policy-making.

2. The challenge for heat pump adoption

Decarbonisation of heat in buildings is a crucial part of reaching net zero and it is widely accepted that heat pumps will play a central role. The major challenges for ramping up mass adoption of heat pumps at the pace required are discussed below.

Heat in UK homes
UK buildings are responsible for around 30% of our national carbon emissions. Heating buildings accounts for the vast majority of this and household heating alone makes up 17% of UK total emissions (BEIS, 2021e) - see Fig.1. For a typical UK household, space heating and domestic hot water together account for 80% (62% and 18% respectively) of its total energy use (Palmer & Cooper, 2013) and around 31% of its carbon emissions (Energy Systems Catapult, 2019c).

Gas central heating (GCH) is the predominant source of heat for the 28 million households in Great Britain, 84% of which are connected to mains gas and use it as their main heating fuel (Ofgem, 2015) (National Grid, 2019). Other primary heating sources in GB homes are made up of heating oil (4.2%[2]), LPG (0.7%), solid fuel (1%) and communal and district heating (1.6%) (Ofgem, 2015). The main non-gas heating source in GB is electricity, used by 8.5% (Ibid) but the vast majority of these households use direct electric heaters, typically with thermal storage, and these homes are more likely to be flats, less energy efficient and in fuel poverty.

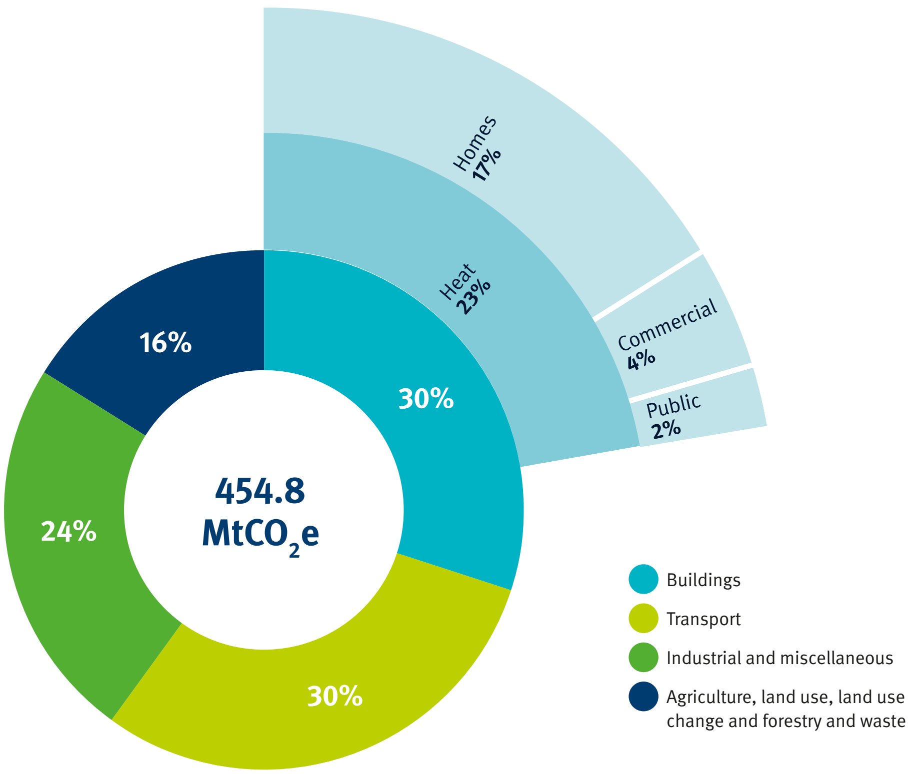


Figure 1: The proportion of UK emissions in 2019 from buildings (30%), heat (23%), and heat in homes (17%). Source: (BEIS, 2021e, p.23)

[2] Though in Northern Ireland this figure is around 68% (The Consumer Council, 2019).

Compared to gas boilers, heat pumps offer emission reductions of 67-74% given the present electricity mix (Rosenow, 2022) - see Fig. 2. This is based on current electricity and gas UK emission factors, a gas power plant efficiency of 48.3% (BEIS, 2021h), and 8% losses in power lines (National Grid ESO, 2019) but ignores upstream emissions from gas extraction and transportation. It assumes a gas boiler efficiency of 85% (The Heating Hub, 2020) and a heat pump operating efficiency of 300% (SCOP of 3). Moreover, emissions reductions from the electrification of heat via heat pumps will improve year-on-year as the carbon intensity of UK grid electricity continues to fall, approaching 100% as power reaches full decarbonisation by the mid-2030s (HM Government, 2021).

The carbon intensity of grid electricity fluctuates, so greater carbon reductions could be realised in the immediate term through flexibility in heat pump loads facilitated by storage devices and rewarded through time-of-use tariffs (for discussion see Carmichael *et al.*, 2020).

An additional and often overlooked co-benefit of the electrification of heating is reduced local air pollution. Taking London as an example, gas combustion in both domestic and commercial boilers is responsible for approximately a fifth of NOx emissions. The public health impacts of gas-powered appliances have not been addressed in Government policies in the same way as emissions from vehicles (Energy and Climate Intelligence Unit, 2020).

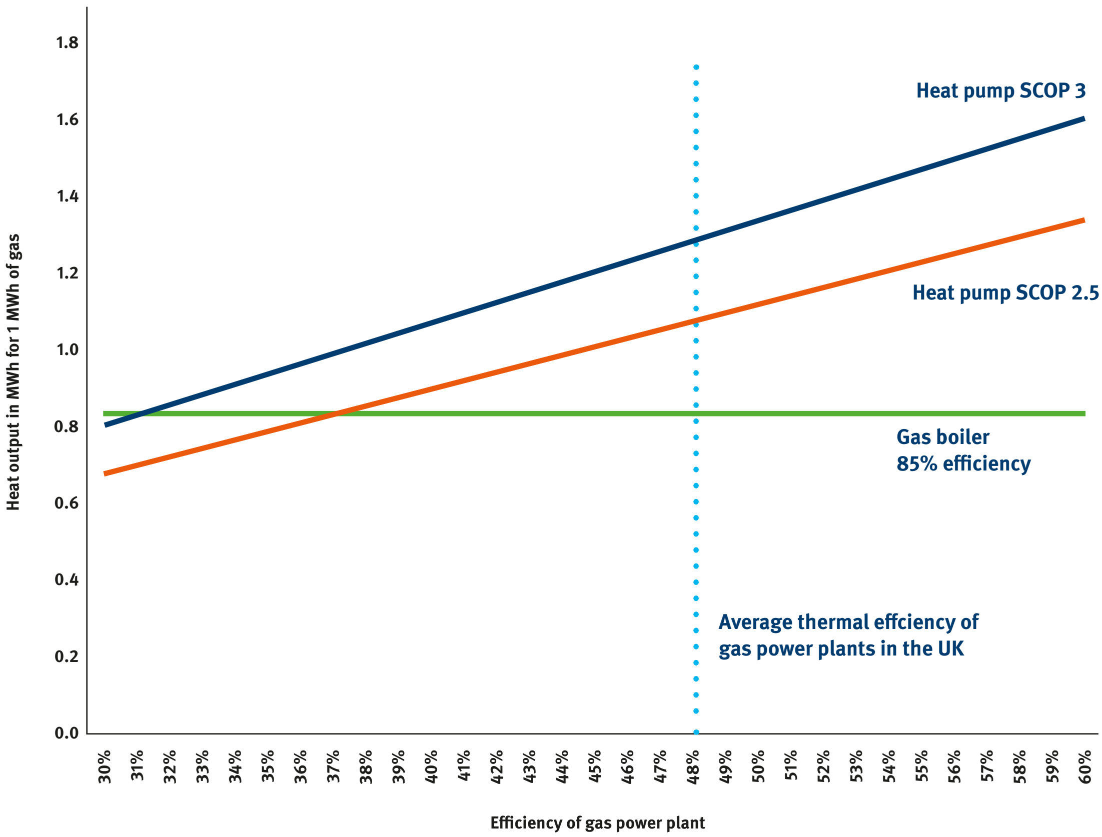


Figure 2: Emissions reductions from the electrification of heat via heat pumps – comparison of heat pump SCOP 3, heat pump SCOP 2.5 and gas boiler of 85% efficiency. (Source: (Rosenow, 2022)

2.1 Targets and delivery

> "Numerous publications, scenarios and models released by the UK government and its advisors have highlighted the importance of heat pumps and the need for rapid growth of this technology"
> (Lowes, Rosenow, & Guertler, 2021, p.6).

While greater energy efficiency, storage and other heating systems/fuels (including district heat networks, solar thermal, biogas and hydrogen[3]) and smart local energy systems will play their parts (for discussion see Morris *et al*., 2022; Trask, Hanna, & Rhodes, 2022; Carmichael *et al*., 2020; Rosenow *et al*., 2020), heat pumps have a leading role within UK heat decarbonisation plans. The UK Government has outlined its aim of reaching 600,000 heat pump installations per year by 2028 (HM Government, 2020) as part of their legal obligation to achieve Net Zero by 2050. The Climate Change Committee's 'Balanced Pathway' recommendations go further: strong growth in the deployment of heat pumps during the 2020s with 900,000 per annum by 2028 under and a supply chain able to supply 1-2 million heat pumps a year by 2035 with 8 million deployed in existing homes by that date (CCC, 2021; Element Energy, 2020).

To date, the total number of heat pump installed in UK homes by end of 2019 was approximately 239,000 (Statista, 2020) – under 1% of homes. Fewer than 30,000 heat pumps are installed annually (CCC, 2020b), 87% of which are air-source heat pumps (ASHPs) (BEIS, 2020b). By contrast, there are 26 million gas boilers in use and 1.7 million replacement gas boilers installed in the UK annually (Rosenow & Thomas, 2020) - over 6,000 each working day. This means that heat pumps account for less than 2% of gas boiler replacement sales (CCC, 2020b), or for each new low-carbon heating system, more than 120 gas boilers are being installed (Rosenow & Thomas, 2020). This is just 6% of the rate of installations needed to reach the Government's 2028 target of 600k annually (IPPR, 2021).

> "Ignoring new homes, at the current rate of deployment, it would take more than 700 years to reach the 19 million heat pumps the Committee on Climate Change (CCC) suggests are needed to meet net zero goals."
> (Rosenow *et al*., 2020, p.4)

In the context of the Net Zero 2050 target, the pace of HP installations has been described as 'achingly slow' (MCS, 2021c). There is much uncertainty about if, and how, we can achieve the rapid acceleration required in coming years and several substantial challenges to do so.

2.2 Barriers and uncertainties

Large-scale heat pumps could supply heat through district heating networks but the scale of current district heating systems is very restricted in the UK, with projections indicating that growth will be limited to areas of high density heat demand and reach perhaps 18% of homes by 2050 (CCC, 2020c). In the UK, therefore, heat will largely continue to be generated by end-user appliances within the home. Unlike the decarbonisation of electricity, which is being achieved through changes to power generation 'upstream' from the consumer, decarbonising heat will, therefore, entail households foregoing their familiar gas central heating and paying to instal and use other heating technologies that are as yet unfamiliar to most people. Heat pump deployment therefore fundamentally depends on customers choosing and engaging with heat pumps and addressing the challenge requires understanding the barriers and drivers to customer adoption.

Drawing on a review of evidence, BEIS list the following as key reasons for low levels of engagement and heat pump adoption: cost, disruption, noise, thermal comfort, space constraints, aesthetics, public awareness, installation time, installer capacity and capability, and manufacturing capacity and capability (BEIS, 2021g). The CCC have observed that,

[3] The viability, availability and case for prioritisation of hydrogen for domestic heating has not yet been demonstrated, despite having gained traction with policymakers (Rosenow *et al*., 2020; Trask *et al*., 2022).

> "the low uptake of heat pumps is symptomatic of low awareness, financing constraints, concerns around disruption and difficulty in finding trusted installers with the right skills" (CCC, 2019d, p.11).

As regards financial barriers, the cost of installing a heat pump system is much higher than a replacement gas boiler[4] and is not yet showing technology 'learning rates' whereby prices fall (Arvanitopoulos & Morton, 2021; Renaldi, Hall, Jamasb, & Roskilly, 2021). The average cost to the consumer of an ASHP installation actually increased in 2019 to £10,433 for a typical system size of 10kW system (MCS, 2021c). However, the financial value case for heat pumps is 'largely dependent' on running costs and heat pump performance (Barnes & Bhagavathy, 2020, p.9) – an important point returned to later.

Consumer awareness, trust and confidence

Most of the barriers given above – concerns about cost, thermal comfort, noise, aesthetics, installation disruption, choice of installer - can be seen collectively as a single broader problem of *low consumer awareness, trust and confidence* in what is as yet uncommon and unfamiliar heat pump technology.

Nine in ten people in GB regard targets and policies for reducing emissions, and heating specifically, to be important, with high levels of support across socio-demographic groups (BEIS, 2020g). But the public did not know that heating is one of the very largest contributors to carbon emissions in the UK, and only a minority reported having heard of specific low-carbon heating technologies (BEIS, 2020g). In a 2020 survey, just 57% of the UK public said they were aware of air source heat pumps (BEIS, 2021a); in a separate 2021 survey 58 per cent of people reported that they know nothing about them (Emden & Rankin, 2021). Similarly, just 51% of people in Scotland report having heard of heat pumps and only 6% say they are 'very likely to consider' installing one (Scottish Government, 2021c). While various surveys (e.g., BEIS, 2021b) have investigated consumers' priorities in boiler replacement decisions and their willingness to adopt and pay for heat pumps (Chapman, Kapetaniou, & Gabriel, 2021; NESTA & BIT, 2022), ultimately all such findings are snapshots contingent upon the context - and the extreme volatility in gas prices in 2021-22 has demonstrated the potential for contexts to shift.

Consumer confidence in HPs is further undermined by a stream of articles in certain sections of UK mass media about high costs and or poor performance outcomes for home-owners (e.g. Dowle, 2021; Faulkner, 2022; Kirkman, 2022; Oliver, 2021; Rudguard, 2022; Walne, 2021) including reports of Government Ministers' own low-confidence in current heat pump technology (Davies, 2021). Positive stories about heat pumps are less common (Brignall, 2021).

There are genuine uncertainties on a range of issues that introduce complexity, doubt and effort into the decision-making process for would-be HP adopters. On costs, Energy System Catapult note that a key lesson from their customer trial is that,

> "consumers will want to understand how their energy bills will change if they install a heat pump, but this is difficult to predict" (Energy Systems Catapult, 2020, p.7)

The anticipated level of disruption is subject to uncertainty around the possible need to undertake additional work such as building fabric upgrades, replacing micro-bore pipes, or switching to underfloor heating or 'oversized' radiators (i.e. larger radiators correctly sized to deliver adequate heat output at lower flow temperatures). Further decisions are required concerning choice between high-temperature or low-temperature heat pumps, multi-zone heating controls, energy storage devices, and which HP, among a range of manufacturers and models, might best satisfy the customer on thermal comfort, aesthetics and noise concerns. Faced with such choice overload consumers tend to defer and procrastinate (Chernev, Böckenholt, & Goodman, 2015; Strong, 2014).

[4] The average cost of a typical 10kW system was £10,433 in 2019 (MCS, 2021c).

2.3 Information, support and advice

Lists of barriers to HP take-up typically do not explicitly mention lack of support for adopter decision-making, despite wide recognition of the importance of information for energy efficiency and heating system choices:

> "*High-quality advice and information is critical for guiding householders' decisions*, and scored highly with the UK Climate Assembly"
> (CCC, 2020a, p.87, emphasis added)

> "To deliver consumer protection, we need to help consumers make choices that best suit their situation and deliver high-quality heating in their homes through *clear, accurate and relevant information and advice*."
> (BEIS, 2021e, p.175, emphasis added)

> "Respondents to the consultation on the draft Strategy highlighted this continuing *need to provide information and support to help consumers make informed choices*."
> (Scottish Government, 2021c, p.30, emphasis added)

There is also recognition that advice on HPs is not adequate:

> "Consumers who considered, but did not proceed with, a heat pump installation through the Renewable Heat Incentive, fed back that *the main barrier was the difficulty finding trustworthy and consistent advice bespoke to their needs*."
> (BEIS, 2021e, p.182, emphasis added)

> "[...]the engagement piece is missing to get people to look for the information in the first place and then to handhold them through the process, because we are asking them to do something quite complex and, in many cases, we are asking them to invest their own money"
> (Laura McGadie, Energy Saving Trust, quoted in Environmental Audit Committee, 2021a, p.53)

A key issue this briefing paper addresses is how consumers might be better empowered to navigate these uncertainties themselves to make informed choices and enjoy positive outcomes.

2.4 Key points

This chapter has considered barriers to heat pump deployment.

- Heat pumps offer clear carbon savings compared to gas central heating and have a leading role in plans for UK heat decarbonisation.
- Heat pump deployment will necessarily involve millions of households choosing to switch from familiar gas boilers to unfamiliar heat pump systems. The delivery of UK targets is in doubt given the current context of very low levels of penetration and adoption and low confidence in HP technology and installers.
- Detailed information and tailored advice is widely recognised as vital for public awareness, consumer confidence and informed adoption choices around energy products and services but insufficient attention has been paid to how heat pump adopter decision-making can be better supported.

Chapter 3 explores the limitations to the information and advice currently provided on the heat pump adopter customer journey.

3. Advice and support on the heat pump adoption customer journey

3.1 Online resources

UK householders or home-owners contemplating or just curious about heat pump installation can initially find advice from the following online resources. These aim to raise awareness of renewable and retrofit technology options and the financial supports available.

Simple Energy Advice and installer search tools

The *Simple Energy Advice* service, implemented by BEIS, consists of a website and associated call centre that provide advice on energy use in the home, mainly based on pulling in EPC data. The Government plan to migrate *Simple Energy Advice* to a GOV.UK URL, with the aim of improving user experience and functionality. Planned developments include social media integration and better information on cost savings and smart meters (BEIS/MHCLG, 2020a).

The *Simple Energy Advice* and the MCS[5] websites both include an installer search tool with links to TrustMark and MCS[6] accredited installers (BEIS/DLUHC, 2021). TrustMark government-endorsed quality scheme was introduced following recommendations made in the *Each Home Counts Review* (Bonfield, 2016) in regard to standards of practice. To register with TrustMark, businesses must adhere to its code of conduct and consumer charter and demonstrate technical competence, good trading practices and good customer service (BEIS, 2021e). The TrustMark scheme now includes a new version of Publicly Available Specification (PAS) standards. PAS standards set an agreed level of quality and good practice and help to maintain and build trust in market products and services. Of most relevance for heat pumps is PAS 2035, which covers how to assess dwellings for retrofit, identify improvement options, design and specify energy efficiency measures, and monitor retrofit projects (BEIS, 2021e).

However, installers participating in the Boiler Upgrade Scheme will *not* be required to be TrustMark registered (BEIS, 2021d), though installers and systems will be required to be MCS-certified (see also Section 3.3) 'or equivalent' and be a member of an appropriate consumer code such as the RECC or HIES that ensures customers are protected by a Trading Standards Institute Approved Code of Practice (BEIS, 2021d).

Online running cost calculators

Heat pump running cost calculators and forums[7] exist but it is not clear how accurate these are given the need for tailored advice and the fact that running costs will depend on the heating system specification and installation, in-situ performance, building heat losses, electricity tariff and occupant behaviour. The online TrustMark guide, 'A guide to retrofitting your home' (TrustMark, 2021) aims to "...explain the How? Why? and What? of Retrofit" but has no information specific to heat pumps.

Pre-April 2022, domestic HP installations complying with requirements were eligible to receive tariff-based quarterly payments for seven years via Ofgem under the domestic Renewable Heat Incentive (RHI). There was a Government-backed online calculator allowing householders to work out in advance the payments they would receive for a heat pump under the RHI. The Boiler Upgrade Scheme that has now replaced the dRHI, offers a fixed sum to go towards the up-front cost (£5k for an ASHP or £6k for GSHP); this, and the recently announced removal of

5 https://mcscertified.com/find-an-installer/
6 Microgeneration Certification Scheme (www.mcscertified.com)
7 E.g. https://www.nibe.eu/en-gb/help-me-choose/savings-calculator; https://great-home.co.uk/air-source-heat-pump-running-costs-calculator/; https://renewableheatinghub.co.uk/

5% VAT on installations, will be simpler than calculating tailored RHI payments.

Scotland

Online resources for potential heat pump adopters are somewhat better in Scotland. The *Let's do Net Zero* national marketing campaign aims to:

> "...deliver a public communications programme to raise awareness of the support and advisory services available and to encourage home upgrades, in order to maximise uptake of these schemes. We will ensure that the most up-to-date information and support for individuals to carry out these actions are provided on the NetZeroNation.scot website."
> (Scottish Government, 2021c, p.29)

Energy Saving Trust's Scottish Home Renewables Service[8] delivers specialist renewables advice from Home Energy Scotland on behalf of the Scottish Government. It offers an online funding finder tool[9], telephone advice line and free home visits to assess and discuss plans. Information about heat pumps includes videos and articles on how heat pumps work, heat pump myths, financial support and an installation checklist and guide.

The Scottish Government have committed to establishing a National Public Energy Agency by 2025 to lead "transformational change in how we heat and use energy in homes and buildings" (Scottish Government, 2021c). The remit of the Agency is subject to an ongoing call for evidence, and a wider process of collaboration and co-development (Scottish Government, 2021b), but may include leading on public communication and advice provision to raise awareness on heat and drive uptake of zero emissions heat and energy efficiency options.

The *Green Homes Network*[10] is a searchable database featuring more than 300 homeowners across Scotland who have installed renewables and wish to share their experiences. A 'Heat Pump Heroes' campaign ran until March 2022 to highlight those who have installed heat pumps and want to encourage others to do the same (Scottish Government, 2021c). The *Green Homes Network* allows users to:

- read case studies (there are also some video case studies)
- make an appointment to visit a *Green Homes Network* member home
- attend a local *Green Homes Network* event
- register your home on the network.

Outcomes of installations are reported via summary text with quotes from householders. This includes details of the model and size of heat pump and other equipment, and often the installer used, but no specific details of costs. Excerpts from typical case studies are given below:

> The homeowners are happy with their investment in heat technology, "we expect a seasonal performance of at least 50% efficiency" explains homeowner Stewart. [...] The householders have also installed a wind turbine, PV panels & solar water heating panels.
> (Energy Saving Trust, 2021c)

> Paul says it is too early to tell if the thermal comfort of his home has improved until after the winter months. However, he is confident the heat pump will save him money and that the investment will be worthwhile.
> (Energy Saving Trust, 2021a)

> "Our home's comfort level and general ambience has unquestionably improved. We have revelled in having the option to set the heating for certain times and taking advantage of the thermostat!" [...] Toby is keeping an eye on his energy bills and has estimated that he will save around £600 - 700 each year.
> (Energy Saving Trust, 2021b)

8 https://energysavingtrust.org.uk/programme/scottish-home-renewables-service

9 https://homeenergyscotland-advice.est.org.uk/fundingfinder

10 https://energysavingtrust.org.uk/tool/green-homes-network

Case studies and current limitations

While it is searchable by technology and location, the database has only around 45 ASHP case studies across Scotland. The reported outcomes are not verified and the level of detail is very limited, which is likely to severely limit the potential for supporting heat pump adoption decisions.

Detailed information is particularly important for unfamiliar technologies such as heat pumps. The 'Each Home Counts' report, an independent review of consumer advice, protection, standards and enforcement for energy efficiency and renewable energy, stated:

> "Experience shows that householders planning more complex and less well-known solutions *have more detailed needs for information, advice and guidance.*"
> (Bonfield, 2016, p.13, emphasis added)

Householders are faced with a choice between different heating systems. Information would also be more useful and actionable if designed to support these choices – ideally this would be a detailed, standardised comparison to clarify their value-case relative to each other:

> "…creating incentives for consumers to buy more efficient devices can only be reached if *precise information* is given. Based on this information, *paired comparisons can lead to reflective customers' choices*"
> (Nolting, Steiger, & Praktiknjo, 2018, p.485, emphasis added)

For example, price comparison websites (PCWs), or Digital Comparison Tools (DCTs), compare different tariff options against each-other to help people to choose between alternatives and are widely used and valued. Over two-thirds of bill-payers looking for energy deals had used these comparison sites in the past year (CMA, 2017b) and 96% are satisfied with their experience (CMA, 2017a). Ofgem acknowledge an important role for the advice and guidance available through third party intermediaries such as PCWs (Ofgem, 2017). By reducing the 'information overload' of calculating future energy costs on different tariffs, DCTs are effective means of supporting informed adoption choices for tariffs and technologies that enable flexible consumption, such as electric vehicles, especially if able to draw on smart meter data (for a discussion see Carmichael, *et al*, 2021). PCWs/DCTs can compare tariffs or products based on 'ex-ante' *predictions* of households' future bills. In contrast, case studies are able to show a comparison of costs (and other variables) *before and after* a service or product has been adopted or installed.

