



UK Government

Homes for Net Zero

Project Summary and Winter 2024-25
Findings



© Crown copyright 2025

This publication is licensed under the terms of the Open Government Licence v3.0 except where otherwise stated. To view this licence, visit nationalarchives.gov.uk/doc/open-government-licence/version/3.

Where we have identified any third-party copyright information you will need to obtain permission from the copyright holders concerned.

Any enquiries regarding this publication should be sent to us at:
energyresearch@energysecurity.gov.uk

Contents

Executive Summary	8
1. Introduction	11
1.1. The heat decarbonisation challenge	11
1.2. Homes for Net Zero	12
1.3. Research questions	16
1.4. Report aims	17
2. Project Approach	18
2.1. Literature review	18
2.2. Recruitment	19
2.3. Technical surveys	27
2.4. Technical measures	29
2.5. Basic monitoring	38
2.6. Detailed monitoring	40
2.7. Data management	44
3. Analysis and findings	47
3.1. Analysis of behavioural measures	47
3.2. Behavioural advice	48
3.3. Development of roadmaps	60
3.4. Roadmaps	63
3.5. Evaluation of roadmaps	66
3.6. Quantitative data analysis methods and findings	79
3.7. Trial profile	92
4. Conclusion	111
Appendices	112
Appendix 1: List of research questions	112
Appendix 2: Data flow	114
Appendix 3: Living Lab and Tableau architectures	114
Appendix 4: Recruitment Challenges	115
Appendix 5: Known and potential biases (AEH – heat battery trial)	120
Appendix 6: Recruitment survey (AEH – heat battery trial)	120

Table of figures

Figure 1: Distribution of number of occupants across core project homes _____	25
Figure 2: Percentage of households at different EPC ratings compared with EHS (2023) _	26
Figure 3: Distribution of built form in core group compared with EHS (2023) _____	27
Figure 4: Schematics of RAAHP system types _____	32
Figure 5: Example of typical outdoor RAAHP unit appearance and positioning from manufacturer marketing material _____	34
Figure 