The Scottish Government have stated their intention to grow their advice services and digital presence including expanding the Green Homes Network and Business Network, "so that people can learn from other householders, businesses and organisations who have already made the transition to warmer, greener and more efficient buildings." (Scottish Government, 2021c). However, making case studies more useful for adopters will require much more rigorous data on building and heat pump performance and installation outcomes. The following sections in this chapter examine the data available to householders through their home's Energy Performance Certificate (EPC) and from heat pump installers during the adoption journey.

3.2 Building Energy Performance Certificates (EPCs)

EPCs are the main source of guidance for householders about the energy efficiency of their home and future measures that would make sense for their home. For existing domestic buildings, EPCs are produced using a Reduced Data Standard Assessment Protocol (RdSAP) assessment methodology: this is carried out by a qualified energy assessor using Government-approved software to process information about a building and its installed heating, lighting, ventilation, and air conditioning systems.

The EPC states the *energy efficiency* of the property (in £/kWh/m2), given as a rating from A (most efficient) to G (least efficient) and as a score from 1 to 100. This is the main EPC rating and is based on the building's estimated energy *costs*, calculated from estimated energy demand, fuel unit costs and system efficiency.

Secondly, an EPC includes *recommendations* on cost effective ways to achieve a better efficiency (i.e. energy cost) rating and what the energy efficiency rating could be if the recommended improvements were made.

Thirdly, EPCs also show an Environmental Impact (EI) Rating (A-G) and score (1-100) for the building based on the estimated *carbon emissions* from running the home (in CO_2/m2).

RdSAP EPCs therefore go beyond building heat loss and include assessments of, and assumptions about, different energy technologies and appliances. A valid EPC is also a requirement when selling or renting property and for obtaining funding through the Boiler Upgrade Scheme (BUS), and its predecessor, the dRHI (for which it was also used to calculate dRHI payments).

3.2.1 Limitations and criticism of EPCs

EPCs and their underlying SAP and RdSAP assessments have been the subject of much debate and criticism in the past decade (Etude, 2021). Limitations highlighted include the accuracy and reliability of EPCs, the metrics used, and the actions recommended to householders – all of which influence customer decisions about adopting low carbon heating systems.

3.2.1.1 Reliability

EPC ratings and recommendations have low inter-rater reliability (Hårsman, Daghbashyan, & Chaudhary, 2016), with an estimated 24% of band D homes being rated in practice as band C (Crawley, Biddulph, Northrop, Wingfield, & Oreszczyn, 2019).

> "Multiple assessors evaluating the same property can produce quite markedly different results and, therefore, recommendations for what that household should do"
> (Jenkins *et al.*, 2017, p. 480)

In a recent BEIS consultation, only 3% of industry respondents rated EPC reliability as "good", with criticisms over energy usage and performance assessments (BEIS/MHCLG, 2020b).

3.2.1.2 Metrics

A major issue is that the main EPC Energy Efficiency Rating is based on the financial cost of heating a property. Electricity prices are a great deal higher than natural gas prices per unit of energy (kWh) so a high energy demand property using low-carbon but high-cost fuels can result in a very poor EPC rating. The EPC system regularly issues poor ratings for homes with heat pumps. The CCC and Scottish Government conclude that:

> 'the nature of the metric means that a switch to heat pumps is disincentivised
> (CCC, 2019, p.117).

> "[an EPC] Energy Efficiency Rating can be improved by installing a cheaper-to-run fossil fuel heating system, such as replacing electric storage heaters with a gas or oil boiler. Conversely, installing a zero emissions system could lead to a worsening of the rating. As such, the current system is not compatible with our zero emissions objectives."
> (Scottish Government, 2021b, p.92).

This cost-based metric is also reflected in the actions recommended on EPCs 'to save money and make your home more efficient'. Recommended actions include improvements to building fabric and changes to appliances and heating systems. Typically, new gas boilers are suggested but not heat pumps (Rosenow, 2019). The information and advice on EPCs is deterring rather than promoting or informing heat pump adoption.

» BOX 1: Alternative EPC formats

A recent Environmental Audit Committee inquiry into Energy Efficiency of Existing Homes recommend the EPC headline rating indicates not only the fuel cost of heating a property but also its energy and carbon metrics (Environmental Audit Committee, 2021a, Paragraph 142).

This assessment is consistent with an EPC format proposed by the Scottish Government which would present three separate ratings: an Energy Use Rating, a Carbon Emissions Rating and an Energy Cost Rating (see Fig. 3).

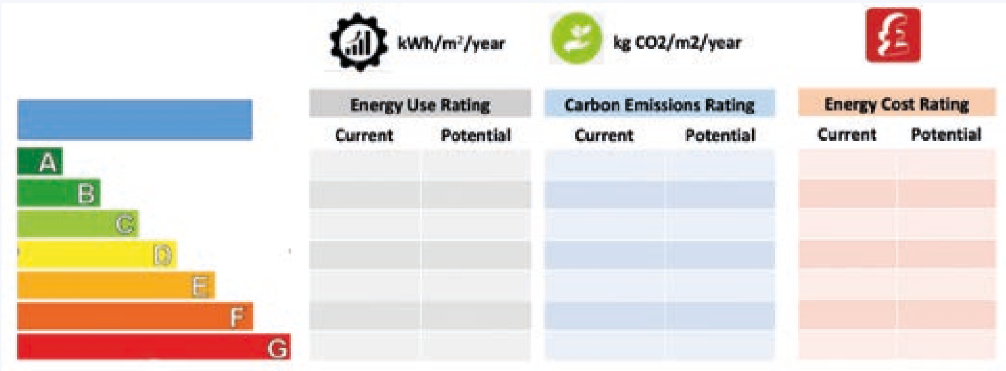


Figure 3: Scottish Government proposal for indicative layout of the three metrics to appear on the reformed EPC certificate. Source: (Scottish Government, 2021a)

3.2.1.3 Accuracy

EPC data is not based on measuring actual building and heating system performance. The RdSAP methodology produces performance estimates using software that combines non-intrusive survey data, modelling and various built-in assumptions. The CCC (2019d) and others have noted significant limitations to the assumptions used and the accuracy of the results.

EPCs have been criticised for over-estimating both running costs and carbon for heat pumps (Rosenow & Lowes, 2020) and even for increasing building heat demand assumptions for these heating systems (Yorkshire Energy Systems, 2021). Official government figures now show that the carbon intensity of electricity is lower than gas (BEIS, 2019b) but the SAP/RdSAP uses an outdated grid carbon factor for electricity dating from 2012 that harms the rating for heat pumps (CCC, 2019d) (Rosenow & Lowes, 2020). This has been recognised and the next version of the Standard Assessment Procedure will use a corrected, lower carbon emissions factor for electricity of 0.233 kg CO2 per kWh, compared to 0.210 kg CO2 per kWh for gas. Rosenow (2019) recommends adopting "a dynamic carbon factor that can be updated as the power system gets cleaner". This carbon factor should, ideally, also reflect variation in grid carbon intensity linked to time-of-use, as the proportion of renewables in the generation mix fluctuates and the lower emissions associated with off-peak and flexible consumption (Carmichael *et al.*, 2020). Furthermore, cost estimates in RdSAP assume a flat-rate tariff for electricity, so possible cost as well as carbon savings from using time-of-use tariffs (preferably enabled by storage) are also not reflected in EPCs (Ibid).

Assessing energy consumption, cost and carbon is complex and involves the efficiency of both the heating system and the building. Flaws have also been highlighted in EPC RdSAP methods of estimating both building performance and HP performance. As concerns buildings:

> "Measurement of the thermal performance of buildings is essential to understand how they operate in-situ. Previous measurement studies have shown that the actual thermal performance of buildings typically varies widely from predicted values, with the largest studies showing average variations of 20% (Gupta & Kotopouleas, 2018) and 60% (Johnston, Miles-Shenton, & Farmer, 2015) across their samples and variations of more than 100% for an individual dwelling in each case. Variations in thermal performance will obviously cause greater than expected energy use but will also have wide-reaching further unintended consequences such as fuel poverty, poor thermal comfort, inappropriate ventilation, condensation and mould growth."
> (Jack *et al*, 2021, p.2).

For heat pump performance, EPCs currently assume an operational efficiency, or Coefficient of Performance (COP), of 2.5 for ASHPs (BEIS, 2021d). For most installations, this is poorer than data on actual performance suggests (Meek, 2021)[11] and using this figure reduces both the main EPC Efficiency (cost) rating and Environmental Impact EPC rating for homes with HPs.

Using estimates rather than measuring real-world in-use performance is a significant problem for energy consumption, cost and carbon although attention has been chiefly on SAP and the building 'performance gap' in newbuild rather than RdSAP and heat pump retrofit:

> "…there are concerns over the suitability, accuracy and reliability of Energy Performance Certificates (EPCs). Grounding estimates in real-world data, such as from smart meters, should be the basis for reform of monitoring metrics and certification"
> (CCC, 2019c, p.36)

> "Energy Performance Certificates have a range of flaws, with their inability to reflect real-world energy performance being the biggest challenge. Desk-based assessments with out-of-date software are doing nothing to improve the market value of decarbonised homes and do not accurately reflect the progress the country is making in improving the energy efficiency of housing stock."
> (Environmental Audit Committee, 2021, Paragraph 141)

The CCC, the Scottish Government's EPC Assessment Short Life Working Group, and responses to recent consultations have all recommended a need to reform EPCs (Scottish Government, 2021b). Reforms should reflect real-world energy use and performance of buildings and heating systems (CCC, 2019d) and ensure they drive the energy efficiency measures needed (CCC, 2020e). A number of recommendations have been put forward and activities begun to do this and are discussed in Chapter 4.

[11] There is a range of achieved COPs but around a quarter of heat pumps fall below a COP of 2.5 (Meek, 2021).

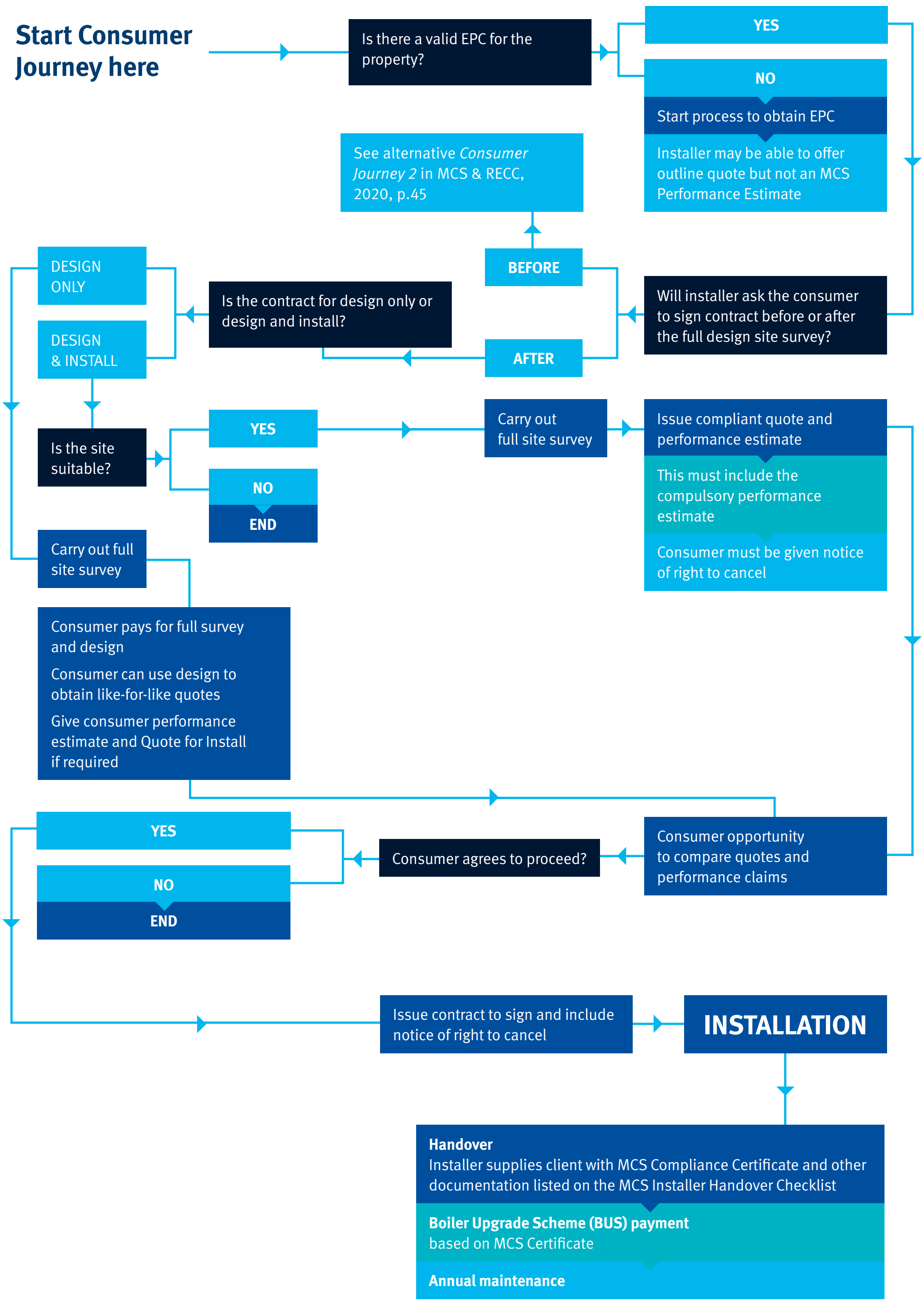


Figure 4: Consumer Journey (MCS MIS 3005 Standard). Source: Adapted from MCS & RECC, 2020

3.3 Heat pump adoption customer journey and MCS MIS 3005

Consumers who go on to contact a MCS-certified heat pump installer will be offered information and advice as part of the MCS-certified installation process. An MCS certificate is not a legal requirement for system installation but MCS certification gives consumers some assurance that an installation or product meets industry-expected levels of quality. Both the equipment and the installation must be MCS-accredited (evidenced by an MCS Certificate) and have a valid EPC to qualify for the Boiler Upgrade Scheme (and dRHI previously) (BEIS, 2021d).

The Microgeneration Installation Standard for heat pump systems (MIS 3005), now Issue 5.0, spells out the MCS requirements for contractors undertaking the supply, design, installation, commissioning and handover of microgeneration heat pump systems. There is some flexibility in the MCS-approved customer journey but the typical customer journey is depicted in Fig. 4, below.

The most likely consumer journey scenarios for MCS installations involve the installer obtaining a valid EPC and carrying out a full room-by-room property survey. This data will be used with software to produce a home heat loss calculation, system design (including heat pump sizing and heat emitter selection), a final MCS quote and the 'MCS Heat Pump System Performance Estimate' (HPSPE). The EPC should not be used for sizing the heat pump but the standard SAP methodology that underpins the EPC can be used. The consumer can obtain and compare quotes and performance estimates from other companies on the same basis before deciding to sign a contract and proceed with installation.

A variation on the customer journey is that the installer can offer to initially provide a full survey service in return for a specified fee. It is common practice for an installer to waive this survey fee if the consumer decides to proceed with them for the installation (MCS & RECC, 2020). Other consumer journeys are possible but the process must comply with the installer's Consumer Code and MIS 3005.

At post-installation handover over to the client, the MCS Contractor should supply the client with the documentation listed on the MCS Installer Handover Checklist (MCS, 2021a). An ASHP will require annual maintenance but can be expected to operate for 20 years (MCS, 2019). After installation there may be an application for financial support that requires an EPC (no more than two years old), an MCS Certificate and a minimum required heat pump efficiency.

» BOX 2: Why does accuracy matter in ex-ante heat pump efficiency forecasts?

An accurate ex-ante (pre-installation) estimate of building heat loss, domestic hot water (DHW) demand[12] and heat pump in-use performance is important for correct heating system design including heat pump sizing.

Under-sizing can lead to issues of poor thermal comfort from being unable to sufficiently heat the building and/or incurring the cost of running expensive supplementary heating.

Over-sizing can produce consumer detriment in terms of greater up-front costs of an unnecessarily large heat pump and also lower heat pump efficiency through short-cycling. Heat pumps run most efficiently when running continuously:

"Most ASHPs, and increasingly, GSHPs have variable-speed inverter compressors. These generally adapt automatically to load demand, often improving efficiency at part load conditions. However, this ability should not be used as a reason for significant oversizing as cycling will occur at lower demand levels due to the limited inverter 'turn-down' available" (MCS & RECC, 2020, p.15).

Work looking at lifetime costs that found that, "the economic competitiveness of HPs is largely dependent on the SPF achieved" (Barnes & Bhagavathy, 2020, p.9). Although this analysis used installer SCOP (see Box 3) performance estimates, modelling by Meek also reports that "the consumer financial value case for heat pump installation was highly sensitive to heat pump efficiency" (Meek, 2021, p.2).

3.3.1 MCS Heat Pump System Performance Estimate (HPSPE)

MIS 3005 contains detailed installer obligations on the provision of performance information that must be given to customers pre-contract including estimates of running costs. Both RECC and the MCS standards require installers to provide consumers with accurate and compliant performance information. The MCS 031 MCS Heat Pump System Performance Estimate Issue-2 includes the following disclaimer:

"The performance of microgeneration heat pump systems is impossible to predict with certainty due to the variability of the climate and its subsequent effect on both heat supply and demand. This estimate is given as guidance only and should not be considered a guarantee" (MCS, 2021b).

However, the performance estimates given to customers have been criticised for installer non-compliance with standards and also for the MCS MIS 3005 method's reliance on estimation rather than measuring actual real-world in-situ performance. These limitations are discussed below.

[12] The MCS standards stipulate that, "Domestic hot water services design should be based on an accurate assessment of the number and types of points of use and anticipated consumption within the property, […] and then discussed and agreed with the customer" (MCS, 2017, p.20). However, "A consensus on how to adequately size the heat pump for domestic hot water production does not currently exist. […] What is established is that with highly insulated buildings becoming ever more present it is no longer adequate to merely size the heat pump for the space heating requirement. The hot water load becomes more significant with very well insulated properties" (MCS & RECC, 2020, p.14).

3.3.1.1 Non-compliance with standards

Analysis for RECC (Meek, 2016) assessed pre-contractual performance estimates for compliance with the main MCS and RECC requirements and found that the information given to customers about potential performance was often confusing and sometimes misleading. Specifically, none of the estimates gave all the required key performance values: overall demand; renewable heat provided; electricity consumed by heat pump; and combined Seasonal Performance Factor/SPF[13] (Ibid).

The MCS MIS 3005 standards were revised in 2017 (current version, Issue 5) with the aim of improving customer protection. This update introduced a requirement specifying a single compulsory method and template for calculating predicted heat pump performance and how that performance should be given to consumers: the MCS Heat Pump System Performance Estimate (HPSPE). This template is in the form of an Excel file that automatically calculates the running costs and savings (and RHI income) depending on a range of values entered by the installer (RECC, 2017). This standard format can be used to help consumers obtain quotes on a like-for-like basis (MCS & RECC, 2020). The HPSPE template includes:

- Energy demand for space heating and for DHW
- heat pump SCOP for space heating
- SCOP for DHW
- capital costs for installation
- annual running costs
- details of existing heating system including running costs
- annual fuel savings and fuel savings over 7 years including RHI payments.

Following these changes, RECC carried out further analysis of heat pump installer estimates which came to similar conclusions (RECC, 2017). Although the sample was small, only four of the 12 estimates examined were clear and accessible and only four included the three critical values consumers need to make an informed choice: the overall demand, the electricity consumed by the pump and the predicted SCOP. Scrutiny of the financial forecasts found some were extremely misleading and based on inaccurate or exaggerated performance values (Ibid). This report also identified non-compliant and misleading claims in heat pump marketing.

13 See Box 3 for definition of COP, SPF and SCOP.

» BOX 3: Measures of heat pump efficiency and performance

Coefficient of Performance (COP) is the efficiency of a heat pump at any given time or over a defined period of time. COP = Heat output divided by electricity input. For example, a COP of 3 is 300% efficiency and so uses 1 kWh of electric energy to generate 3kWh of heat energy.

$$\text{COP} = \frac{\text{total energy output (kWh)}}{\text{total input electricity (kWh)}}$$

Seasonal Coefficient of Performance (SCOP/SCoP) is a theoretical indication of the anticipated efficiency of a heat pump *product* not a heating system. It is an *estimation* or *forecast* of heat pump performance aggregated over a year using standard climate data. SCOP is used for installers' estimates of performance and may be combined with climate data to estimate renewable energy output. The SCoP method used for MCS accreditations is based on stringent factory-based tests for equipment but misses a number of important issues that may affect the performance of a heat pump *when installed in a home* (MCS, 2021b).

Seasonal Performance Factor (SPF) is the actual achieved Coefficient of Performance (CoP) *of an installed heat pump system operating in a specific location and averaged over the full heating season*. It is the measured annual efficiency, although SPF may also be estimated using factory-based tests with a range of adjustments.

SPF may use different 'system boundaries' – for example, including or excluding electrical energy needed for different heat pump system components. Comparisons of SPFs are difficult unless the system boundaries for these electricity inputs and heat outputs are specified and shared but the SEasonal PErformance factor and MOnitoring (SEPEMO) system boundaries (see Fig. 5) are now used as the standard established methodology, at least in Europe (Lowe, Summerfield, *et al.*, 2017). SPF usually uses the "SPF H4" system boundary that includes "all the electricity supplied to the heat pump, all fans or pumps and electricity delivered to any incorporated auxiliary heaters used to boost space heating, and immersion heaters used to provide extra hot water. Electricity used by any other fans or pumps included in the building's heating and hot water system is also included" (Energy Saving Trust, 2013, p.23). This 'whole system' boundary best indicates overall costs so this is considered is the most appropriate boundary from a customer's point of view (Dunbabin, Charlick, & Green, 2013; Meek, 2021).

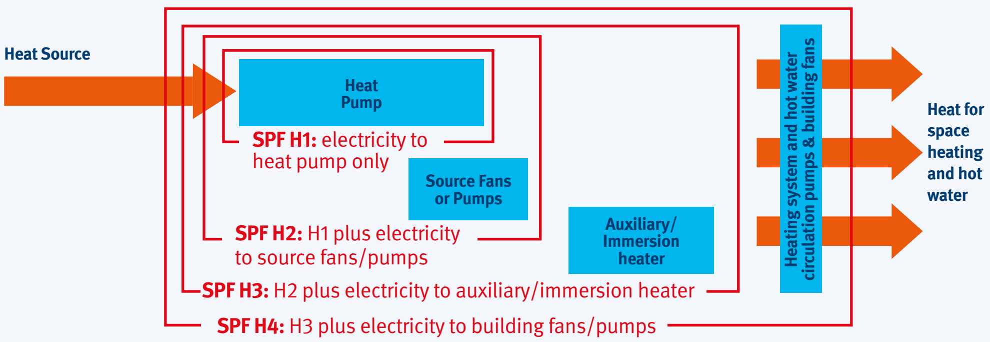


Figure 5: SEasonal PErformance factor and MOnitoring (SEPEMO) system boundaries for measuring heat pump Seasonal Performance Factor (SPF), SPF H1 to SPF H4. Source: Adapted from BRE, 2017, p.30, and MCS & RECC, 2020, p.29.

3.3.1.2 Accuracy

Even when installer practices are fully compliant with the MCS and RECC standards, the MIS 3005 MCS methodology used for producing estimates of performance has been challenged on a more fundamental level. The current MCS heat pumps standard, MIS 3005 (MCS, 2017), requires installers to provide performance estimates that are based on the Seasonal Coefficient of Performance (SCOP) metric. SCOP is a measure of *product* efficiency (Griffiths, 2018) that has been criticised as being inappropriate for predicting the performance of a whole heating system and is likely to overestimate in-situ performance (Meek, 2021). Nolting *et al* evaluated the EU's Ecodesign labelling scheme for HP efficiency, which uses the SCOP metric, against efficiency-influencing factors known in the scientific literature and found "high deviations from the label value" (Nolting *et al*., 2018, p.476).

> "Our results show that a HP device with higher label value does not necessarily have higher efficiency under real life conditions [...] an exact label cannot be assigned to a HP unit per se, but rather to a HP unit within its operation as a composite system and its interaction with the integrated surrounding." (Nolting *et al*., 2018, p.485)

The SCOP calculation method of estimating heat pump performance misses several criteria essential for accurately determining heat pump performance as part of a domestic heating system. These include:

1. Heat loss of the actual dwelling in which the heat pump is installed is ignored
2. It uses European average weather data, which is less accurate for UK purposes[14]
3. Weather compensation is always assumed to be present and active
4. Hot water heating operation is ignored, including its impact on space heating operation
5. Operating hours - the effect of intermittent heating, which is prevalent in the UK, is ignored
6. Design flow temperature – only two options: 35°C or 55°C
7. The minimum heat output is not defined (some inverter heat pumps can modulate minimum heat output to a lower level than others, avoiding on/off cycling)
8. Backup heating is effectively ignored. (BRE, 2019; Griffiths, 2018)

Analysis of data from heat pump trials and monitoring has explored whether the MCS-accredited predictions of heat pump performance are accurate when compared to the actual measured in-use performance of installed heat pump systems.

RHPP Trial

Analysis of data from heat pumps installed between 2013-15, via the Renewable Heat Premium Payment (RHPP) Scheme, used multiple research approaches to empirically determine the performance of domestic heat pumps in 699 dwellings. Datasheets completed by heat pump installers through the MCS scheme were compared against schematics provided by BRE and physical monitoring data to assess heat pump performance, MCS compliance and customer satisfaction.

A wide distribution of SPFs was observed, partly attributed to differences between dwellings, patterns of use and occupants' lifestyles. The measured SPFs achieved were significantly lower than the installer estimates (Gleeson *et al*., 2017). Around one in three ASHPs and one in five GSHPs did not reach SPF 2.5, the threshold for renewable energy within the EU's Renewable Energy Directive (Lowe, *et al*., 2017). However, the RHPP trial used a range of system boundaries (see Box 3, Fig. 5) and methods and did not report the performance of heat pumps during a period of very cold weather, thereby limiting the robustness of conclusions possible.

[14] Outside temperature affects: building heat demand; building heat loss; and HP efficiency as the closer the source temperature (outside air) is to the sink temperature (indoor) the greater the efficiency.

Analysis of RHI Metering-for-Payment data

In 2019 RECC obtained from Ofgem the RHI 'metering for payment' data for over 2,000[15] domestic installations carried out from 2015. This data allowed a comparison between the installer performance forecasts (the SCOP) and actual efficiencies (SPFs) achieved and shown by the Ofgem metering data. Analysis showed that:

- The overall average actual efficiencies for the heat pumps was 2.67 for ASHPS and 3.15 for GSHPs. These results are marginally higher than the SPF observed in the RHPP field trial data which also used the H4 system boundary[16] (RECC, 2020).
- A minimum SPF of 2.5 was a requirement for RHI eligibility (since increased to 2.8 for the BUS), and so there were no installer SCOP forecasts below 2.5 in this RHI dataset. However, almost 30% of all installations (85/300) were found to be performing with an efficiency lower than 2.5 and 77% of the installations were found to have an actual efficiency lower than that indicated by the installer's SCOP (RECC, 2020).
- Overall, *there is a very wide disparity and little correlation between the installer SCOP forecasts and actual SPFs outcomes as seen in metered data* (RECC, 2020) – see Fig. 6.

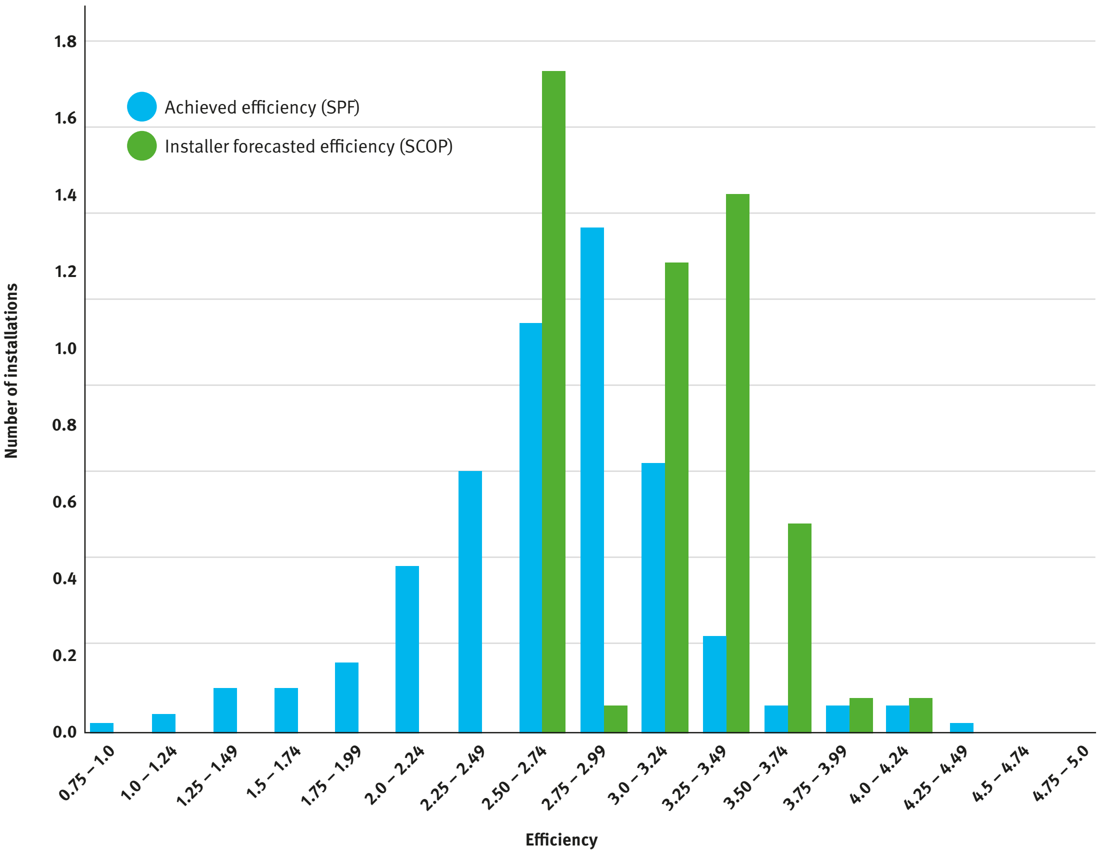


Figure 6: Distribution of ASHP efficiency: installer SCOP forecasts versus actual in-situ SPF achieved (obtained from RHI metering-for-payment data from RHI installations 2015-2019; n=300)

Source: adapted from (RECC, 2020)

15 A sample of 300 installations were included in the analysis.

16 The heat pump metering used for RHI purposes may not always replicate an exact SEPEMO H4 boundary (Meek, 2021).

Analysis of this RHI metering for payment dataset by Meek reports an average SPF of 2.71 for ASHPs and 3.07 for GSHPs (Meek, 2021). There was *no correlation between the installer performance forecasts and the actual performance* and no discernible improvement in performance after the UK MCS standards for heat pump installation were changed in 2017 (Ibid). Meek acknowledges limitations to the dataset used[17], but does not consider these to have seriously affected the results, concluding:

> "Overall, these results raise significant questions about installation design and execution and about the methodology used for the provision of consumer [heat pump] performance estimates [in the MCS Standard 3005 Version 5] [...] It is concluded that information asymmetries may damage consumer confidence in heat pumps and that this represents a challenge to market growth."
> (Meek, 2021, p.2)

Ultimately, poor understanding and estimates of heat pump efficiency increase the risk of poor customer outcomes (both financial and comfort) and undermine consumer confidence and informed adoption.

> "If reasonable confidence in performance estimates – namely the annual efficiency – cannot be guaranteed, then the long-term uptake of heat pumps also cannot be assured"
> (Griffiths, 2018, p.44).

Markets improve when consumers can make informed choices (RECC, 2017). Meek's recommendations include that all stakeholders, including the Government, should stop using SCOP-based forecasts as a proxy for in-situ performance and replace the SCOP methodology with BRE's Domestic Annual Heat Pump System Efficiency (DAHPSE) which forecasts the performance of the whole generator system. This method is based on the SEPEMO H4 system boundary and incorporates a range of criteria not used for SCOP calculations that the developers of DAHPSE consider essential for assessing domestic heat pump performance (Ibid). This method is still an estimate but would better reflect heat pump *in-situ* performance.

[17] Limitations included: meter data were obtained via manual submissions; installation arrangements are highly variable and, in some cases, may not conform the SPFH2 boundary or to the rules set out by Ofgem; and the dataset is an imperfect sample of installations.

3.4 Key points

This chapter has considered the heat pump adoption customer journey with a focus on the information and advice available to support consumer decision-making.

- Energy advice services and online resources are not providing households with accurate or tailored support for heat pump adoption. A small number of case studies of early adopters are available online but these lack sufficient rigour and detail to clarify the value case of heat pumps versus other options and support consumer choices.
- Building energy performance certificates (RdSAP EPCs) are widely used but their primarily cost-based metrics and ratings discredit heat pumps and their recommended actions consistently deter households from adopting them. There are serious concerns over the reliability, accuracy and suitability of EPCs and their dependence on estimates and out-dated assumptions instead of real-world measurement.
- The MCS's 'MIS 3005' installation standards contains detailed installer obligations on the provision of information that must be given to customers pre-contract, including forecasts of performance and running costs (the Heat Pump System Performance Estimate/HPSPE). However, HPSPEs have received criticism for both non-compliance with the MCS's installation standards and also for their inherent use of Seasonal Coefficient of Performance (SCOP), which estimates performance based on the heat pump *product* and misses a number of important issues that may affect the actual in-situ performance of a heat pump system

when installed in homes (the Seasonal Performance Factor/SPF). HPSPE has been found to have little correlation with the actual in-situ performance and running costs of the heating system. This is important because the consumer financial value case for installing a heat pump is highly sensitive to heat pump efficiency (Meek, 2021).

- Both EPCs and installer heat pump performance forecasts (HPSPEs) rely on estimated performance rather than measurement. There is a fundamental lack of accurate information and support for consumers that is grounded in measurement of in-situ performance of HPs and the advice given is often inaccurate. This performance gap between estimates and actual real-world performance not only affects buildings and heat pumps but is a known issue for condensing gas boilers, most of which run well below their A-rated efficiency (Alsop, 2021; Orr, Lelyveld, & Burton, 2009).
- There is growing recognition of the need for reform in how the energy performance of buildings and heating systems is assessed: to move away from estimation and modelling and towards more measurement-based assessments of real-world, in-situ and in-use energy performance.

Chapter 4 summarises ongoing and planned activities that may improve the assessment of in-use performance for heat through more measurement-based methods.

4. Towards measurement-based evaluation of buildings and heat pumps

4.1 Measuring building performance

4.1.1 EPC Action Plan

A body of work, by the Climate Change Committee (CCC), Environmental Audit Committee (EAC), Scottish Government and others, has strongly criticised EPCs and advocated their reform to reflect much greater measurement and use of real-world outcomes in order to better drive change to low-carbon heating, flexible demand and building efficiency. The UK Government has recognised this urgent need to improve EPCs to ensure they are fit to support near-term progress, with a range of improvements proposed in the recent EPC Action Plan.

Following a Call for Evidence on EPCs in 2018 the Government published responses (BEIS/MHCLG, 2020a) and an EPC Action Plan with 35 actions designed to achieve three broad aims:

i. An EPC system that produces accurate, reliable, and trusted EPCs

ii. An EPC that engages consumers and supports policies to drive action

iii. A data infrastructure fit for the future of EPCs. (BEIS/MHCLG, 2020b)

So far, changes to the EPC format now gives greater prominence to the main EPC efficiency rating and includes the Unique Property Reference Number (UPRN). Actions delivered to date also include moving EPC certificates to an online register, which presents EPC data online at a GOV.UK URL instead of the previous PDF document, with a helpdesk for service users. Bringing EPCs in-house to the Government-operated Energy Performance of Buildings Register[18] has not changed the maths or EPC ratings but does create a basis for possible implementation of some other recommendations from the EPC consultation (BEIS/MHCLG, 2020a).

Various further actions are ongoing or planned, most of which are more complex, require legislative changes and are dependent upon a consultation in 2022 on the Energy Performance of Buildings Regulations (BEIS/DLUHC, 2021). Actions include the following.

- Development of an update to the Reduced Data SAP (RdSAP) methodology (to follow the SAP update for new buildings that will come into force in 2022). This will take into account updated fuel prices, CO2 emissions and primary energy factors and include monthly variation in these factors. This will refine the assumed heating pattern and summer internal temperature calculations.
- Following the update of the SAP methodology (10.2) and an update of the EPC format, the presence of a smart meter in a building will be shown on the certificate.
- Developing a scalable, queryable data warehousing solution to improve the extraction of data from the EPC Register to tackle data input errors, non-compliance and enforcement.
- Developing proposals to further the use of, and access to, data to improve the audit of EPCs to raise their quality and reliability.

On the data infrastructure aims of the EPC Action Plan, Government has also indicated that it will consider and commission work to explore the potential pathways for the inclusion in RdSAP of technologies that measure the thermal performance of homes using smart meter and other data (BEIS/DLUHC, 2021). Emerging findings from this work are outlined below.

[18] The register for England, Wales and NI is at https://www.gov.uk/find-energy-certificate; the register for Scotland is at https://www.scottishepcregister.org.uk/

» BOX 4: Heat Transfer Coefficient (HTC)

All models of thermal performance or energy consumption in buildings are based upon a measure of thermal performance (how well the home keeps heat in and cold out) known as the Heat Transfer Coefficient (HTC). The HTC is a measure of the rate of heat loss per degree of temperature difference between inside and outside. The HTC, in units of Watts/Kelvin (W/K), encompasses all of the heat lost from a dwelling during the winter - through the walls, roof, floor and windows and by air movement from outside to inside the home. The HTC can be normalised by floor area and expressed as W/m2K, the Heat Loss Parameter (HLP).

An alternative metric that characterises the thermal losses of both the heating system and the building fabric together and makes use of whole-dwelling metered fuel consumption data is the Heating Power Loss Coefficient (HPLC), introduced by Chambers and Oreszczyn (2019).

4.1.2 Smart Meter Enabled Thermal Efficiency Ratings (SMETERs)

The 'gold standard' method to measure the thermal performance (HTC) of buildings has been the 'co-heating test'.[19] Although the method is reliable (Jack *et al*, 2018), the test has been limited to specialist applications because of the disruption, cost and invasiveness (it requires a building to be vacated for two weeks and costs several thousand pounds). As discussed in Section 3.2.1, the RdSAP EPC estimates of HTC typically vary widely from the actual thermal performance of buildings (Jack *et al*., 2021). There is also no currently mandated verification test to compare the estimated HTC to the real-world as-built and in-use performance achieved in newbuild or retrofits scenarios. *There is therefore a need for an accurate yet workable measurement of actual building HTC that can be used at scale to inform energy efficiency and heating investment decisions.*

The Call for Evidence on EPCs (BEIS/MHCLG, 2020a) and a review by BEIS noted the market potential of methods that could use smart meter and weather data, and potentially other measurements (e.g. indoor temperature and home survey data), to improve the accuracy of the SAP calculation and the resulting EPC rating.

These products have been collectively termed 'Smart Meter Enabled Thermal Efficiency Rating' products - SMETERs (BEIS, 2018).

The Smart Meter Enabled Thermal Efficiency Ratings (SMETER) Innovation Programme (BEIS, 2019a) aimed to develop, test and demonstrate *technologies that use smart meter and other data to generate in-use thermal performance metrics for homes*, in particular Heat Transfer Coefficients (HTCs). Participating organisations were asked to calculate the in-use[20] HTC in a blind trial against the HTC measured using a modified version[21] of the co-heating test method. Building HTC was also calculated using the Reduced (RdSAP) methodology in SAP using data collected by an expert member of the team (SMETER Project, 2021b). Eight projects[22] secured funding in Phase II of the programme to demonstrate their SMETER method. Two projects used only smart meter data, while six projects required temperature sensors or other devices installed in the home.

[19] Several other, less commonly-used methods have been developed to determine the actual HTC of the building fabric in-situ including PRISM, PSTAR, QUB and ISABELE (Sougkakis, Meulemans, Wood, Gillott, & Cox, 2022).

[20] While there is a need for the results to be to some degree independent of the behaviour of specific occupants (Crawley, McKenna, Gori, & Oreszczyn, 2020), methods that reflect in-use performance could offer advantages over the co-heating method that assesses unoccupied buildings.

[21] This version is commensurate with the Standard Assessment Procedure (SAP) but provided a better comparator for the in-use HTC calculated by SMETERs.

[22] These were led by: Building Research Establishment (BRE), Build Test Solutions (BTS), Cambridge Architectural Research (CAR), Centre for Sustainable Energy (CSE), EDF, Hoare Lea, Passiv UK, and Switchee (https://www.gov.uk/guidance/smart-meter-enabled-thermal-efficiency-ratings-smeter-innovation-programme#history)

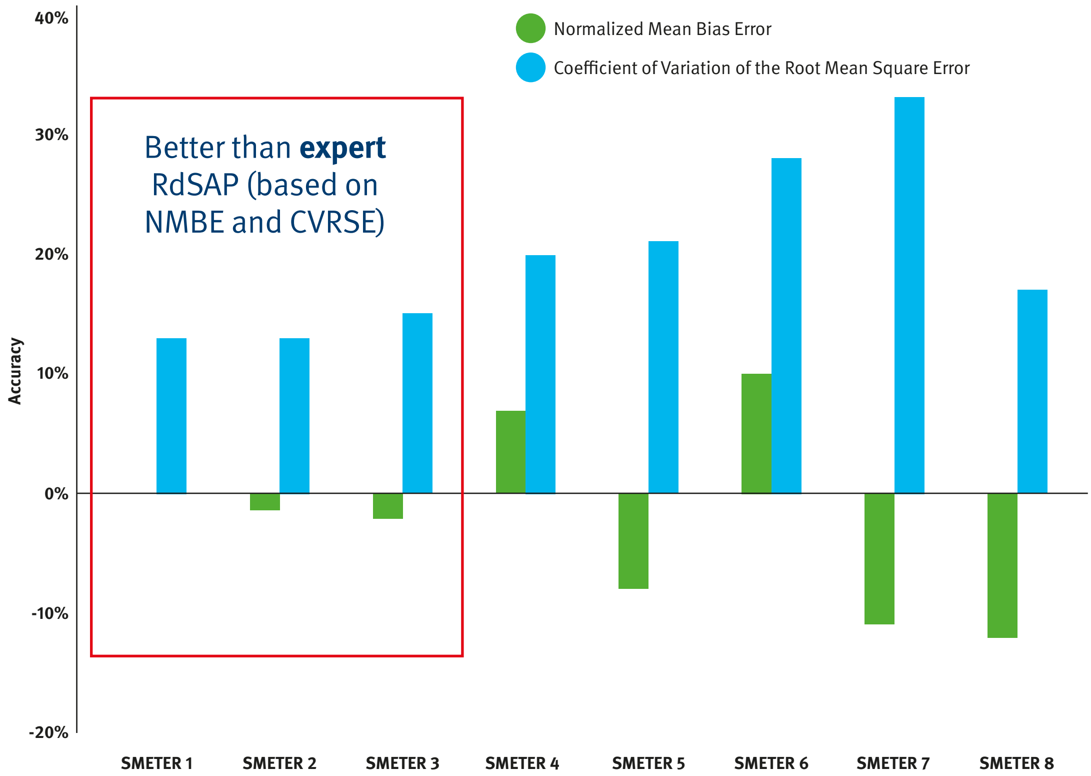


Figure 7: Accuracy (NMBE and CVRMSE) of the in-use HTC generated using SMETERs compared to in-use HTC using modified co-heating test. Three SMETER products were more accurate than the expert RdSAP calculation of HTC.

Source: Allinson, Gorse, Elwell and Loveday, ‘Technical Evaluation of SMETER Technologies (TEST) Project’, in (SMETER Project, 2021a)

The ‘Technical Evaluation of SMETER Technologies’ (TEST) found that three out of the eight SMETERs were more accurate than a RdSAP assessment carried out by an expert. A late-joining SMETER method also successfully predicted the HTC of two separate homes. Overall, the final TEST report for SMETER concluded:

> “This work has shown that the concept of using smart meter data to calculate HTCs clearly has merit. The use of SMETERs might provide a more robust procedure, with more clearly defined error characteristics, than HTCs derived by surveyors and RdSAP.
>
> [...] SMETERs could play a role, not only in the energy rating of homes, but also in quantifying the improvement to energy efficiency following refurbishment.
> (Allinson, 2022b, p.94)

The two “best-performing SMETER technologies” were those from Build Test Solutions (BTS) and Switchee (Allinson, 2022, p.12) but they have different requirements for data collection and in-home sensors.

Both use data from an EPC survey and require an additional home survey to capture floorplan and details of all windows (type, size, and orientation, overshading) (Jack *et al*., 2021).

The Switchee SMETER does not require any additional room sensors or external internet connection but does require a professional installation to electrically connect their proprietary smart central heating controller to the boiler; it measures temperature, relative humidity, and motion detection.

The BTS SMETER calculates a 'SmartHTC' and requires five wireless, battery-powered sensors (for temperature and relative humidity) that report to an internet-connected hub. A 21-day period during winter (October-March) is required during which time the building may be occupied as normal. Half-hourly energy data can be provided from the smart meter or, if smart meter data is not available, via standard meter readings at the start and end of the temperature monitoring period. The cost is estimated to be similar to an EPC test (Jack *et al.*, 2021).

The technical evaluation also assessed the SMETERs on a range of other aspects: accuracy requirements for thermal performance metrics; consumer engagement and support; market development; data access and communications requirements; and validation or approval mechanisms. Additional field trials were recommended as the sample was not representative of the UK housing stock. Homes used had EPC ratings of C or D; had gas combi central heating and little use of secondary heating; and did not include flats, new-build homes and larger homes (Allinson, 2022).

The TEST report and an expert workshop highlighted the following conclusions, outstanding issues and requirements for research, innovation and implementation at scale.

Measurement-based performance assessments are valuable

> "HTC measurement is key to delivering on the expectations of energy efficiency improvements...it should be a routine part of asset management. (Participant of SMETER Workshop)"
> (SMETER Project, 2021a, p.42)

Methods and metrics should follow functions

> "The design criteria for any new system to measure in-use thermal performance metrics should be steered by their purpose and functions: criteria for effective metrics as identified by workshop participants most frequently mentioned consumer use/understandability as the key criterion, followed by accuracy, repeatability and consistency. Participants also identified a range of interested stakeholders, and wider developments such as heat pumps, demand management and future changes to the regulatory system, which would be relevant to any new system of in-use performance metrics."
> (SMETER Project, 2021b, p.3)

Trade-offs between accuracy, convenience and cost

> "There is a cost/complication/accuracy trade-off. I.e. there is no point chasing the best accuracy if it becomes a barrier to practical action"
> (SMETER Project, 2021b, p.4)

> "The SMETER technologies with no product in the home (Types T1a and T1b) did not always perform as well as those with sensors (Types T2, T3 and T4). This suggests that the measurement of internal temperatures is likely to lead to more accurate SMETER-calculated HTCs. However, the cost, intrusiveness and reliability of SMETER products must be considered. [...] Based on the response of the 30 households in this study, almost all would have no problem having SMETER products installed in their home, and especially if the use of plug sockets is minimised and sensors are unobtrusive."
> (Allinson, 2022, p.94)

Effects of occupancy on in-use measurement

One of the complex and unresolved questions for in-use assessment of buildings concerns whether assessment should reflect the influence of occupant behaviour on performance. On the one hand, an in-use assessment of building performance might be unduly affected by out-of-the-ordinary occupant behaviour:

> "If used for regulatory purposes, methods would have to be robust enough to reproduce a similar HTC value *under different occupancy scenarios* [...]
> (SMETER Project, 2021b, p.4, emphasis added)

However, reflecting occupant behaviour within in-use assessments also has value, particularly if this information will inform decisions by current occupiers:

> "There would be value in being able to accurately predict savings to occupiers from retrofit *under existing occupancy conditions*"
> (SMETER Project, 2021b, p.4, emphasis added)

Although outside of building fabric performance, domestic hot water load is one component of energy use that would be greatly affected by household size and habits. Hot water load becomes a more significant demand with very well insulated properties (MCS & RECC, 2020). The assessment of heating system performance alongside building performance is a key issue and is discussed in Section 4.2.

Given the acknowledged limitations of EPCs and the low trust consumers have in them (BEIS/MHCLG, 2020b), questions remain about how suited EPCs are to the task of supporting householders' informed adoption of heat pumps and other energy improvements to their property, and whether EPCs – even with Smart Meter-Enabled Thermal Efficiency Ratings - should be replaced rather than reformed.

4.1.3 Building Renovation Passports (BRPs)

The Green Finance Taskforce (2018), the CCC (2020d), Green Finance Institute (GFI/CEEB, 2021), Environmental Audit Committee (2021a) and several witnesses in the inquiry on EPCs (BEIS/MHCLG, 2020b) have all supported the introduction of Building Renovation Passports (BRPs) as a successor to Energy Performance Certificates.

> "We recommend the Government develop an approved, standardised methodology and data framework for Building Renovation Passports and supports their roll-out, with a view to the eventual replacement of Energy Performance Certificates."
> EAC, 2021a, p.52)

BRPs are an evolution of the EPC and use measurement of both outputs and outcomes (GFI/CEEB, 2021) rather than deemed energy performance (as used in SAP) and so "have the potential to provide much more accurate data on energy usage" (EAC, 2021a, p.52).

> "BRPs typically contain a *digital logbook* of renovations at a property-level, with historical and contemporary information about the property, its construction and operational performance; and a long-term *renovation roadmap* that identifies future retrofits and installations to decarbonise the property, along with links to contractors, other service providers and finance options."
> (GFI/CEEB, 2021, p.4; emphasis addded)

GFI identified BRPs as a critical enabler for unlocking green finance and assembled a working group to establish a standardised approach for introducing BRPs suitable for the UK market (GFI, 2020). Following consultation, the Green Finance Institute's Coalition for the Energy Efficiency of Buildings (CEEB) will publish an initial standardised framework for Building Renovation Passports in the UK. GFI/CEEB have so far outlined a number of important issues for data requirements and accessibility, roles, benefits and opportunities. The UK Government has indicated that they are currently engaging with industry stakeholders to explore the potential mechanisms to deliver a Building Renovation Passport and considering whether further intervention from government is required (Environmental Audit Committee, 2021b, p.22).

Proponents clearly intend BRPs to support retrofit decisions by outlining a long-term, step-by-step renovation roadmap to achieve deep renovation for a specific property, providing them with “renovation options and expected benefits, including energy savings and comfort improvement” (EAC, 2021a, p.50). However, there may be a risk that action focuses on providing logbooks that catalogue building data up to the present rather than supporting retrofit decisions going forward. In response to EAC’s recommendation to pursue BRPs, the Government refers to logbooks to facilitate the conveyance process and show works that have been carried out (EAC, 2021b, p.22). Activities on renovation *roadmaps* and real-world data collection were less clear, and the same document offered little in response to EAC’s recommendation to set up “a bespoke advice service on energy efficient retrofitting” (Ibid, p.22).

While digital logbooks would have clear benefits for compiling comprehensive and up-to-date building data, it would be valuable for them to retain sufficient data from subsequent phases in a building’s life to reveal the benefits achieved from renovation work that has been carried out. A more explicit focus on measuring the benefits and value case of retrofit is seen in work on Metered Energy Savings.

4.1.4 Metered energy savings (MES)

The GFI/CEEB Working Group report on Metered Energy Savings (MES) provides a rationale for this approach:

> “Energy savings in UK buildings can be ‘measured’ by creating an industry-standard protocol to calculate a counterfactual baseline – the estimated amount of energy that would have been used in a specific building had an energy efficiency retrofit not taken place. Actual energy use after the retrofit is then compared against this baseline in order to quantify – or ‘meter’ – the amount of energy use avoided.”
> (Rathmell, *et al*, 2021, p.3)

Suggested applications for MES include:

- providing a basis for performance guarantees to underpin new retrofit financing products, business models and new forms of contracting and procurement (between energy utilities, networks and aggregators of energy efficiency projects);
- assessing the benefits of different retrofit options and estimation of the potential benefit in similar properties;
- measuring and verifying ‘avoided carbon’/ greenness;
- increasing consumer confidence and reducing supplier risk for Heat-as-a-service (HaaS) offerings;
- assigning a monetary value to efficiency and flexibility;
- predicting performance and savings on the basis of in-use data;
- enhancing the data richness of BRPs logbooks and renovation roadmaps. (Ibid)

GFI/CEEB’s recommendations for the MES protocol include that it should be Open Source to allow service providers to use a consistent approach. As highlighted by the SMETER work, candidate models should be developed and tested to create a reliable and sufficiently accurate yet workable approach. They advise drawing on existing data sets where possible and identify the following data requirements considered essential for core functionality: retrofit dates; energy consumption (e.g. via smart meter[23]); weather; occupancy. Additional highly desirable data are: indoor environmental quality (IEQ) monitoring; carbon savings; and data from assets in the home such as smart thermostats.

Collecting energy data from households under a MES protocol will also require a thorough legal review to guarantee it is compliant with the Smart Energy Code (SEC)[24] and Data Access and Privacy Framework (DAPF) while protecting personal data (Rathmell *et al.*, 2021).

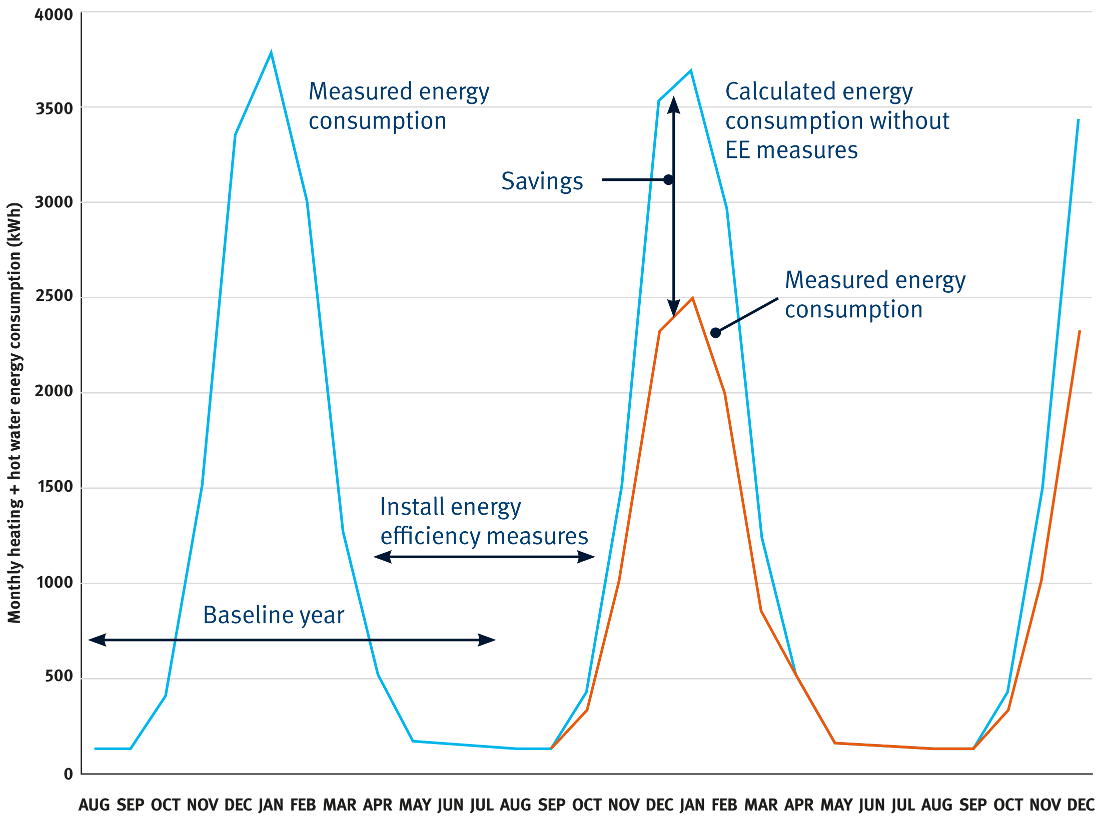


Figure 8: Metered Energy Savings (MES) in practice – establishing a baseline and measuring energy savings. Source: (Rathmell *et al.*, 2021)

[23] Up to 13 months of historic smart meter data are stored on smart meters, providing a useful baseline.

[24] The Smart Energy Code (SEC) is a multi-Party agreement which defines the rights and obligations of energy suppliers, network operators and other relevant parties involved in the end-to-end management of smart metering in Great Britain.

4.2 Measuring heat pump performance

Both air-source and ground-source heat pump technologies are proven, reliable and remarkably efficient: thermal output from heat pumps is several times the electricity input - as long as they are installed correctly. The greatest efficiency is achieved when heat pumps are correctly sized and run continuously at lower temperatures and paired with emitters with large surface areas such as underfloor heating or larger-sized radiators.

A better understanding of HP performance before installation can allow more efficient heating system design, better outcomes and more informed adoption. Post-installation assessment can check actual efficiency and also enable system optimisation but requires collection of in-situ performance data. Section 4.1 explored measurement-based assessment of building performance. The measurement of heat pump in-situ performance is considered below. To date, in-situ HP assessment has been carried out under three scenarios: metering heat pumps as a requirement for the Renewable Heat Incentive (RHI); as part of field trials; or monitoring of HP operation by manufacturers or interested heat-pump owners.

4.2.1 Metering requirements for dRHI and BUS eligibility

Metering HP performance has been, and continues to be, one of the requirements for receiving quarterly payments under the RHI. Domestic RHI payments are made for seven years from application and so, although new applications to the dRHI ended in March 2022, some payments and metering will continue until 2029. For ASHPs, there are two elements: metering for payment and metering for performance.

4.2.1.1 dRHI Metering for payment

For most applicants to the RHI, the size of financial payments are based on the estimated ('deemed') annual heat demand from the EPC and the estimated heat pump efficiency. In circumstances where estimates are difficult (for example, when a hybrid or back-up heating system exists), 'metering-for-payment' is required (Ofgem, 2018b). Applicants must have *electricity meters and heat meters* installed on the heating system and submit regular readings to Ofgem to receive payments.

The electricity meters are required to record and display electricity consumption used by the heat pump to generate heat and - if controlled by the same control system as the heat pump - any supplementary electric heater and any immersion heater for a domestic hot water cylinder (Ofgem, 2018b). The electricity metering therefore uses a 'system boundary' that includes electricity consumption by all this equipment (including fans and pumps) known as the SEPEMO H4 (see Box 3, Figure 5), although it may not replicate this exactly (Meek, 2021).

Heat meters measure the amount of heat the renewable heating system produces and consist of a flow meter, matched pair of temperature sensors, and a calculator (MCS, 2013).

Even if an ASHP installation is not metered for payment it must be 'meter ready' – i.e., an MCS engineer must leave sufficient accessible pipework for the installation of heat meter temperature sensors (MCS, 2013).

4.2.1.2 dRHI Metering for performance

Post-May 2018, all heat pumps applications to the dRHI required metering of the *electricity* consumption of the heat pump. This change was introduced "to help people to better understand their heat pump system's electricity usage and efficiency" (Ofgem, 2018a, p.6). This too, uses the SEPEMO H4 boundary.

4.2.1.3 dRHI Metering and Monitoring Service Package (MMSP)

The 'Metering and Monitoring Service Package' is an option that can allow a household to meet the requirements for metering-for-payment or metering-for-performance. For Domestic RHI participants it is also "a useful way of checking how well the heating system is performing and whether or not it is performing to the level promised by your installer" (Ofgem, 2022). The data also provides information for industry and for BEIS to evaluate the effectiveness of the RHI scheme.[25] Householders pay for the meter installation but receive extra MMSP payments[26] (Ofgem, 2018b). Heat meters, temperature sensors and electricity meters are installed by an MCS certified installer as detailed below (MCS, 2013; Ofgem, 2018d).

Electrical meters meter:

- all electrical supplies feeding the heat pump installation; and
- any electrical input to immersion heaters used for the DHW.

Heat meters meter:

- the heat output from the heat pump (more than one heat meter may be needed depending on the number of flow/return pipes exiting/entering the installation); and
- the heat output of any additional heaters that are connected to the same heat distribution system.

Temperature measurements:

- temperature sensors measure internal temperature at a minimum of one location;
- temperature sensors measure space heating flow temperature (the temperature sensor incorporated into the heat meter can be used);
- temperature sensors measure DHW flow temperature (the temperature sensor incorporated into the heat meter can be used); and
- for air source heat pumps, a temperature sensor (or data from a weather station within a 50-mile radius) measures external air temperature.

A software package monitors and records the system performance data at least every two minutes and logs data at least once per month. The data is pulled together and presented on a data-viewing online platform that shows the analysis and can be accessed remotely via a computer, laptop, tablet or smartphone (Ofgem, 2018d, 2018b). Ofgem may request MMSP data from the household on a regular basis, generally twice a year. Customers may give permission for Ofgem to obtain data directly from their installer who must store the data for 12 months (Ofgem, 2018c).

4.2.1.4 Boiler Upgrade Scheme (BUS) requirements

In April 2022 the dRHI was replaced by the Boiler Upgrade Scheme (formerly known as the Clean Heat Grant). Instead of quarterly payments, based on estimated heat demand or metered output, the BUS makes a single payment of a fixed sum (£5k for ASHP or £6k for GSHP). The BUS does not require new heat pump installations to be metered for payment. Further, eligibility for BUS requires no metering for performance either, ceasing the in-situ performance metering under the dRHI (BEIS, 2021d).

In a consultation on the 'Future support for low carbon heat', launched in 2020, 89% (140/157) of responses agreed with the proposal to require electricity metering for all heat pump installations, with only 2.5% (4/157) against (BEIS, 2021d). BEIS' decision to drop their proposed requirement for electricity metering of heat pump installations was based on their intention of "simplifying eligibility and facilitating scheme uptake" (Ibid, p.21), noting that accurately assessing system performance would require both electricity and heat meters.

The shift to up-front payments in the Boiler Upgrade Scheme also raised customer protection concerns in many consultation responses, specifically: an increased risk of "poor product and installation standards and under-sizing" and a "lack of incentive to install the most suitable system" or "any

[25] The number of MMSP registrations was limited to 11,255 (Ofgem, 2018d).

[26] For heat pumps, MMSP Payments were: £230.00 per year (for up to 7 years) pre-May 2018; or a lump sum payment of £805.00, plus £115.00 per year after May 2018; a total £1,610 in each case (Ofgem, 2018d).

need to determine their home's suitability for a heat pump" (BEIS, 2021c, p.27). Installers participating in the BUS do not need to be Trustmark registered nor is a whole-house retrofit assessment prepared under PAS 2035[27] a mandatory eligibility criterion (Ibid).

The lack of heat pump metering requirements for BUS, combined with a shift to grant funding without TrustMark accreditation or whole-house retrofit assessment is perhaps unfortunate in the context of ongoing debate and low confidence about heat pump installation outcomes and their suitability in homes. The dataset generated through metering-for-payment and the MMSP scheme has been valuable for revealing the inaccuracy of installer-forecasts of HP efficiencies – as seen in analysis by Meek (2021) that found more than 28% of ASHPs fell below the benchmark required under the RHI. Eligibility for BUS will,

> "require that all heat pumps have a minimum SCOP rating of 2.8, an increase from the minimum SCOP rating of 2.5 on the domestic RHI. The system *efficiency will be evidenced through the MCS certificate submitted by the installer* at the point of voucher redemption" (BEIS, 2021c, p.20; emphasis added).

But given the known problems of inaccurate installer performance forecasts, and a wide range of installer competences, with no metering of performance there is a risk that forecasted COPs will rise to 2.8 but actual SPFs will not. In light of this, and Government's awareness of "the need to increase consumer understanding of system performance" (p.20, Ibid), the ending of requirements to measure and report in-situ system performance may be a missed opportunity. BEIS cite the value of trial data as an alternative to ongoing metering:

> "There are other ways through which we are increasing the evidence base around the in-situ performance of heat pumps. For example, we are currently monitoring the in-situ performance of heat pumps through the BEIS Energy Innovation Programme's Electrification of Heat Demonstration Project which seeks to demonstrate the feasibility of a large-scale rollout of heat pumps, evaluating innovative products and services and addressing barriers to deployment" (BEIS, 2021c, p.20-21)

The Electrification of Heat Demonstration Project[28] launched in 2019 with a budget of £14.6 million and has now installed heat pumps in a range of homes. Technologies are provided free of charge in return for participating in the research and monitoring aspects of the project. It seeks to understand how participants perceive the performance of different types of heat pump, what challenges may be faced, and to understand how heat pumps could appeal to more consumers (BEIS, 2020a). Following completion of the installation phase, monitoring of heat pump performance will begin. Early findings indicate that "The suggestion that there are particular home archetypes in Great Britain that are "unsuitable" for heat pumps is not supported by the project data" (Energy Systems Catapult, 2021b, p.4). However, some types of properties are under-represented in the project, including flats, Victorian terraces and large old detached properties (Frerk, 2021).

As with the Ofgem RHI metering-for-performance dataset, analyses of heat pump field trial data have helped to reveal the wide distribution of achieved efficiencies (SPFs) and a performance gap between forecasted and actual efficiency (Gleeson *et al.*, 2017; Lowe, Summerfield, *et al.*, 2017) (see Section 3.3.1). Rather than being an alternative to widespread ex-post assessment and monitoring, data from trials have underlined the need for them.

[27] PAS 2035:2019 is an over-arching document in the retrofit standards framework introduced following the recommendations of the Each Home Counts review. It essentially provides best practice guidance for what is called 'whole-house' retrofit of domestic buildings, which takes into account the requirements of the entire building to eliminate problems with defects, shallow retrofit, accountability, poor design and performance gap.

[28] https://es.catapult.org.uk/project/electrification-of-heat-demonstration/

Moreover, there is a broad spectrum of installer competence (pers. comm., N. Gambling, Nov 2021) and while learning from field trials sheds light on some questions it is unclear how it would drive up practices and outcomes in the market day-to-day. Nor are field trials by themselves able to reassure and support individual consumers choosing a heating system and installer for their particular home.

4.2.2 Manufacturer and open-source monitoring

4.2.2.1 Remote system management

Another scenario under which HP real-world performance is metered and measured post-installation is for on-going monitoring to diagnose problems and optimise and manage the HP operation from a distance. A number of heat pump manufacturers have incorporated more hardware into heat pump installations to offer smart, cloud-based monitoring and remote management, typically via a smartphone app, e.g. Mitsubishi (MELCloud), Nibe (UpLink) and Daikin (Daikin Cloud Service and Residential Controller). Different hardware and services use different wireless technology standards such as Zigbee (e.g. Octopus API and Hildebrand Glow API), Z-Wave and wi-fi.

Monitoring the heating system (and any storage devices) can also improve the ability to optimise on running costs and carbon via smart automated controls that take advantage of time-of-use tariffs. For example, HP integration with the Agile Octopus tariff is possible by using the Octopus Agile API or, for MasterTherm heat pumps, using the Homely smart thermostat. Monitoring by the manufacturer, supplier or installer may, however, have limitations in terms of independent verification, common standards and data sharing that could facilitate like-for-like comparisons with other installations. In some cases, more independent performance monitoring may be possible by interrogating the HP's existing controllers to retrieve data, but the lack of a common standard protocol would mean separate programming for different manufacturers.

4.2.2.2 DIY and open-source monitoring

DIY and open-source monitoring kits are also available[29] which could offer monitoring equipment for any system at modest costs. Heatpumpmonitor.org is an initiative to develop a web-connected open-source hardware and software solution with monitoring, data visualisation, analysis and sharing of open heat pump data. A number of levels of monitoring accuracy are possible (Cantor, 2022b; openenergymonitor.org, 2022) – see Figure 9.

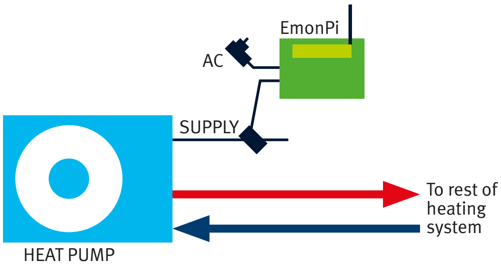
- At a basic level it is possible to monitor the electrical consumption of a heat pump by clipping a *current clamp* (CT sensor)[30] around the cable supplying the HP unit.
- The performance of a heat pump is greatly affected by the working temperatures so using *temperature sensors* to monitor the following will increase accuracy: water flow and return temperature from the heat pump unit; hot water cylinder temperature; outside air temperature.
- A further level of accuracy in performance monitoring is achievable by using *heat meters* that are more expensive than single-wire digital temperature sensors. These measure: total heat delivered in kWh; real-time heating power in Watts; flow and return temperatures; and flow rate in L/min of m3/hr (Lea, 2022). There are a number of different heat meter brands and models available that are RHI approved but most heat meters include an M-Bus[31] interface that can be used for reading the metering data, though a pulse counter is another option.

[29] E.g. https://guide.openenergymonitor.org/applications/heatpump/ https://heatpumpmonitor.org/

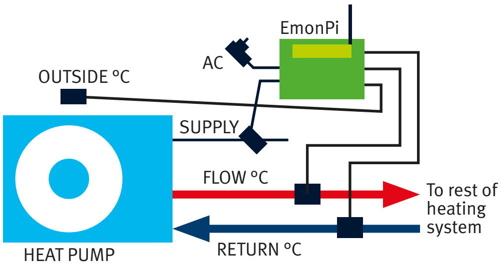
[30] Current Transformers (CTs) are battery-powered clip-on sensors that measure alternating current (AC) in a wire.

[31] M-bus or Meter-Bus is a European communication protocol standard used between meters and data collection systems. It is used for the remote reading of water, gas, electricity meters and is usable for other types of consumption meters such as heat meters. The M-Bus interface is made for communication on two wires, making it cost-effective.

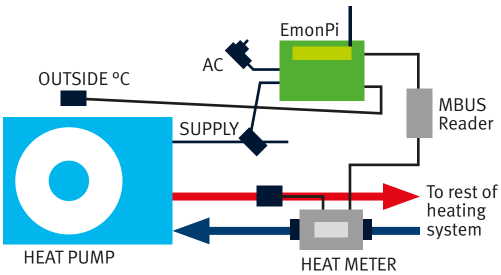
Data is typically received at the monitoring unit (such as an EmonPi open-hardware Raspberry Pi-Based Energy Monitor) then sent via Wi-fi/Ethernet connection to www.emoncms.org[32] where it can be stored and displayed on dashboards with real-time graphs and data for the previous hour/week/month or year.



Level 1: Electricity Consumption



Level 2: Adding system temperatures sensors



Level 3: Adding heat metering and flow rate

Figure 9: Hardware set-ups for three levels of accuracy in heat pump performance monitoring. Source: adapted from openenergymonitor.org, 2022

32 EmonCMS is a powerful open-source web-app for processing, logging and visualising energy, temperature and other environmental data.

As noted by the work on SMETERs and MES, the design criteria for systems measuring in-use performance should be steered by their purpose and functions and will involve trade-offs that include costs. The system boundaries shown here do not necessarily match the SEPEMO H4 boundary used for RHI metering but sensor-placement for system diagnosis and optimisation will differ to those for measuring whole-system energy use or costs and additional sensors could be placed to collect data at different system boundaries.

As heat pump installations involve an investment of several thousand pounds, and HP efficiency delivers greater comfort and lower bills, some customers will be willing to pay for monitoring to provide peace-of-mind and allow system optimisation and fault detection. If HP monitoring was more mainstream, hardware costs may drop with learning effects. Even without the more expensive hardware like heat meters, useful data could be collected to assess outcomes that matter to consumers such as whole house energy costs, basic HP performance data and indoor environmental quality (IEQ).

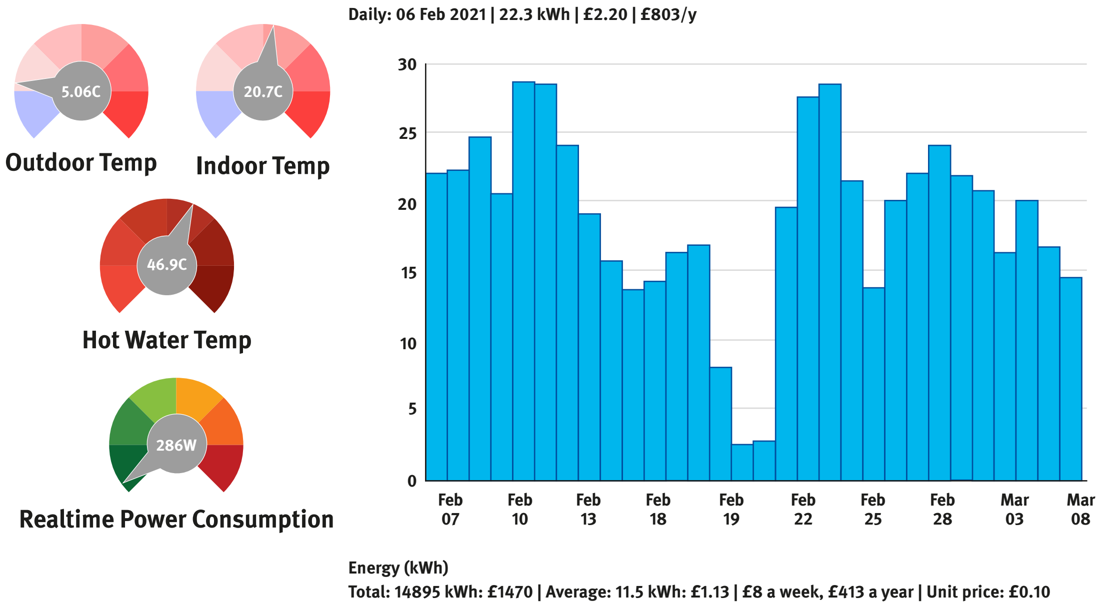


Figure 10: Example of heat pump monitoring display. Source: adapted from Cantor, 2022a

4.3 Key points

This chapter has explored the current and emerging policy and technology that might support a move towards greater measurement of in-situ and in-use performance of buildings and heat pumps.

- The Government's EPC Action Plan aims to produce accurate, reliable, and trusted EPCs that support low-carbon technology adoption and policy and are backed-up by a data infrastructure fit for the future. Planned changes to RdSAP methodology will correct out-dated carbon and fuel price assumptions, which currently discourage take-up of HPs. However, calls for more fundamental reforms have been widespread.

- The RdSAP EPC estimates of building heat loss typically vary widely from the actual thermal performance of buildings. There is also no currently mandated test to compare the estimated or predicted building performance to the real-world as-built and in-use performance achieved in either newbuild or retrofits scenarios. There is therefore a need for an accurate yet workable measurement of actual building performance that can be used at scale to inform energy efficiency and heating investment decisions.

- Signs of potential movement away from estimation to greater *measurement-based* assessment of building performance is apparent in work on Smart Meter Enabled Thermal Efficiency Ratings for homes (SMETERs), Building Renovation Passports (BRPs) and Metered Energy Savings (MES). SMETER technologies have successfully demonstrated the feasibility of using data from smart meters and sensors to calculate building heat loss (as Heat Transfer Coefficients/HTCs) with more accuracy than an expert RdSAP calculation and with more reliability than typical EPCs. Building Renovation Passports could improve on EPCs by using measured energy performance and providing both a digital logbook and a renovation roadmap for a property. Digital logbooks would have clear benefits for making building data updatable and accessible, but at present there appears to be more focus on logbooks to catalogue past work than on roadmaps to guide retrofit decisions going forward. Metered Energy Savings have a stronger focus on developing a protocol for making before-and-after comparisons to clarify the value-case of retrofit options. This could help unlock finance and potentially support retrofit decision-making. MES recommends an open-source approach and has sketched out data requirements.

- The work on SMETERs, BRPs and MES has also highlighted some common issues for implementing measurement-based assessment, notably: methods and metrics should follow purpose and functions; trade-offs will need to be made between accuracy, convenience and cost; and there are unresolved issues around how to deal with the effects of occupancy on in-use measurement.

- Heat pump installations were required to be metered for payment and or performance under the dRHI and were paid to do so under the MMSP. This has demonstrated that the in-situ performance of HPs can be measured using electricity meters, temperature sensors and heat meters. Some hardware is substantially more costly and may require professional installation. Proprietary and open-source monitoring of HP performance for system control and optimisation has also shown that collecting in-situ performance data is both technically and commercially feasible.

- With the introduction of the Boiler Upgrade Scheme (BUS), in April 2022, there are no requirements for in-situ HP metering in new HPs. Combined with other changes (a move to up-front financial support, no requirement for a PAS 2035 whole-house assessment for HP suitability, and no TrustMark requirements for BUS installations) there may be increased risk of poor outcomes for consumers. The move to requiring less, rather than more, data collection on HP real-world performance is regrettable in the present context of evidence gaps, contentious debate and low consumer confidence about heat pump installation outcomes and their suitability in homes.

- While data and learnings from HP trials and demonstration projects has value, their datasets are inevitably constrained and they have no impact on the day-to-day practices of installers in the heat pump market through transparency, accountability or learning. Nor do trials give peace-of-mind to individual householders about their installer or the performance of their HP system as installed.

Overall, the UK and devolved governments recognise the importance of engagement, education and access to impartial information and support for consumer choices. However, the detail on how to do this, and where data will come from, is scant. Policy commitment to measuring in-situ performance of new HP installations has retreated. This chapter has reviewed a range of assessment, metering and monitoring solutions that could reduce or replace current reliance on estimated or deemed performance of buildings and heat pump systems. Chapter 5 considers how greater commitment to making such measurement mainstream could enable multiple stakeholder benefits if fully leveraged through sharing this data.

5. Sharing case study data for peer-to-peer learning

The previous chapter explored possibilities for moving towards greater use of measurement-based assessment of in-situ building and heat pump performance. This chapter explores how sharing widely such real-world performance data from HP installations, along with consumer experiences, could help support and accelerate the HP transition. It also considers some issues for accessing and sharing such data.

5.1 Peer-to-peer learning and diffusion of innovations

The HP transition in the UK has remained somewhat stuck in the start-up phase (Gross & Hanna, 2019) and consumers have been largely passive (Martiskainen *et al*., 2021). But where HP consumers and users have taken a more active role the transition to HPs has progressed much farther and faster. A clear example is peer-to-peer (P2P) learning via online forums and its contribution to the HP transition in Finland – see Box 5.

» BOX 5: Online heat pump forums in Finland

Online forums have been cited as having been effective in driving uptake of heat pumps in Finland (Hyysalo, Juntunen & Martiskainen, 2018; Martiskainen *et al*., 2021; NESTA, 2021; Sovacool & Martiskainen, 2020).

> "In the early 2000s, there was still a lack of awareness of heat pumps amongst the public (FINExpert02), with many doubting ASHPs' suitability in a cold climate [...] many users set up online internet forums (Hyysalo *et al*., 2018), motivated by the need to create independent platforms which allowed the sharing of user experience through user-intermediaries. Heat pump sales in Finland have seen a steady increase since 2010 [...]. In 2019, 930,000 heat pumps had been sold, rising to over a million in 2020"
> (Martiskainen *et al*., 2021, p.128)

Forum participants include both customers and installers:

"The internet brought heat pump discussion forums, where users and installers swapped stories in an environment of trust and collaboration. This is important to note: although regulation has driven the scale of this transition, individual households have played a key role."
(NESTA, 2021, p.1-2)

Other work in Finland on peer-to-peer learning for adoption of residential energy solutions has found that community-based Open Homes and 'Energy Walks' can support discussion and reflection (Heiskanen, Nissilä, & Tainio, 2017).

Martiskainen *et al* (2021) note that in the UK, while there are some blogs, websites and social media activity, such collective action by user-intermediaries seen in Finland is scarce:

> "We argue that this passive attitude of users may be an important missing factor for a domestic heating transition in the UK. In Finland users have been very active, and without them the transition would have been much slower, resulting in persistent market uncertainties that manufacturers and installers may not have been able to solve just by themselves."
> (Martiskainen *et al*., 2021, p.136)

Word-of-mouth and peer-to-peer learning in households' energy-related decision-making is recognised more widely:

> "the influence of peers such as family members, neighbors or colleagues is a significant determinant for [residential heating systems] uptake (see e.g. Claudy *et al*., 2011; Michelsen and Madlener, 2012, 2013, 2016; Nyrud *et al*., 2008; Scarpa and Willis, 2010; Sopha and Klöckner, 2011; Woersdorfer and Kaus, 2011). Thus, the word-of-mouth communication resulting from the experiences of earlier adopters plays a crucial role in the uptake and diffusion of low-carbon [residential heating systems]."
> (Michelsen & Madlener, 2017, p.1286)

> "When sourcing an [gas boiler] installer, word of mouth and recommendations from friends, family and neighbours played a key role"
> (BEIS, 2021b, p.13)

> "Peer-to-peer informal learning can help spread new, low-carbon technologies. Learning from the success of neighbours and others, while quickly creating a positive regulatory environment with financial incentives, can help combine state-led regulation with bottom-up innovation and enterprise. Consumers can help if governments make it easy for them."
> (NESTA, 2021, p.1)

The regulatory environment and financial incentives can make it easier for consumers to play this active role. But government could also help by making peer-to-peer learning and knowledge-exchange easier. Discussions of practical interventions to support HP adoption have generally overlooked the potential of P2P-learning, the lessons from the Finland transition, and peers as trusted sources of information for low-carbon heating decisions (e.g. BEIS, 2020c, 2020d). In a survey for BEIS, respondents were asked what source(s) they would most trust for advice or information about low-carbon heating systems (BEIS, 2020g): 19% listed 'Friends & family'[33]. However, unlike gas boilers, it is unlikely that friends or family would have first-hand experience with low-carbon heating systems given the low levels of penetration currently. *Peers with first-hand experience* of low-carbon heating are key to P2P learning but were not included in the survey.

The principle of encouraging behaviours to spread peer-to-peer is, however, not unfamiliar. For example, the well-known EAST framework recommends 'using the power of networks':

> "We are embedded in a network of social relationships, and those we come into contact with shape our actions. *Governments can foster networks* to enable collective action, provide mutual support, and encourage behaviours to spread peer-to-peer."
> (Service *et al*., 2014, p.5, emphasis added)

There are a number of reasons why enabling peer-to-peer knowledge-sharing could be exceptionally effective for supporting the transition to heat pumps and why fostering these networks should be pursued. Diffusion of Innovation (DoI) theory suggests some further opportunities for a P2P approach to heat pumps.

[33] Respondents were able to select a maximum of three sources from a list of seven.

5.1.1 Accelerating the Diffusion-of-Innovation cycle

As recent work by NESTA on the user journey for heat pump adoption has highlighted,

> "less than 1 per cent of home heating installations per year are heat pumps. [...] Thus, according to Rogers' model of the innovation adoption lifecycle, we are still firmly in the innovator phase. [...] Innovators pave the way for the Early Adopters who will follow them, helping mature the market and allowing suppliers to develop methods and approaches."
> (Cretu & Zanetti, 2021, p.4)

The authors conclude that efforts to increase heat pump uptake now should focus *not* on smoothing the journey for the majority of householders and "trying to run before we can walk", but rather "it's about making the journey for Innovators less complicated" (Cretu & Zanetti, 2021, p.4-6). Importantly, this recognises that heat pump adoption is a process of diffusion through society over time and that different users adopt at different points in the diffusion lifecycle and may require different support. This perspective also prompts reflection on what interventions are most appropriate to the current stage within the DoI lifecycle.

However, it may not be productive to be overly-focussed on 'Innovators' and their psychology, which is characterised by: 'venturesomeness'; a higher tolerance for uncertainty and risk; more favourable attitudes towards science and technology; and higher self-efficacy and internal locus of control (Rogers, 2003)[34]. We need to consider the innovation as well as the adopter. Rogers stresses that innovations are not equivalent units of analysis and that "the characteristics of innovations, as perceived by individuals, help to explain their different rates of adoption" (Ibid, p.15).

We know that the distribution of HPs to date is not uniform nor driven only by Innovator personality variables. Heat pumps have serious impacts on finances and comfort. Adoption decisions are in large part driven by the perceived *value-case and benefits* of switching heating systems, and these will be clearer for some properties than for others. The financial value-case for HP retrofit is clearer for off-gas grid properties whose existing heating system is an oil or LPG-powered boiler. Accordingly,

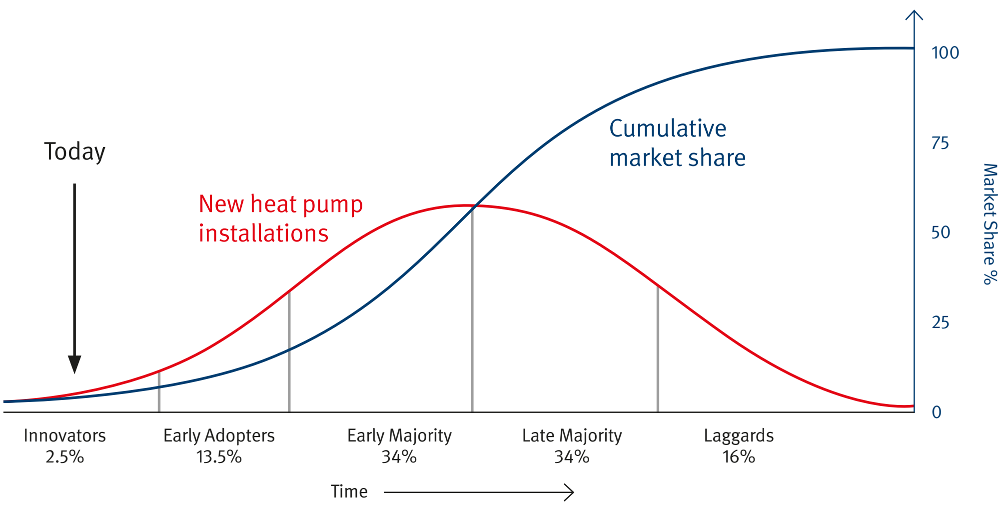


Figure 11: The Diffusion of Innovation lifecycle for heat pumps. Source: adapted from Rogers, 2003.

[34] Rogers (2003) notes that the personality variables of each of the adopter categories is sometimes overplayed and is clear that there is a continuum of 'innovativeness' and no support for there being discontinuities between those adopting at different stages.

domestic installations are predominantly seen in rural locations off the gas grid and are most common in remote parts of Scotland (MCS, 2021c). The payback period is much less convincing for a small, energy-efficient flat that might benefit from lower-cost modern storage heaters (Frerk, 2020a) that could also reduce peak-time consumption. As Frerk (2021) puts it, there is a need to recognise an important element of 'horses for courses' in heating solutions decisions. The ability of some HPs to supply cooling to combat overheating might also be factored into choice of heating system, again depending on characteristics of the property rather than the 'venturesomeness' of the householder.

In DoI theory, the expected financial and thermal comfort outcomes from a HP installation are crucial to the 'relative advantage'. Relative advantage is one of five *perceived attributes of innovations* that influence the rate of adoption for *all* adopters. Innovative technologies and services are adopted more rapidly when they are seen as having: high *relative advantage*, high *trialability*, high *observability*, high *compatibility* and low *complexity* (see Table 1).

Table 1 Perceived attributes of innovations associated with rate of adoption

Perceived attribute of innovation	Definition (Rogers, 2003)	Relevance for the diffusion of heat pumps (HPs)
Relative advantage	The perceived superiority and attractiveness compared to pre-existing products/ innovations.	Consumers will need to believe HP propositions are at least as attractive as the gas and oil powered boilers to which they have grown accustomed. Cost and comfort will be key aspects, but awareness and confidence is low.
Compatibility	The degree to which an innovation is seen as being compatible with consumers' existing values, past experiences, habits and needs.	The perceived compatibility of HPs may suffer due to low awareness and unfamiliarity with HP technology, new controls, and time-of-use tariffs. Whereas a like-for-like swap is possible with a replacement gas boiler, a HP may require additional changes to the building and further disruption.
Complexity	The perceived difficulty to understand and use the innovation.	There is considerable complexity involved in HP adoption decisions. The perceived complexity of HPs may be increased by new heating controls and operating the HP flexibly.
Trialability	The degree to which an innovation may be tried or experimented with on a limited basis.	Heat pumps are a high-cost item that cannot be returned or resold and 'try-before-you buy' is not possible.
Observability	The visibility of the innovation, its effects and or its adoption.	Heat pumps, and heat pump adoption are often not conspicuous to passers-by or even neighbours; they have low observability.

Most consumers are not confident that heat pumps offer them the high relative advantage, high compatibility and low complexity that would support adoption. The *trialability* and *observability* of HPs are also inhibiting rapid diffusion (Carmichael, 2019). Heat pumps are a high-cost item that cannot be returned or resold, and 'try-before-you buy' is not possible, so they can be said to have low trialability. For electric vehicles (EVs), by contrast, a potential adopter can test-drive, hire, or lease various models without needing to commit to a purchase. HP adoption also has low observability: HPs are largely inconspicuous whereas EVs are quite visible on the street and on the roads (still more so with the introduction in the UK of green number plates for EVs) and purchases of rooftop PV panels have been observed to occur in clusters due to their high observability (Baranzini, Carattini, & Péclat, 2017).

Innovators pave the way for Early Adopters, but Early Adopters in turn "help trigger the critical mass when they adopt an innovation" (Rogers, 2003, p.283). The broad point is that all adopters can be influenced, reassured and emboldened by those who adopt before them and that accelerating the diffusion-of-innovation lifecycle for heat pumps will mean considering the range of perceived attributes of HPs that currently inhibit take-up. Facilitating peer-to-peer learning through case studies could deliver much towards these objectives.

5.2 Case study database: crowdsourcing data and sharing experiences

Earlier work has recommended supporting heat pump diffusion via a public database of case studies showing the real-world outcomes and experiences of heat pump installations and has briefly outlined the rationale and potential benefits of this approach (Carmichael, 2019; Carmichael *et al.*, 2020). This would involve two components: *measuring* actual installation outcomes for energy performance, costs, and customer satisfaction and then *sharing* this data to make it widely accessible. Chapters 3 & 4 of this briefing paper have explored in more detail the need for, and feasibility of, moving to more measurement-based assessment of heat pump and building performance. The range of potential stakeholder benefits from sharing this and other data as case studies is discussed below. Some practical aspects of sharing data are also considered and some suggested data requirements are sketched out.

5.2.1 Case study data

The Green Homes Network (see Section 3.1) offers case studies of households who have adopted low-carbon heating and other energy technologies, but these lack the detail and data that would enable adopters to compare HPs with other options or deliver wider stakeholder benefits. Borrowing an expression applied to debates about power generation, we need *numbers* not adjectives:

> "This heated debate is fundamentally about numbers. How much energy could each source deliver, at what economic and social cost, and with what risks? But actual numbers are rarely mentioned. [...] . *To make this comparison, we need numbers, not adjectives*."
> (MacKay, 2009, p.3, emphasis added)

The case studies proposed here would present detailed and accurate quantitative assessments of energy use, costs and consumer satisfaction before and after the installation of the heat pump (and any other retrofit measures). Data would cover a pre-installation baseline period and post-installation outcomes and would be designed to enable a before-and-after comparison. This could clarify the value-case and thereby support adopter decision-making.

Each case study would provide details of the property, previous and secondary heating systems, the installed technology and services, and installer. No personally identifying information would be included unless informed consent is obtained. Technical data would draw on smart meters, sensors, monitors and analysis and include measured assessments of: building performance (including use of SMETERs); HP in-situ performance (as SPF); indoor temperature and humidity; and estimated carbon emissions. Financial information would include installation costs, financial support received, running costs and energy tariff information. This technical, quantitative data would be accompanied in the case studies by consumer satisfaction data collected from the adopter and/or occupant(s). See Appendix, Table 3, for an indicative summary of data requirements and collection methods.

Data collection for cases studies would be based on crowdsourcing data from heat pump installations occurring spontaneously. There are number of advantages to this approach compared to heat pump field trial data, including:

i. the data would reflect outcomes from installations carried out under real-world market conditions and installer practices and competence levels;

ii. more cost-effective form of data-collection;

iii. allowing adopters to contribute data and experiences allows previously passive consumers an active role in helping to shape and support energy transitions;

iv. the database would contain a large and varied range of properties, technologies, services and occupants – this heterogeneity is highly valuable for P2P learning and addressing evidence gaps (see Section 5.3.3 Researchers and Policymakers).

5.2.2 Consumer satisfaction

Decarbonisation of heat and buildings will require people to make changes within their homes. This includes new heating systems and energy efficiency upgrades but also getting used to new heating controls, tariffs and habits. Customer satisfaction data would be designed to answer potential adopters' questions and concerns about installation and outcomes, technologies and installers. Data collection about adopter and occupant satisfaction would include:

- does the HP keep the home warm enough?
- is there always enough hot water?
- are occupants satisfied with the running costs and tariff?
- is the heating system reliable?
- have occupants experienced issues with noise from their HP?
- are the HP system controls easy to operate?
- how disruptive was installation?
- were they satisfied with their installer?
- is technical support adequate?

Satisfaction would be reported in the form of a numeric/quantitative rating format – for clarity and ease of comparison and to allow graphical presentation, such as a spider plot (see Box 6, Fig. 12). As highlighted in the work on measurement-based assessments such as MES and BRPs, there will likely be a need for trade-offs when determining metrics of satisfaction, for example, between detail, accuracy, simplicity, clarity and ease of data collection (see Box 6: Measuring occupant satisfaction).

An additional free-text field for adopters/occupants to share experiences in their own words should also be included. This could also help to: build engagement and trust among database users; explain unexpected technical data and quantitative satisfaction scores; and reflect the needs, habits and experiences of atypical households, such as those with unusual requirements for indoor temperatures or DHW due to occupancy, age or health conditions.

» BOX 6: Measuring occupant satisfaction with heat pumps

Previous work on occupant satisfaction with heat pumps reveals the complexity of the notion of satisfaction:

“Many factors appear to contribute to occupants’ satisfaction with their heat pumps. These include perceived comfort, bills, perceived environmental benefits, controllability, experience with previous heating system, information provided by the installer, time to fix faults etc.” (Lowe, Chiu, *et al.*, 2017, p.33)

Metrics of occupants’ experience of thermal comfort is potentially complex, particularly when considering its connection with sense of control, preferences (e.g. comfort tolerances), understanding of HPs, and occupant behaviours (including how the HP is operated). Some of these would, ideally, also be captured, particularly as continuous operation of heat pumps is associated with higher efficiencies and, therefore, user satisfaction. Some work, however, finds that “relatively simple metrics for heating performance, relating to occupant comfort and energy use, can be powerful tools for comparing upgrade options.” (Energy Systems Catapult, 2018a, p.113).

Generally, users have reported good levels of satisfaction with HP systems (e.g., Lowe, Chiu, *et al.*, 2017). Caird, Roy and Potter (2012) found high levels of satisfaction with space-heating and DHW requirements, though a significant minority of users experienced one or more problems - see Fig. 12.

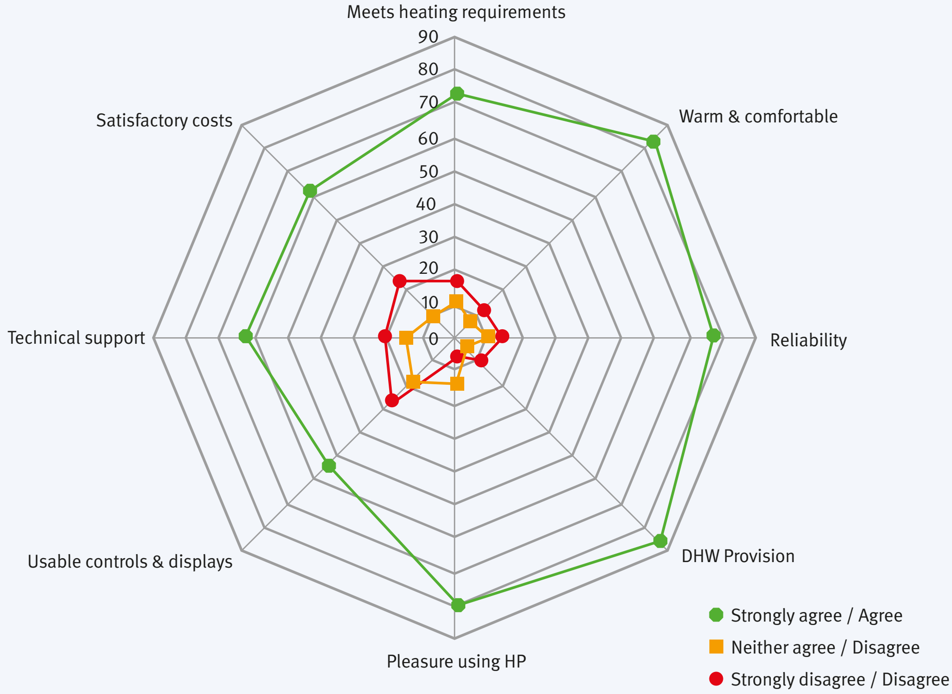


Figure 12: User satisfaction with the heat pump system
Note: Radial lines present users’ responses in percentages.
n = 66-74 (n for DHW question = 49)
Source: Caird *et al.*, 2012

5.3 Users and benefits

Two main communities would use a case studies database: heat pump adopters and heat pump installers. The dataset of real-world HP outcomes in a wide range of households could also be of great help to policymakers and researchers.

5.3.1 Adopters and occupants

The case study database would afford adopters of HPs two opportunities to play more active roles in the low-carbon heat transition: as case study participants and as users of the case study database.

Moving to a situation where HP in-situ performance is measured as common practice would offer potential adopters some immediate benefits: the reassurance of checking the performance forecast given by their installer and also monitoring to optimise the system operation (see Chapter 4). If the adopter then chose to share their installation on the case study database this would fully leverage their installation data for the benefit of multiple stakeholders.

Consumers at the stage of contemplating HP adoption could enjoy the following benefits from using the HP case study database. In terms of Diffusion of Innovation (DoI) theory, the case study database has potential to address several perceived attributes of heat pumps associated with a slow rate of adoption: trialability, relative advantage, complexity, compatibility and observability.

Mitigate the low trialability of HPs: if heat pumps can't be tried out temporarily before committing to an expensive purchase, the next best thing is for potential adopters to learn from other people's experiences of their HPs via peer-to-peer learning and knowledge exchange.

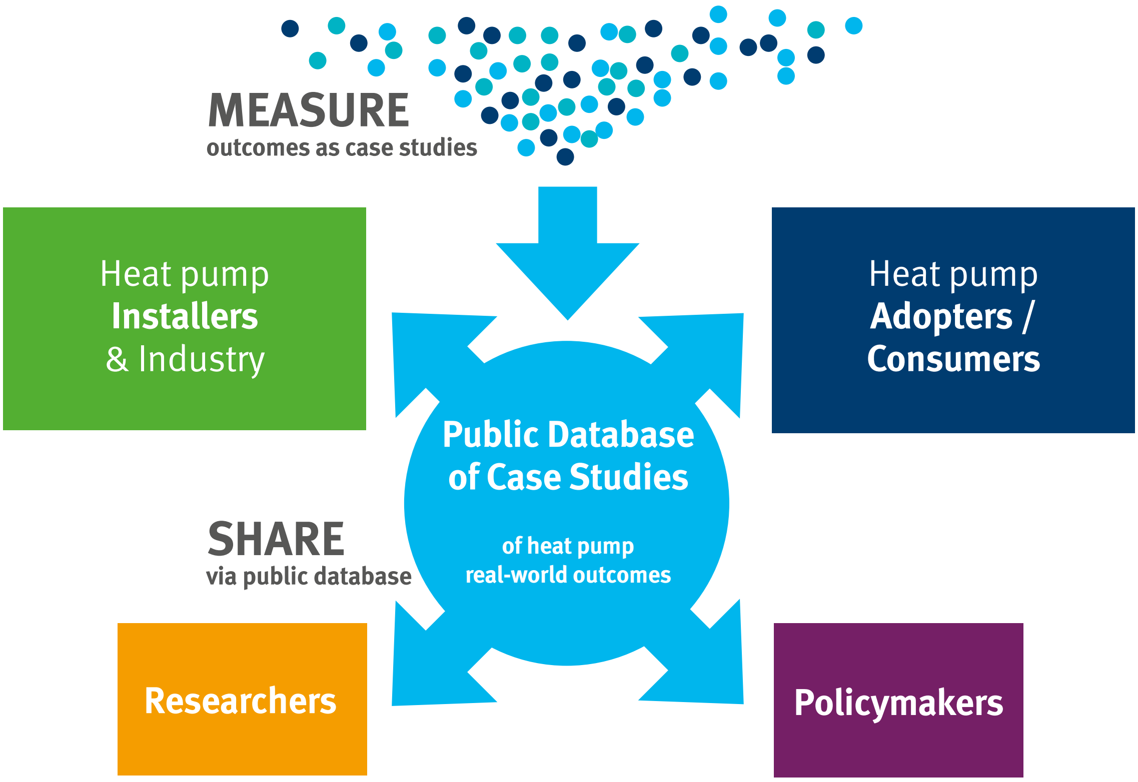


Figure 13: A database of case studies of heat pump installation outcomes would be of use to multiple stakeholders

Improve the perceived relative advantage, complexity and compatibility of heat pumps compared to gas/oil or other heating systems: P2P learning could allow clarification of a great many issues affecting the current low consumer awareness of and confidence in HP technology and installers. Potential adopters have a range of specific concerns about the in-situ performance and costs of HPs. Any of these complexities and uncertainties could cause a potential adopter to hesitate, defer or abandon their decision to adopt. Potential adopters' questions include:

- what would the installation costs, return on investment (ROI), and payback period be?
- what would my heating bills be with a heat pump?
- how disruptive will installation be?
- which brand and model of heat pump to choose?
- will the HP be noisy?
- should I choose a low temperature or high temperature heat pump?
- which installer should I use?
- which heating system controls should I choose?

Further complexity and choice overload is introduced by the need to consider efficiency (e.g. building fabric improvements) and flexibility (e.g. storage, smart tariffs and/or secondary heating systems).

> "The 'right' balance between energy efficiency and flexibility and low-carbon heat supply is highly context-dependent but in most, if not all, cases will include all three elements in order to avoid unnecessary overinvestment."
> (Rosenow & Lowes, 2020, p.9-10)

UK building energy efficiency retrofits have stalled (Rosenow *et al.*, 2020) but case studies showing before-and-after comparisons could help to clarify for consumers the value-case for fabric first investment that lowers bills through reduced heat demand and increased HP efficiency. Lower building heat losses may also have potential to allow greater flexibility in heat pump loads by pre-heating, further reducing bills and carbon (Carmichael *et al.*, 2020).

Additional questions include:

- is my home 'heat pump ready' and what, if any, fabric improvements should I undertake first?
- should I keep a secondary heating source or choose a smart hybrid heating system?
- could I save on bills using a time-of-use electricity tariff?
- what would be the most cost-effective, efficient and convenient combination of technologies alongside a HP? – e.g. heat pump with water thermal store, heat battery or battery storage device.
- should I swap existing radiators for larger ones or under-floor heating?
- should I upgrade to wider-bore pipework?

Hyysalo *et al* list a similar range of concerns that are discussed in posts to online forums:

> "Guiding prospective users to these parameters is paired with instructions, calculators and long threads related to each of these key topics"
> (Hyysalo *et al.*, 2018, p.877).

This kind of P2P learning will be too time-consuming, complicated and piecemeal for many potential adopters. A case study database could draw on reliable measured data from many more examples of installations and present it in a systematic and more actionable format. A standard template would summarise key outcomes in an accessible way, with more detailed data behind that for those who wish to look deeper. The database should be searchable and filterable by a variety of building, occupant and installation characteristics (technology, budget, installer, etc.) to allow users to find and compare cases of most relevance for their circumstances and objectives. Discussions and Q&A on online forums could still be helpful but would be more productive if able to draw on case study material. Forum users could post questions referring to specific case numbers.

For households with less digital literacy or access, the case study database could be used by customer advice organisations (e.g. Simple Energy Advice, Citizens Advice, Energy Saving Trust, Home Energy Scotland, National Energy Action) to provide tailored support over the phone or in person.

5.3.1.1 Observability and Social influence

Information provision is sometimes criticised as being an individualistic and ineffective approach to behaviour change that assumes consumers act as an overly-rational *Homo economicus* or 'Economic Man' making decisions according to a cost-benefit calculus. However, as seen with price comparison sites and DCTs, data-led third-party digital tools are used and appreciated by the majority of UK households when making energy tariff choices. Even more clearly, consumers do not purchase a mortgage without using a digital calculator tool to know what their monthly payments would be and clarify affordability. Moreover, cases studies are not just 'information' and advice: providing technical and customer satisfaction data would unlock P2P learning, thereby bringing to bear social networks and social influence effects.

Low observability of heat pump adoption could be mitigated by case studies making adoption more visible, albeit digitally. A database displaying the number of installations, approximate location, and customer satisfaction ratings could demonstrate to potential adopters that people are buying heat pumps now and are happy with them. This would help the social side of innovation diffusion to work in support of, not against HPs, including both normative social influence and informational social influence effects.

Informational social influence (or *social proof*) is the tendency for a person to be guided by others when faced with complex, ambiguous and unfamiliar situations and choices (Kahneman, 2003). Heat pump adoption involves dealing with the unfamiliar and complex. Influence tends to be stronger when there is information from a number of sources (the 'multiple source effect'), so it will be important to grow the number of case studies to better reflect the scale of adoption. Potential barriers to adopters/occupants sharing their installation on the database (such as concerns over privacy and inconvenience) should be mitigated in order to maximise case study numbers.

Normative social influence refers to pressure to fit in and conform with the group so as to not appear foolish or be left out. Currently, this too is acting to perpetuate gas boilers as the 'sensible' choice of 'normal' people. Visibility of mass adoption of HPs would help to shift norms and make them a more acceptable and easier option.

Work from behavioural economics, including the MINDSPACE report (Dolan *et al*, 2009) has stressed norms: "we are strongly influenced by what others do" (p.18). This work also highlights that "we are heavily influenced by *who* communicates information" (ibid, emphasis added) – here expertise matters, but so do peer effects. Messengers seen as *similar* to the recipient (in terms of demographics, behaviour or identity) tend to be more influential. Policymakers recognise the importance of trusted advice and trusted messengers, but the potential of peer-to-peer solutions has not yet been explored. Case studies from a broad range of households could effectively combine both expertise (though their first-hand experience) with relatability. Users would also be able to search and see cases with properties and households similar to their own, further increasing perceived similarity.

People are often held to account for their purchasing decisions (Strong, 2014) and the opinions or reactions of others may be a further social barrier to adoption. As previously noted for energy price comparison tools (Carmichael, 2019), the case study database could provide potential HP buyers with credible and accessible information not only for their own peace-of-mind but also to justify adoption to a potentially sceptical spouse or critical neighbour, thereby further lowering social barriers.

Heat pump adoption may be a decision taken jointly by more than one person in a household. In the rental sector, landlords' and housing association decisions about heating systems and retrofit affect their tenants. The case study database could be useful for reaching agreement and avoiding conflict between these parties by using data to get beyond differences of opinion.

The current social environment is not supporting the behaviour change needed for heat pump adoption or for Net Zero targets more broadly. Enabling social influence effects, as outlined above, could help to turn a previously negative, inhibiting effect of low observability and norms for heat pumps into a self-reinforcing positive feedback effect: more visibility of adoption leading to more installations which produce stronger social influence effects leading to still faster adoption. There is evidence of such 'social contagion' in a range of consumer behaviours, including rooftop PV panels (Baranzini *et al.*, 2017), SUV sales, excessive calorie intake, smoking and electricity conservation behaviours (Frank, 2020). The online database of HP case studies is an example of how data-driven digital tools could contribute to social environments becoming more supportive of net zero behaviours: it would go beyond online forums or word-of-mouth and 'supercharge' peer-to-peer learning, leveraging both technical/financial data and social influence effects. (See Section 5.3.4 for wider positive feedback effects.)

As highlighted for online forums, users sharing their experiences can play a role in 'policing' and scrutinizing market actors such as heat pump suppliers and installers (Martiskainen *et al.*, 2021; Sovacool & Martiskainen, 2020). As the database of case studies grows, it would be possible to produce up-to-date rankings of installers based on installation performance and customer ratings. This could be invaluable for helping adopters to find a trusted installer (see Box 7). This also gives currently passive 'consumers' a much more active and influential role in heat transitions as they share their data and experiences, appraise technologies and market actors, and become more discerning adopters.

» BOX 7: Online customer reviews and electronic word-of-mouth (eWOM)

A report by the CMA found that online reviews are popular, trusted, reliable and form an important part of consumers' decision-making processes, including playing a role when narrowing down or widening product options:

"Across the six broad sectors that we looked at, we estimate that £23 billion a year of UK consumer spending is potentially influenced by online reviews [including] £3.93 billion on home improvements" (CMA, 2015, p.16)

Online consumer reviews are now widely used and influential (Littlechild, 2021a). Trustpilot.com, for example, offers customers the ability to leave reviews of companies and products and has grown rapidly in the UK to over 37 million reviews of over 97,000 UK businesses in mid-2020. Scientific work is lacking on how online reviews and electronic word-of-mouth (eWOM) influence purchase decisions of heating systems. Within the energy retail market, energy suppliers increasingly see achieving a satisfactory TrustScore and analysing customer reviews to improve customer service as essential components of company policy and most large companies continued to be active in inviting reviews (Littlechild, 2021b). Price comparison sites advising customers on energy suppliers are active users of Trustpilot and score highly (Littlechild, 2021a).

Some concerns and issues exist regarding online customer product or seller reviews (BEIS, 2021i). The CMA (2015) highlights: fake online reviews; businesses paying for endorsements; and negative reviews not being published. An OECD (2019) report, *Understanding Online Consumer Ratings and Reviews*, notes the following longer list of limitations to online reviews:

- fake and incentivised reviews;
- missing reviews supressing negative feedback;
- lack of accuracy;
- consumer bias - consumers tend to both write, and be more influenced by, extremely positive or negative ratings and reviews;
- selection bias - consumers are inclined to post more polarised ratings and reviews to influence ratings and reviews of a product in order to align them with their own opinion;
- confidence in user-generated feedback is highly contextual and variable.

There are several ways in which an online database of heat pump case studies would be less vulnerable to the issues identified above. Fake or incentivised reviews will not be possible, as only confirmed installations would be on the database (MCS already keeps a register of certified installations). It would not be possible to entirely avoid the issue of negative customer feedback being supressed through missing reviews or overly-generous reviews (the work being carried out at the customer's home, involving face-to-face interaction with the installers, can make some consumers uncomfortable with leaving a negative review for a local installer. However, the presence of 'hard' technical data, from independently-measured assessment of heat pump and building performance and costs, will do much to counter missing customer satisfaction data and identify when customers' feedback does not match outcomes.

5.3.2 Installers and industry

A shortage of heat pump expertise is a bottleneck for supply and also undermines consumer confidence and demand. There is a widely-recognised shortage of trained heat pump installers required to meet UK installation targets (CCC, 2019d; MCS, 2021c). Even among trained installers there is a very wide spectrum of competence (pers. comm., N. Gambling, Nov 2021). There is very little incentive for installers to upskill in the current context: few installers and slow market growth; no assessment of the actual HP performance post-installation; and eligibility criteria for the Boiler Upgrade Scheme which does not require installers to be Trustmark registered or to carry out a whole house retrofit assessment under PAS 2035.

Typical recommendations for addressing the skills gap suggest: expanding existing training standards; introducing high-quality job standards; more funding for training and skills academies; and clamping down on bad certification practices (Emden & Rankin, 2021). A vital complement to these measures will be to provide both the *incentive* and the *learning material*[35] for increasing the number and competence of installers. Assessing and sharing outcomes via case studies could provide the missing piece to improve both.

Firstly, a public database displaying the achieved performance, costs and customer satisfaction with HP installations would *incentivise* installers to deliver good outcomes and would reward excellence and good practice, while weeding out incompetent operators.

Secondly, the proposed case study data would provide practical *support* for upskilling and continuous learning:

- measurement of building performance would provide installers with more accurate data for system design (including HP sizing calculations) and performance forecasts given to customers;
- ex-post assessments of HP and building performance would supply feedback on results to enable learning-by-doing and could also support CPD and monitoring of competence by MCS and RECC);
- the case study material would provide a rich resource ideal for training, teaching and peer-to-peer learning activities. Online discussion forums and more formal training could greatly benefit from interrogating and comparing case studies - for example:
  - "In Case 1420, why do you think the achieved SPF did not meet the forecasted efficiency (HPSPE) and how might this be remedied?"
  - "Why did Case 3037 achieve a better heat pump SPF but lower customer satisfaction than Case 902?" or
  - "Why did the combination of ASHP and energy storage produce better SPF and lower costs in Case 711 than in Case 88?"
- Access to data on real-world performance and outcomes could also permit exploration of possible improvements to current best practice guidelines, manufacturer guidance, design tools, MCS documentation and training. Standard practice could be assessed and compared with alternative installation practices to explore opportunities for lowering installation costs while still ensuring safety and high performance. Issues within current best practice that might benefit from evidence-based scrutiny include: assumptions (e.g. about building air change rates and DHW demand) embedded within HP sizing calculator tools; the requirement of a buffer tank or low-loss header or secondary pump; use of DHW cylinders with high gain coils versus lower-cost models with external plate heat exchangers; requirement to add glycol anti-freeze; the potential feasibility of producing standardised installation designs, appropriate to different buildings,

[35] This has been expressed as providing *resources* instead of the usual focus on courses (N.Gambling, pers. comm.)

that specify kit, parts, instructions and support to install and configure (P. Miller, pers. comm., May 2022).

BetaTeach, an award-winning provider of training in the heat pump industry, has confirmed that a public database of detailed case study material, that includes measurement-based assessment of HP in-situ performance post-installation, would have great value for developing installer competence, incentivising excellence and enhancing the reputations of installers producing good outcomes (pers. comm., N. Gambling, Nov 2021).

This combination of transparency and growing expertise could build the reputation of the HP industry and increase consumer confidence, driving up both demand and supply (see also discussion of positive feedback loops in see Section 5.3.4).

Better data on outcomes, costs and satisfaction could also help to inform industry market offerings, business models, target markets and engagement strategies. Commercialisation of innovative products or business models (e.g. shared ASHP and shared ground loop arrays) could benefit from case study evidence and reassure clients and occupants.

5.3.2.1 Proactive customer protection

Supporting transparency in outcomes and building competence could also deliver more effective customer protection. Currently, customer protection for poor installer practice focusses on minimum standards and rather than fostering excellence. BetaTeach characterise the problem as one of regulation valuing *compliance* rather than competence (BetaTeach, 2022). Given the wide range of installer competence, driving-up installer skills and weeding out poor installers would provide customer protection that is based on more effectively preventing, rather than redressing, poor practice.

5.3.3 Researchers and policymakers

Access to HP installation case studies would also be of value to researchers and policymakers. Both of these communities are interested in a range of evidence gaps that extend beyond the issues of interest to consumers and installers. Broadly, these concern how HP and other heating system installation outcomes (including consumption, cost, carbon, flexibility, security and customer satisfaction) vary by building type, heating system, installer competence and occupant behaviour.

5.3.3.1 Evidence gaps and heterogeneity

Ongoing evidence gaps around HP retrofit are stressed in recommendations made by Meek, which also highlight the *heterogeneity* of UK heating demand and housing stock:

> "There is an urgent need for more research on the performance of heat pumps in retrofit situations. This should be undertaken with the specific aim of understanding the improvements needed to the thermal fabric of buildings necessary to achieve SPFs of at least 3.0. The research should accommodate the heterogeneity of UK residential demand and housing stock and should place less emphasis on 'demonstration' projects"
> (Meek, 2021, p.44).

This issue of heterogeneity in buildings and occupants is a crucial one for evidence gaps:

> "Learning how different low-carbon heating technologies perform in different types of buildings, occupied by different occupants, is critical for making informed policy decisions in the future"
> (Rosenow & Lowes, 2020, p.10)

> "There was a high amount of heterogeneity in the way that case study households used and controlled their heat pump"
> (UCL, 2017, p.2)

> "There are complex trade-offs between a number of factors that determine overall costs and emissions produced for a given heating option. [...] this study shows that the abatement cost and system suitability varies across the housing stock"
> (Flower, Hawker, & Bell, 2020, p. 10).

A crowdsourced database of case studies that features a wide variety of property types, occupants and technologies, and retains these differences, would reflect this heterogeneity and provide a much more diverse and informative dataset than data from heat pump field trials. As noted already, this data would also reflect outcomes from installations carried out under real-world market conditions and installer practices.

The inclusion of both technical energy data and customer satisfaction data in case studies also offers further benefits for research and policy. Analysis of Heat Pump Data from the Renewable Heat Premium Payment (RHPP) scheme reported the value of "combining social and technical information" (Lowe, Summerfield *et al*., 2017, p.23), which can permit cross-checking to detect faults in monitored data (Lowe, Chiu, *et al*., 2017) and further development of comfort metrics (Energy Systems Catapult, 2018a).

Energy Digitalisation Taskforce (Energy Systems Catapult, 2021a) and the Smart Meter Public Interest Advisory Group (PIAG) support greater access to depersonalised smart meter data for research in the public interest, including extending the Smart Energy Research Lab (SERL)[36]. Access to this 'suitably aggregated or anonymised' smart meter data (Frerk, 2019c, p.5) could inform regulatory oversight of the energy transition and aid public policy making. However, a case study database would offer further insights by retaining a much more comprehensive and unified set of data at the level of an individual household-level. It is a fundamental feature of the case study that detail, completeness and differences are not lost through aggregation or anonymisation.

[36] serl.ac.uk

The household is the level at which HP adoption decisions are made and distributional impacts are felt. Accessing and sharing non-aggregated and pseudonymised data would, however, pose greater data privacy issues; these are discussed in Section 5.4.

5.3.3.2 Policy

> "All BEIS policies and projects should develop proportionate good quality monitoring to assess and improve performance and inform learning, ahead of and throughout implementation."
> (BEIS, 2020c, p.10)

For policymakers, there is a paucity of real-world customer data to inform policy thinking on heat (Frerk, 2020b) and there is, more broadly, a danger of "policy makers 'flying blind' into the energy transition" (Frerk, 2019c, p.34). The huge increase in gas and oil prices in 2021-22 has thrown the topics of heating bills, energy security and the distributional impacts and affordability of net zero policy goals under intense scrutiny. There is now a pressing need for well-informed policy that avoids any missteps and offers appropriate support and advice on heating options to households while also providing value-for-money to the public purse.

Specific evidence gaps of interest to policymakers that case studies could address include:

- Data on HP installation performance, customer satisfaction and running costs would help to clarify the distributional impacts and affordability of HPs across different households and vulnerable groups.
- Understanding the level of building efficiency required for a property to be 'heat pump ready', including when it makes sense to improve building fabric and replace radiators, pipework or DHW tank.

- Better understanding of the performance in different households of more innovative HP systems and technologies, such as high-temperature HPs and hybrid HP systems.

- Better understanding of outcomes (consumption, cost, carbon and user experience) when combining several technologies and services, e.g. HP with building upgrades, storage devices, solar PV and smart tariff or HaaS[37].

- Understanding the scope for flexibility in HP loads. Flexibility, or demand response (DR), in electricity consumption for heating will be of growing importance as HP adoption builds. When winter morning and evening demand for heat peaks at 300GW it is five times greater than the peak for electricity (Ofgem, 2016) and switching to a heat pump would raise a typical UK household's annual electricity consumption from around 3 MWh (Ofgem, 2020) to 8 MWh (Energy Technologies Institute, 2019). Charging for electric vehicles will typically add a further 3 MWh (Ibid). If the grid is to be operated in a secure and cost-effective manner these new electricity loads for heat and transport will both need to have a degree of flexibility to remain within the constraints of supply and the distribution network. Recent work indicates that the complete electrification of heating would increase peak electricity demand by 170% and underlines thermal storage and smart operation schemes at the consumer end as valuable for providing flexibility (Hoseinpoori *et al*, 2022). Understanding flexibility in real-world HP operation will require more data that reflects a broader range of households and flexibility-enabling technologies including fabric improvement, storage and automation (Carmichael, Gross, & Rhodes, 2018; Carmichael *et al.*, 2020).

- Tracking HP purchase and running costs to observe learning curves.

Better understanding of the above issues could help inform policy areas such as:

- the type and levels of financial support needed to make low-carbon heat and energy efficiency technologies more affordable for different households to help ensure a fair and just transition for heat;

- developing consumer advice for informed adoption of smart heat pump tariffs in light of what flexibility and bill savings are feasible in different households;

- designing policy for a programme of building retrofit that is informed by a better understanding of what fabric improvements are required for good heat pump performance;

- improving the assessment and monitoring of heat and buildings policy effectiveness through use of real-world data;

- Possible improvements to installation best practice guidelines, tools and regulations and policy support for installer training, upskilling and job creation to fill the skills gap;

- Building and certification standards could also move to more measurement-based compliance requirements. In the US, Seattle and Boulder both have an in-use performance path as part of their buildings energy efficiency standards regulations, with metered energy data being supplied via automated reporting from utilities to the regulators (Etude, 2021).

While the focus of this briefing paper is on heat pump retrofit, the principles of measuring and sharing outcomes could be applied to other low-carbon heating technologies and services. Building up a diverse collection of case studies would help to identify appropriate solutions for a range of property types and to clarify the role of alternatives to HPs, such as smart electric storage heaters (Frerk, 2020a).

[37] For more detail on HaaS see Energy Systems Catapult, 2019b, 2019a.

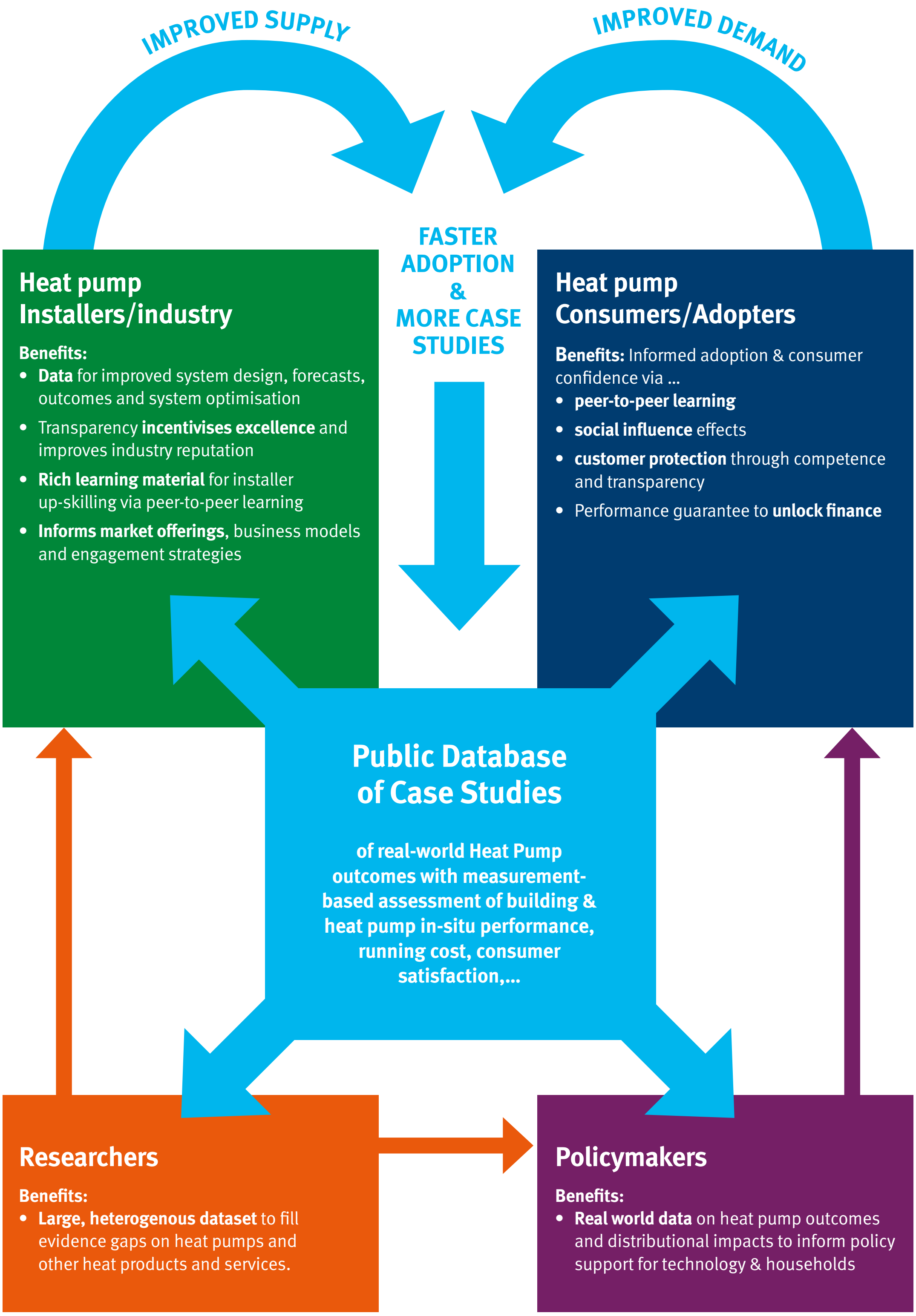


Figure 14 A public database of case studies of heat pump installation outcomes: multiple stakeholder benefits and positive feedback loops

5.3.4 Stakeholder coordination, positive feedback effects and system change

This chapter has outlined how sharing real-world HP performance and outcomes could deliver a range of benefits for consumers, installers, policymakers and researchers. This is summarised in Figure 14. This is a holistic approach that increases coordination between stakeholders - both features that have been identified in a recent rapid evidence assessment as particularly important for facilitating an effective large-scale HP rollout:

> "It has been noted throughout the literature that for a large-scale heat transformation to be effective, the coordination between stakeholders becomes the primary aspect worth considering"
> (BEIS, 2021e, p.20)

> "innovation activity that consider all aspects holistically/simultaneously are particularly important."
> (Ibid, p.8)

The literature often also stresses the importance of heat pump field trials and pilots (BEIS, 2021f). However, greater and more direct real-world impacts on the HP transition could be achieved by changing stakeholders' day-to-day activities on both the demand side and supply side. Measuring and sharing installation outcomes, as proposed here, has the potential to do this, to address market failures and create a more supportive context for heat pump diffusion.

5.3.4.1 Positive feedback effects

UK heat decarbonisation is a massive challenge that will take time. If we are going to meet net zero targets, we urgently need to begin making progress now (Lowes *et al.*, 2021). We also need to seize opportunities to build momentum and accelerate the pace of the transition.

Fig. 14 shows the range of stakeholder benefits from measuring and sharing HP outcomes and also shows the positive feedback effects between stakeholders to create increasingly rapid system-wide change. A virtuous circle of increasing impact may be achieved as: measuring and sharing HP outcomes produces more informed consumers and better-skilled installers creating stronger demand and supply; this delivers faster adoption and better outcomes and further builds the case study database; a growing set of case studies increasingly helps to fill research gaps and inform both policy and industry market offerings; more informed market offerings and evidence-led policy for supporting technologies and household investments, in turn, further support consumer demand and supply.

These positive feedback effects can involve rapid change via self-reinforcing 'tipping dynamics', a concept from systems thinking that is drawing increasing attention within climate mitigation circles (Sharpe & Lenton, 2021). In the complex physical climate system, there are tipping dynamics (including the Albedo effect, permafrost and forest fires) that could lead to runaway climate change. Similarly, the socioeconomic and social-ecological systems involved in Net Zero are complex adaptive systems in which components *learn* in response to change (CECAN, 2020). There are therefore opportunities to create *social* tipping interventions (STIs) that can "activate contagious processes of rapidly spreading technologies, behaviors, social norms, and structural re-organization" (Otto *et al.*, 2020, p.2354). These include social contagion effects and shifting norms discussed in Section 5.3.1.

5.4 Data access and sharing

Chapter 5 has considered the benefits of widely sharing HP installation outcomes among consumers, installers, researchers and policymakers. How this data might actually be accessed and shared in practice is examined below.

5.4.1. UK GDPR, DAPF and data privacy

Since 2021, the UK GDPR and Data Protection Act of 2018 are the *de facto* Data Protection Legislation for the United Kingdom, enforced by the Information Commissioner's Office (ICO). UK GDPR is largely the same as the EU-wide GDPR and strengthens requirements around consent for the use of personal data. Consent must be "given freely and actively (i.e. through 'opt-in' rather than 'opt-out'), and be specific, informed and unambiguous" (Deloitte, 2017, p.18). The GDPR enhanced individuals' rights in relation to their data, including the right to request their data be provided in a machine-readable format or transferred between organisations (Ibid).

The smart metering programme has developed the Data Access and Privacy Framework (DAPF) governing access to smart meter data by authorised parties, whilst safeguarding consumer interests and enhancing public trust in the smart meter roll-out. It goes beyond GDPR stipulations regarding what data can be used for once consent is obtained (Judson *et al*, 2020).

Consent is not the sole legal basis for sharing personal data in the infrastructure sectors. Regulations must manage a complex trade-off between safeguarding personal privacy without making the process of consent so burdensome that it dissuades consumers from giving consent when it would benefit them (Deloitte, 2017). Data sharing can also be legitimised when it is necessary for the performance of a task that is in the *public interest*, balanced against the rights, freedoms and interests of the individuals (ibid). For example, access to smart meter data that is "sufficiently aggregated or anonymised" (Frerk, 2019c, p.34) has been explored in depth by the Smart Meter Data Public Interest Advisory Group (PIAG) work and the UKRI-funded Smart Energy Research Lab (SERL) provides access to smart meter energy data for UK researchers (Webborn *et al*, 2019).

However, a public database of case studies, as advocated here, would require the sharing of non-aggregated data at the level of individual households and involve access by a much wider set of users. As noted in Section 5.3.3, case study data has particular value because it retains an integrated set of data at the household level, neither broken-up through anonymisation nor lost by aggregation. Sharing detailed data at this level offers opportunities for many additional benefits and insights but also poses different risks and challenges for access. There is scope to mitigate or resolve these challenges by:

- pseudonymising case study data (see Table 2).
- reporting key higher-level outcomes, with more detailed data available only to certain stakeholders (e.g. installers/researchers/policymakers).
- offering households participating in the case studies database different levels of privacy along a continuum of pseudonymisation. Informed consent would need to communicate the limits to privacy afforded by the pseudonymisation techniques used and customer preferences should be updatable, e.g. via a data dashboard (see Box 9).
- The Digital Economy Act includes principles for data handling by a 'trusted processor'. Such actors and principles could play a useful role in bridging the gap between data inputs that may raise privacy issues and pseudonymised outputs (Frerk, 2019c, p.34).

Table 2 Data anonymisation and pseudonymisation techniques in data best practice
Source: Information Comissioner's Office, 2019; Ofgem, 2021

Term	Description & Commentary
Personal data	Personal data only includes information relating to natural persons who: (i) can be identified or who are identifiable, directly from the information in question; or (ii) who can be indirectly identified from that information in combination with other information. Information which has had identifiers removed or replaced in order to pseudonymise the data is still personal data for the purposes of UK GDPR. Information which is truly anonymous will not be considered personal data or covered by the UK GDPR (Information Comissioner's Office, 2019).
Anonymisation	*Removing or altering identifying features* Simple anonymisation can be very effective at protecting personal data but it needs to be undertaken with care to minimise the risk of individuals being reidentified. Anonymisation techniques can be combined with other mitigation techniques to minimise this risk. The UK ICO have provided an anonymisation code of practice (Information Comissioner's Office, 2012) which should be adhered to. The UK Anonymisation Network publishes the Anonymisation Decision Making Framework (https://ukanon.net/framework/) to address a need for a practical guide to GDPR-compliant anonymisation that gives more operational advice than other publications.
Pseudonymisation	*Replacing identifying features with a unique identifier that retains the reference to an individual whilst breaking the link with the 'real world' identity.* Pseudonymisation is distinct from anonymisation as it is possible to consistently identify individuals but not link this to a specific, named person. For example, replacing the customer name and address with a random unique identifier whilst protecting the identity of an individual user. Pseudonymisation should be used carefully as it is possible to utilise external datasets and data analysis to match identifiers and trends such that the individual can be reidentified. The ICO (2019) provide useful guidance in this area.

5.4.2 Barriers and consent for data sharing

There are cultural, technical, legal and other barriers to accessing and sharing energy data - see Fig. 15.

» BOX 8: Barriers to data sharing

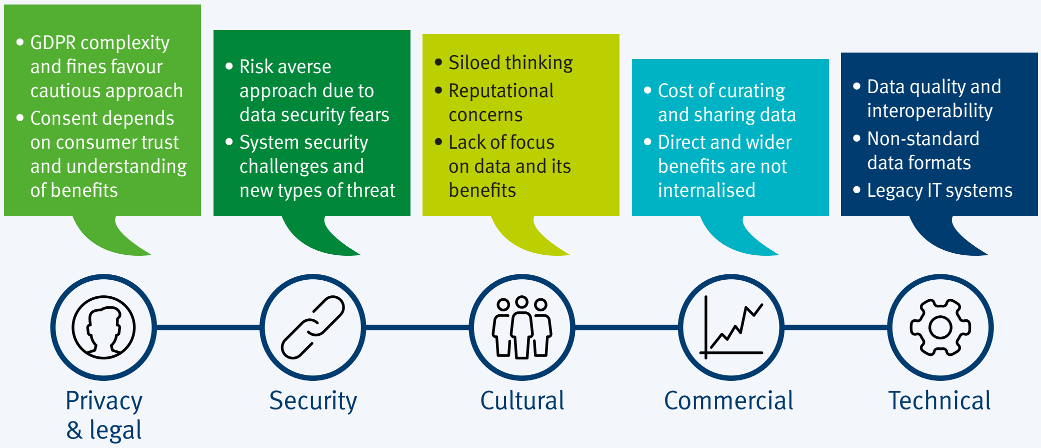


Figure 15 Barriers to sharing data in infrastructure sectors (Source: Deloitte, 2017)

The Open Data Institute (ODI) also notes several barriers that are impeding businesses from unlocking the value of data in ways that will help address a variety of social, environmental and economic problems (D'Addario, 2022). Despite growing opportunities for new data-led products and services, limiting factors include expertise, not seeing the value of sharing data, and concerns about commercial and legal risks around sharing data (Ibid).

For energy consumers, the cultural barriers are generally less challenging than technical and legal or regulatory barriers. Most consumers are relatively unconcerned about sharing smart meter data (Frerk, 2018; Navigator, 2012). Research by Ofgem finds that bill-payers rank half-hourly energy consumption data as much less sensitive than most other kinds of personal data (Ofgem, 2018a). About half would share smart meter data with chosen third parties to receive personal benefits and two-thirds to improve the operational efficiency of the system or market; willingness to share this data was higher among consumers with a smart meter (Ibid).

Compared to sharing smart meter data with selected third parties, sharing case study data on an online database would involve sharing a wider set of data with a wider set of users. Sharing case study data, which is by nature not aggregated and fully anonymised, would require opt-in informed consent. But for some adopters, at least, other motivations may outweigh privacy issues. Many people actively share their experience via online product reviews and volunteer information in online forums. Participants on the online Green Homes Network (see Chapter 3) appear to be comfortable with a high degree of potentially identifying information, including approximate location, type of building, type of technology, and even first name or surname (assuming this has not been pseudonymised). There is broad public support for: low-carbon energy (BEIS, 2021a); energy system components that are clean, efficient, fair and safe and for greater transparency (Demski *et al*, 2019; Parkhill *et al*, 2013); a willingness to contribute to the public interest and sense of citizenship with respect to the energy system (Energy and Climate Change Committee, 2013). Ultimately, obtaining informed consent from consumers to share their case study data will, as it should, depend on consumers seeing something they value in it.

Despite Ofgem's acknowledgement of an important role for the advice and guidance available through third party intermediaries (TPIs), a consumer's ability to access and share their own energy data is currently very limited. An important barrier is the current lack of infrastructure enabling consumers to share, or 'port', their smart meter half-hourly electricity consumption data to third parties (FSB, 2018).

The most direct solution for third parties to access smart meter data is for them to become registered users of the Data Communications Company (DCC) secure network, though this process involves considerable complexity and cost (Frerk, 2019). Another opportunity for data portability may be offered by consumer access devices (CADs) that allow highly granular consumption data to be collected from the smart meter via the Home Area Network (HAN) and sent by broadband directly to the cloud and shared, entirely bypassing the DCC.

'Midata', a programme to give consumers access to their personal consumption data in portable electronic format was launched in 2011 but development has been very slow. Now led by Ofgem, it is focussing on smart meter data portability for tariff comparisons[38] rather than a broader set of data and use cases. Midata has now been paused to ensure alignment with wider energy industry programmes that will impact the availability and quality of energy data that Midata could use (BEIS, 2020d). Several programmes will substantially change the energy data landscape over coming years, including: the Retail Code Consolidation Significant Code Review; the Switching Programme; the Market-wide Half-Hourly Settlement programme; the smart metering implementation programme (SMIP); and the wider work on Smart Data (BEIS, 2021j). For example, Ofgem's incoming market-wide half-hourly settlement (HHS) programme, will enable and require energy suppliers to access and securely process domestic consumers' smart meter half-hourly consumption data for settlement and forecasting; consumers would need to opt-*out* from sharing data for these

[38] This use case has also been explored by the BEIS-funded Smarter Tariffs-¬Smarter Comparisons project (2020-2021) which developed an open-source tool for tariff comparisons that are easier, more accurate and include smart tariffs for the first time (https://www.gov.uk/government/publications/smart-meter-enabled-tariffs-comparison-project-smarter-tariffs-smarter-comparisons). See also Wilson, Cooper, Carmichael *et al* (forthcoming) and (Carmichael *et al*., 2021).

purposes (BEIS, 2021c). Third parties who are Smart Energy Code (SEC)[39] signatories can access smart meter data of any granularity via confirmation that the consumer has opted-*in* (with regular reminders) (Judson *et al*., 2020).

However, data access and portability solutions have not progressed:

> "Despite existing data mobility interventions, processes remain complicated and there is a lack of standardization, and slow progress of 'Smart Data' initiatives that aim to improve customers' experience of data portability. Intervention is necessary: to resolve these issues giving customers more effective ways to use their data."
> (BEIS, 2020e, p.1)

5.4.3 Ongoing Smart Data and Open Data initiatives

The Energy Data Taskforce report, *A Strategy for a Modern Digitalised Energy System* (Energy Data Taskforce, 2019), found that data in the energy sector needs to be more open - defined as being *discoverable, searchable* and *understandable*. The Smart Data Review has also identified that there is considerable potential for 'Smart Data' to support better consumer outcomes across consumer markets (HM Government, 2019).

> "Smart Data is the secure sharing of customer data with authorised third-party providers (TPPs), upon the customer's request. These providers then use this data to provide innovative services for the consumer."
> (BEIS, 2021b, p.7)

There are now a number of ongoing cross-sector and energy-specific activities in Smart Data.

The UK's data protection laws already give consumers the right to request that businesses provide their data to third party providers (TPPs) in a commonly used format - this is known as the right to data portability. 'Smart Data' represents a logical extension of this right and provides an enhanced framework for sharing consumer data that allows for further innovation (HM Government, 2019).

The Smart Data Review will focus on data portability and will identify the steps that the government, regulators and others need to take to accelerate the development of innovative intermediary and other services, for a wide range of consumers, within a regulatory and policy framework that builds consumer trust (UK Government, 2019). Current governance arrangements enable Smart Data initiatives to develop independently of one another, with BEIS responsible for Smart Data policy coordination. The Smart Data Working Group was established to progress Smart Data initiatives, reduce duplication and maximise the combined potential of these initiatives (BEIS, 2020d).

It is envisaged that an enhanced Smart Data framework will include common technical standards, data formats and definitions to minimise access barriers and ensure interoperability and the use of Application Programming Interfaces (APIs) to allow consumers to share their data swiftly and securely with TPPs. Ensuring that the Data Providers can trust all the TPPs within the accreditation regime is key and BEIS is looking to clarify what conditions TPPs need to meet in order to be accredited. Analysis demonstrates that there are similarities in conditions for accreditation of TPPs across sectors and these could be standardised for Smart Data (Reynolds & Johnson, 2021). In practice, accreditation is very broad, encompassing the high-level regulations that exist in GDPR, the sector-specific regulations that confer access to the regulated roles[40], and the technical conformance that may accredit the actual technology implementation (Ibid).

[39] https://smartenergycodecompany.co.uk/the-smart-energy-code-2/

[40] Roles in the energy sector are far more varied than those in the banking sector (where open data is further advanced) leading to huge potential complexity of data sharing options (Reynolds & Johnson, 2021).

Other Smart Data activities are more focussed on the energy system level rather than individual consumers. These include the Modernising Energy Data Access (MEDA) competition, launched by Innovate UK, that aims to implement the recommendations of the Energy Data Taskforce and enable the exchange of digital energy information between organisations and with other stakeholders. Its sub-project, The Energy Data Visibility Project (EDVP), focusses on making energy data more visible; in the Alpha phase, Icebreaker One and partners are developing an Open Energy platform[41] focussed so far on organisations and business users. The Scottish Government's planned National Public Energy Agency may include operating a national level data hub.

The Open Data Institute (ODI) and others are conducting work on a range of issues for more open data, including data assurance (Oxford Insights, 2022; Snaith, Yates, & Evans, 2021), data access initiatives (ODI, 2021), data infrastructures (Evans, 2022) and data institutions (Hardinges, 2020). This could shed further light on processes to help build confidence in how the case study data discussed in this paper is collected, accessed, used and shared. For example, assurance can be applied to *data* and data collection and management *practices*. Assurance of *data* includes activities such as: checking the accuracy of individual data points; checking the structure of a dataset; checking for personal data. Assurance of data *practices* includes: checking how data is collected, managed and shared to confirm that data is managed legally, securely and ethically; and ensuring that those involved in data practices have the necessary skills and knowledge to work with data (Oxford Insights, 2022).

Ultimately, enabling data access and sharing that could support a public database of HP case studies will depend on specifics - such as what data is being collected, who has access and for what purpose, how it is held and for how long – and making these clear for informed consent. Some trusted organisations, independent from installers, would also need to fill the role of collecting, verifying and pseudonymising the case study data and managing the database in a transparent manner. Mapping out the data value chain (which data goes from where to where, from which legal entities and what systems and why) would help to clarify which entities need accreditation such as by the Open Energy Trust Framework (pers. comm., G. Starks, Jan 2022). Table 3, Appendix, provides an indicative summary of possible data requirements that could support the 'measure and share' approach advocated in this paper.

41 https://icebreakerone.org/energy/

» BOX 9: Smart Data user requirements and a data dashboard

Although consumers make extensive use of data-driven services they are wary of them (Citizens Advice, 2018). Such services offer potential benefits, especially around new services that make it easier for consumers to become more engaged with the energy market and save time and money. But they also pose possible risks, including data being sold without consent and data being used without users' permission or understanding in order to profile consumers or exclude from accessing certain services (Ibid).

As the Data Communications Company (DCC) has no consumer interface, Citizens Advice present a proof of concept for a 'smart metering data dashboard' - a tool to help consumers *see* and *control* what their own smart meter data is used for. Adequate transparency would allow customers to *see*: who is accessing their smart meter data; the period over which it is being collected; the level of detail of data collected; who is collecting and accessing the data and what they are using the data for. The second half of the consumer requirement, *control*, would require allowing consumers to query, flag concern, and amend access (Citizens Advice, 2018).

The data dashboard concept could be extended beyond smart meter data to a broader set of consumer energy and personal data. A single customer consent data dashboard has also been recommended by the Energy Digitalisation Taskforce (Energy Systems Catapult, 2021a) and has already been implemented in Estonia's Estfeed[42] solution.

The development of any smart data system or service should incorporate user testing to increase:

- Utility: can it deliver useful outcomes?
- Usability: is it simple and intuitive?
- Persuasiveness: do users have trust and confidence in the system and do they complete the task? (Swinfen Green, 2021).

5.5 Key points

This chapter has explored the potential benefits for the HP transition that could come from sharing HP installation outcomes via a public database of case studies (Carmichael, 2019). It has also considered some issues for accessing and sharing such data.

- Sharing data on the in-situ performance of buildings and heat pumps, along with consumer experiences, could deliver a range of benefits to consumers, installers, the HP industry, policymakers and researchers to address both demand side and supply side issues.
- Case studies could present detailed and accurate assessments of building performance, heating system energy use, costs, carbon and consumer satisfaction before and after the installation of the heat

42 https://www.estfeed.eu/en/home; https://elering.ee/en/smart-grid-development

pump (and any other measures). This would help to clarify the value case for getting a HP and provide much-needed support to the adoption decision-making process. A standardised format for case studies and a searchable and filterable database would allow easy comparisons of technologies and installers. Browsing, searching and comparing case studies would reduce the time, effort, complexity and uncertainty in adopter choices and increase consumer confidence.

- Such a database would not simply provide 'information' - an approach sometimes criticised for assuming an overly-rational model of consumer behaviour. Providing technical and customer satisfaction data would also harness social networks and social influence effects to inform adoption choices.

- For consumers, heat pumps are a high-cost purchase that cannot be returned or resold and 'try-before-you buy' is not possible. Low 'trialability' and low 'observability' of HP adoption compound and perpetuate low consumer confidence and adoption rates but could be mitigated by enabling potential adopters to see and learn from early adopters.

- The impact of HP online forums in Finland, and the influence of word-of-mouth (WoM) more broadly, strongly suggest that peer-to-peer (P2P) learning could play an important role in normalising, 'policing' and driving heat pump transitions. To date, this is missing and policy has not focussed on enabling more P2P learning and knowledge-exchange. Public access to a case studies database showing outcomes of HP installations could 'supercharge' P2P learning among both consumers and installers, allowing both communities to move from passive to active roles and accelerate the Diffusion-of-Innovation cycle for heat pumps, which are languishing in the Innovator adoption phase.

- Benefits for installers and the HP industry include transparency in HP installation outcomes that would *incentivise and reward installer excellence*, weed out poor installers, and improve industry reputation. Complete case studies would also provide a large, rich *learning resource to support upskilling* via online P2P learning among installers and more formal training. Data may also shed light on areas where current installation best practice guidelines might be revised to optimise cost, safety and efficiency. Incentivising and enabling excellence and transparency in installer skills would provide more effective and proactive consumer protection than current compliance and redress-based approaches.

- Researchers and policymakers would benefit from a large and heterogenous dataset crowdsourced from installations that better reflect real-world contexts and outcomes and is more cost-effective compared to HP demonstration projects. This diverse set of case studies would be of great value for addressing many evidence gaps in HP systems outcomes (consumption, cost, carbon, flexibility and customer satisfaction) across a range of buildings and occupants. Insights could inform industry practice, technology development, market offerings, business models and policy support for a faster and fair HP transition.

- This range of stakeholder benefits (see Fig. 14) would provide the holistic approach and coordination between stakeholders that have been identified as particularly important for facilitating an effective large-scale HP rollout. Several self-reinforcing positive feedback effects would also be expected to accelerate wider system change for HP transitions.

- Data privacy issues for households sharing their data in a public case studies database would be greater than for households sharing their smart meter data with selected third parties (such as price comparison services) or researchers accessing anonymised or aggregated smart meter data for public interest purposes. Informed opt-*in* consent would be required for sharing this wider set of data with a wider set of users in a format which is at best pseudonymised. But evidence of public support and sense of citizenship towards a clean energy transformation, and consumers' willingness to share experiences (seen in online product reviews), could outweigh privacy concerns for many, as already seen in the Green Homes Network.

- There are many ongoing Smart Data initiatives which aim to facilitate data sharing. However, activity to date has tended to focus on organisational and commercial users while consumer-focussed use cases have considered choice of services (e.g. tariffs) rather than supporting decision-making for adoption of technology such as heat pumps.

6. Conclusions and recommendations

A rapid transition to heat pumps (HPs) will require supporting faster and better-informed adoption and maximising positive outcomes in terms of reliable, affordable and flexible low-carbon heat and improved building efficiency. The diffusion of heat pumps will also require growth in installer expertise and stronger evidence for policy. All of these involve a high degree of complexity and uncertainty, but data is not being routinely collected to fortify demand, supply or policy.

This briefing paper has considered in some detail the proposal that a transition to low-carbon domestic heating using heat pumps could be accelerated by leveraging early adoption: *measuring* the outcomes of installations and *sharing* them as case studies on a public database (Carmichael, 2019; Carmichael *et al*, 2020). Exploring the potential impacts and feasibility of this suggestion has required a review and discussion of several topics and innovation areas including: the role of advice and support in the heat pump adoption customer journey; the need for building and heat pump assessment to move from estimation and modelling to measurement-based assessment of actual in-situ performance; the potential stakeholder benefits of sharing data on actual outcomes; and the technical, cultural, policy and regulatory contexts for implementing these recommendations.

It is widely recognised that detailed information and tailored advice is vital for public awareness, consumer confidence and informed adoption choices of energy products and services. Households considering more complex and unfamiliar solutions need *more detailed* advice and guidance (Bonfield, 2016), such as precise information and paired comparisons that enable reflective customer choices (Nolting, Steiger, & Praktiknjo, 2018). However, policy has not yet grasped the nettle of how to provide this support for heat pump adoption decisions and the information that is available is not helping. Crucially, the actual real-world performance of buildings and heat pumps are not being measured.

Building energy performance certificates (EPCs) are the main source of guidance for householders about the energy efficiency of their home and future measures that would make sense for them. But EPC ratings and cost-based metrics discredit heat pumps and their recommended actions consistently deter households from adopting them. The EPC RdSAP methodology relies on assumptions and modelled estimates of energy efficiency within the home that are not accurate or reliable enough. The Climate Change Committee (CCC), Environmental Audit Committee (EAC), Scottish Government and others have strongly criticised EPCs and advocated their reform with much greater measurement and use of real-world outcomes in order to better drive change to low-carbon heating, flexible demand and building efficiency.

The financial value case for installing a heat pump is highly sensitive to heat pump efficiency (Meek, 2021) but the flawed SAP methodology is used for HP sizing calculations and in-situ performance is estimated not measured. The Heat Pump System Performance Estimates (HPSPE) that customers receive from installers have been found to have little correlation with the actual in-situ performance and running costs of the heating system.

For buildings, signs of potential movement away from estimation to greater *measurement-based* assessment of performance are apparent in work on smart meter enabled thermal efficiency ratings for homes (SMETERs), Building Renovation Passports (BRPs) and Metered Energy Savings (MES). SMETER technologies have successfully demonstrated the feasibility of using data from smart meters and sensors to calculate building heat loss (as Heat Transfer Coefficients/HTCs) with greater accuracy than an expert RdSAP calculation (SMETER Project, 2021a) and more reliability than typical EPCs. Work on Building Renovation Passports and Metered Energy Savings (MES) suggests they could improve on EPCs by using measured energy performance and indicates potential for data to unlock finance for retrofit (GFI, 2020). This work has also highlighted some common issues for implementing measurement-based assessment, but it is unclear exactly how they would support consumers' decisions about retrofit measures.

For heat pumps, policy commitment to measuring real-world in-situ performance has retreated. Under the Domestic Renewable Heat Incentive (dRHI) HPs were metered for payment and or performance, demonstrating that the in-situ performance of HPs can be measured using electricity meters, temperature sensors and heat meters. But since the introduction of the Boiler Upgrade Scheme (BUS), in April 2022, there are no requirements to meter new HP installations.

Householders and landlords considering installing a heat pump system are still faced with complexity, uncertainty and a list of potential concerns, doubts and questions. The impact of heat pump online forums in Finland, and word-of-mouth (WoM) more broadly, strongly suggest that peer-to-peer (P2P) learning could play an important role in normalising, 'policing' and driving heat pump transitions (Martiskainen *et al.*, 2021). This is missing in the UK: consumers are passive and policy has not focussed on fostering networks or supporting P2P learning for heat pumps. The Energy Saving Trust Scotland's Green Homes Network is a laudable exception but much greater detail and data ('*numbers*, not adjectives') are needed for case studies to effectively support the HP transition.

Figure 16, below, depicts a simplified version of the customer journey for heat pump adoption and shows improvements to the journey from *measuring* performance and outcomes and *sharing* them widely. The existing customer journey for adoption is shown in light blue. Current barriers include: a skills gap and varied competence among installers; low consumer trust in HP technology and installers; the complexity of decision-making about viable or optimal combinations of technologies and services for a particular home (including building fabric improvements, storage, automation and flexibility services); low 'trialability' and 'observability' in HP adoption; and reliance on estimations of building and HP performance. A move to making measurement mainstream during installations would deliver some immediate benefits. Sharing data from the installation, along with other case studies, could deliver many more stakeholder benefits for accelerating the HP transition.

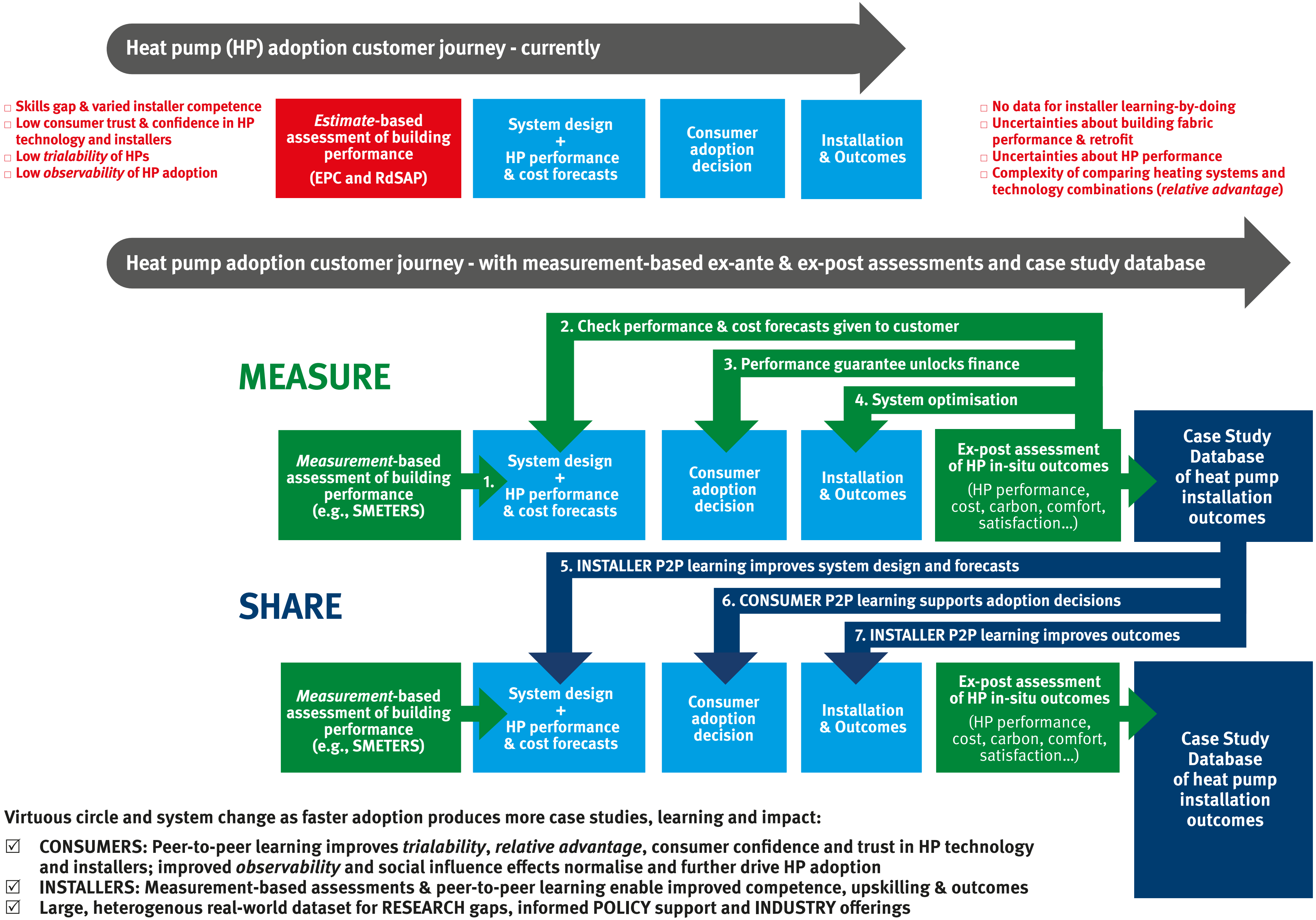


Figure 16 The customer journey for heat pump adoption: benefits of measurement-based assessment and case studies database

6.1 Measure real-world outcomes routinely

Shown in green in Fig. 16, pre-installation *measurement-based assessment of building performance* would provide more accurate heat loss data for heating system design (including HP sizing) and forecasts of HP performance and costs given to the consumer ('1' in Fig. 16). After installation, *ex-post assessment of HP system in-situ performance* (including the Seasonal Performance Factor/SPF) would allow a check on the installer forecasts given to customers ('2'). Anticipation of this check should provide reassurance to the prospective adopter that their system will perform as predicted. Data on outcomes could also support installer learning-by-doing, CPD and monitoring of competence by MCS and RECC.

This ex-post assessment could also provide a performance guarantee to unlock finance options ('3' in Fig. 16), as noted by work on Building Renovation Passports (BRP) and Metered Energy Savings (MES) (GFI, 2020; Rathmell *et al.*, 2021). Ongoing monitoring could, furthermore, support fault detection and optimisation of HP system performance ('4').

6.2 Share outcomes widely for peer-to-peer learning and system-wide benefits

Sharing HP installation outcomes through a database of case studies could deliver further important benefits (shown in dark blue in Fig. 16). Such a database could kick-start and 'super-charge' P2P learning among both consumers and installers, allowing both communities to take much more active roles in accelerating the diffusion-of-innovation cycle for heat pumps, which is languishing in the 'Innovator' adoption phase.

For prospective buyers, heat pump systems are unfamiliar, uncommon, and 'try-before-you buy' is not possible. This unfamiliarity and low 'trialability' (Rogers, 2003) could be mitigated by enabling buyers to learn from the experiences of those who have already installed HPs before they commit to an expensive purchase. Case studies could present detailed and accurate assessments of building performance, heating system energy use, costs, carbon and consumer satisfaction before and after the installation of the heat pump (and any other retrofit measures). This would help to clarify the value case for getting a HP and provide much-needed support for adoption choices. A standardised format for case studies and a searchable and filterable database would allow easy comparisons of technologies and installers. Such peer-to-peer learning among consumers - through browsing, searching and comparing case studies - would reduce the time, effort, complexity and uncertainty in adopter decision-making and increase consumer confidence ('6' in Fig. 16).

Information provision is sometimes criticised for being an individualistic approach to behaviour change that assumes consumers act as an overly-rational *Homo economicus*, or "Economic Man", but case studies would also leverage powerful social dimensions of adoption by fostering social networks and harnessing peer effects. The case study database would increase the 'observability' of HP adoption, which is associated with more rapid diffusion of innovation (Rogers, 2003): being able to see that more and more households are installing HPs could help to turn social influence effects (both *informational* and *normative* social influence) from an inhibitor to a driver that normalises and accelerates HP adoption through social contagion (Frank, 2020). Clarity about the HP value case and occupant experiences could also help householders, landlords and tenants reach agreement and avoid conflict where adoption decisions and impacts are shared.

For installers, case studies would provide a rich resource to support upskilling via peer-to-peer learning, thereby improving heating system design decisions, HPSPE performance forecasts and, potentially, best practice guidelines ('5' in Fig. 16) - ultimately delivering improved outcomes for the consumer ('7'). The database would also provide transparency in outcomes that would incentivise and reward installer excellence and weed out poor installers - thereby further helping to close the skills gap and improve the HP industry reputation. Supporting transparency and excellence would, moreover, provide more proactive and effective consumer protection than current approaches that are based on compliance with minimum standards and redress after-the-fact.

6.3 A holistic approach: stakeholder coordination and systemic change

Beyond the consumer adoption journey and installer upskilling, measuring and sharing HP installation outcomes could deliver wider stakeholder benefits (see Fig. 14, Ch.5). A large and diverse dataset of cases studies, that better reflects real-world contexts and outcomes, would be valuable to researchers, policymakers and industry to fill evidence gaps and better understand how HP systems (including high-temperature HPs and hybrid HPs) perform - on consumption, cost, carbon, flexibility and customer satisfaction - across a range of buildings and occupants. This could help to inform industry practices, technology development, market offerings, business models and help policymakers design and monitor support for fast and fair uptake of technologies, services and building fabric improvement.

This broad range of stakeholder benefits would provide the *holistic approach and coordination between stakeholders* that have been identified as particularly important for facilitating an effective large-scale HP rollout (BEIS, 2021e). While data and learnings from HP field trials and demonstration projects have value, their datasets are constrained and removed from real-world market activities: they are unlikely to impact transparency, accountability or learning in the day-to-day practices of installers or give peace-of-mind to individual householders about their choice of installer, the quality of their installation or the performance of their HP.

Impacts from measuring and sharing installation outcomes could also support self-reinforcing positive feedback effects and wider system change for a HP transition. A virtuous circle would be expected as the database drives stronger demand and installer competence, thereby increasing adoption and growing the number of case studies in the database; this in turn produces a burgeoning impact through social influence and the value of the data for industry and policy support, further accelerating demand, supply and adoption (see Fig. 14).

6.4 Data sharing and consent

There are many ongoing Smart Data and open data initiatives which aim to facilitate data sharing. However, activity to date has tended to focus on organisational and commercial users while consumer-focussed use cases have centred on supporting consumer choice of services such as energy tariffs. Consumers also need support for making decisions on adopting low-carbon *technologies* such as heat pumps.

Households sharing their data in a public case study database presents greater data privacy issues than households sharing their smart meter data with selected third parties (such as price comparison services) or organisations accessing anonymised or aggregated smart meter data for public interest purposes. Informed opt-*in* consent would be required for households to share this wider set of data with a wider set of users in a format which is at best pseudonymised. But the public's strong support and sense of citizenship towards a clean energy transformation, the opportunity to participate more actively in the energy transition, and consumers' willingness to share their experiences, could outweigh privacy concerns for many, as evidenced by participation in the Green Homes Network, online forums and online product reviews more generally.

6.5 Recommendations for Government

1. Support the development of standardised procedures for measuring the in-situ performance of buildings and heat pumps.

   These protocols should:

   a. Be affordable and suitable for rapid scale-up.

   b. Provide data that is accurate and detailed enough for the purposes of heat pump case studies of value to users.

   c. Use cost-effective hardware (exploring opportunities to reduce costs of monitoring equipment and operative time).

   d. Minimise inconvenience and other concerns for households and installers.

This could draw on outputs from the SMETERs programme as well as insights from the work on Metered Energy Savings (MES) and the Electrification of Heat Demonstration Project. See Appendix, Table 3, for an initial, indicative summary of data requirements and collection methods.

2. Introduce a requirement that all new heat pump installations carry out measurement-based assessment of the actual in-situ performance of the building and heat pump system (according to standardised procedures suggested in Recommendation 1).

Options should be explored for how the costs of pre- and post-installation assessment should be funded, including Government financial support where needed and the possible division of cost between HP client, installer, industry and Government, based on the benefits delivered to these different stakeholders. Financially supporting an extra layer of 'crowdsourced' data collection that piggybacks on installations occurring spontaneously could offer good value for money, especially in view of the multiple stakeholder benefits from sharing case study data.

Also consider introducing a measurement-based assessment for compliance with the minimum heat pump performance requirements within the Boiler Upgrade Scheme (BUS) (now 2.8 COP) rather than efficiency being evidenced through the MCS certificate submitted by the installer (BEIS, 2021c). Such a shift to measurement-based compliance with building energy efficiency standards has been pursued by some cities in the USA (Etude, 2021). Governmental or regulatory support may be required to clarify and define procedures, responsibilities and liabilities in cases where an ex-post assessment reveals that a HP is not performing as forecast and corrective work is needed.

3. Fund the development, operation and oversight of a publicly-accessible database for case studies of heat pump installations.

   This database should:

   a. Develop relatively frictionless informed opt-in consent procedures for owner-occupiers, landlords and occupants to participate as case studies. Consent should accommodate preferences for levels of openness and privacy - such as what data is shared and which stakeholder groups access their data.

   b. Develop and implement procedures for data verification/assurance and data privacy while retaining the value and integrity of pseudonymised case studies.

   c. Be trusted by users and those sharing their data. Ongoing work on open data could offer insights to help build stakeholder confidence in how case study data is collected, accessed, used and shared.

   d. Be designed with good user experience and inclusion in mind. Use by households with poor digital literacy or access could be supported by customer advice organisations via phone or in person.

Government/developers should consult with the HP industry on risks and the possible need for mitigations. For example, there is a potential risk that a public database will make poor installation outcomes more visible and thereby damage the reputation of some installers or the HP industry. Transparency is, however, needed to incentivise and support upskilling (delivering better outcomes and customer satisfaction) and also as a basis for increasing consumer trust. One way of mitigating this risk could be for case studies to be accessible only to installers and industry for the first 12 months. Staggering access in this way would allow some time for installer upskilling before the database is viewable by the public. Similarly, anonymising or pseudonymising installers in case studies for an initial period could be preferable in order to increase installers' willingness to share and discuss installations with less concern about negative feedback and reputational damage.

This paper has focussed on retrofit installation of heat pumps, but the model proposed here should, in time, be expanded to include a wider range of innovative energy technologies and services not yet familiar and trusted by consumers and for which there are gaps in skills and data. This could support innovation, adoption and learning across heating systems, building efficiency, micro-generation and storage, and shed light on the most appropriate solutions for different circumstances. The use of smart meter data for measurement-based assessment and P2P learning could also help householders see value in smart meters and the data they provide and so bolster public engagement with the smart metering rollout, now just halfway to completion (BEIS, 2022) and with a deadline of 2025.

Broader still, the 'measure and share' approach advocated here has two further implications for delivering Net Zero generally. Firstly, *enabling currently passive consumers to play more active roles through peer-to-peer learning (exchanging data, knowledge and experiences) could be applied more widely as a model for public engagement* in other areas of UK decarbonisation. Secondly, these proposals also underline the potential to *support positive feedback effects by leveraging what progress has been achieved*: whether this progress is technology adoption, behaviour change or the accrual of co-benefits[43], making these visible and learning from them can build momentum in societal change and system change for Net Zero goals (Carmichael, 2020). The heat pump case studies database discussed here illustrates the potential of data-led digital tools and ICT in this area.

[43] See https://ukerc.ac.uk/project/win-window/

Appendix - Case study data collection requirements

Table 3, below, is an indicative summary of data collection required for case studies of installation outcomes for heat pumps.

Mapping the collection and processing of data is vital for clarifying feasibility, costs, informed consent, and data access and storage solutions. The table contents below are not definitive and are focussed on heat pumps.

The table is structured broadly according to how data could be presented in case studies aimed at supporting HP adoption decisions by clarifying the value-case for HPs vs other heating systems and services. The data should therefore support users to:

i. make/see comparisons between before and after installation of HP and other retrofit measures/products and services;

ii. make/see comparison between different case studies; and

iii. see relevance of case studies for their specific context, home and their heating options.

Procedures for data collection should:

i. support data verification/assurance and data privacy procedures;

ii. balance data quality with cost, inconvenience and privacy concerns;

iii. be preceded/accompanied by appropriate informed consent procedures.

The data covers six main areas:

i. Building performance

ii. Heat pump performance

iii. Costs and savings

iv. Carbon emissions

v. Customer satisfaction

vi. Building & occupant characteristics

Table 3 Case study data collection requirements

DATA/METRIC SHOWN IN CASE STUDY (for both pre- and post-installation where possible)	DETAILS OF REQUIRED DATA AND COLLECTION METHODS/SOURCE/ MONITORING DEVICES...
1. Building performance: a. Heat Transfer Coefficient (HTC) (using SMETER solutions). b. Indoor environmental quality (IEQ). NB. • Building performance estimates in EPCs/ RdSAP are not reliable enough (Crawley *et al.*, 2019); SMETERS have been shown to be accurate (Allinson, 2022). • Comparison between pre- and post-installation will require a period of baseline data for which smart meters store 13 months of historic data. • For more details, see Section 4.1	The best-performing SMETER technologies, by Build Test Solutions (BTS) and Switchee (Allinson, 2022), have different requirements for in-home sensors: BTS SMETER ('SmartHTC'): five wireless, battery-powered sensors (for temperature and relative humidity) that report to an internet-connected hub. Data collection over a 21-day period in Oct-Mar. Additional home survey to capture floorplan and details of all windows (type, size, and orientation, overshading). Switchee SMETER: professional installation of proprietary smart central heating controller measuring temperature, relative humidity, and motion detection. Also: • Energy consumption data: half-hourly consumption data from the electricity and gas smart meters (or manual readings from standard meter at the start and end of the temperature monitoring period if smart meter data is not available). • EPC data. • Building characteristics (installer on-site survey). • Additional information via questionnaire from owner-occupier or occupant and landlord.

DATA/METRIC SHOWN IN CASE STUDY (for both pre- and post-installation where possible)	DETAILS OF REQUIRED DATA AND COLLECTION METHODS/SOURCE/ MONITORING DEVICES...
2. Heat pump performance: a. Seasonal Performance Factor (SPF) for system at SEPEMO H4 boundary NB. • Heat pump SCoP Seasonal Coefficient of Performance, used in EPCs/RdSAP, are always estimated and there is no routine measurement of ex-post in-situ performance. • For more details, see Section 4.2	• Building performance HTC obtained with SMETERs (see above). • HP performance data may be available where heat pump manufacturers have incorporated more monitoring hardware into heat pump installations. • Current clamps (CT sensor) or other electricity meters on heat pump (at H4/SEPEMO system boundary). • Single-wire digital temperature sensors to monitor: the flow and return water temperature from the HP unit; hot water cylinder temperature; the outside air temperature. Or more expensive heat meters that measure: total heat delivered in kWh; real-time heating power in Watts; flow and return temperatures; and flow rate in L/min or m3/hr. (NB. all MCS heat pump installations are expected to have adequate space for fitting heat meters (MCS, 2013)). • Indoor temperature via monitor (see SMETERs). • Weather/outdoor temperature from local weather station data or exterior monitoring device (see SMETERs). • Duration: 12 months or minimum of winter season. • Data on secondary heating output (via smart meters and self-report questionnaire from occupants). • Further hardware will be required to collect and transmit data from sensors for cloud-based storage and analysis.

DATA/METRIC SHOWN IN CASE STUDY (for both pre- and post-installation where possible)	DETAILS OF REQUIRED DATA AND COLLECTION METHODS/SOURCE/ MONITORING DEVICES...
3. Costs: a. Installation costs. b. Running costs for heat and for whole house. c. Return on investment (ROI) and estimate of payback period and savings relative to previous heating system.	Installation costs for heating system and building fabric retrofit from: contract/invoices/ receipts; details of grants/loans. Case studies should show separate costs for parts and cost of labour for transparency and comparisons. Running costs: • HP consumption data from HP sub-meter (see ‘2’, above). • Tariff information (from supplier). • Billing information (from bill-payer or supplier). • Energy consumption data from electricity and gas smart meters (from DCC or direct from meters via CAD). • Maintenance and servicing costs of HP and other heating system components. • Calculation of a counter-factual for costs of running and maintaining previous/ alternative heating system(s).
4. Carbon emissions from heating system a. Average kg CO2/kWh b. Total CO2/year)	Calculate from: • Smart meter half-hourly consumption data. • Supplier tariff information. • Grid generation mix and grid carbon-intensity at different times (use averages, estimates or actual ex-post data). • Where applicable, should reflect on-site micro-generation and self-consumption/export.

DATA/METRIC SHOWN IN CASE STUDY (for both pre- and post-installation where possible)	DETAILS OF REQUIRED DATA AND COLLECTION METHODS/SOURCE/ MONITORING DEVICES...
5. Customer satisfaction (adopter & occupant) To include satisfaction with: a. Costs (installation costs, running costs, ROI) b. Installation experience (disruption etc.) c. Installer d. Thermal comfort e. DHW provision f. Controls (functionality, usability) g. Noise h. Reliability i. Technical support	Self-report questionnaire from occupant(s) and adoption decision-maker (owner-occupiers/landlords/housing association etc.) For rental properties, data collection on customer satisfaction will be split into areas answered by: • the occupant (e.g. installation experience; thermal comfort; DHW; controls, noise); • the adoption decision-maker/landlord (e.g. installation costs). Customer satisfaction to be measured using: i. a numeric/quantitative rating metric; ii. plus a free text field. Possible metrics for reporting satisfaction to be subject to testing with both those giving the data and those using it.
6. Building and occupant characteristics Description (for both pre- and post-installation) of: a. household (number of occupants and any unusual patterns of heat demand); b. building characteristics; c. heating system (primary and secondary heat sources); d. any energy storage devices (e.g. DHW tank, battery); e. energy tariffs/services; f. zoning of property g. smart/automation controls.	Collected by self-reported questionnaire from installer, owner-occupier or occupant(s) and landlord Motion sensors for SMETERs will also contribute to identifying occupancy patterns.

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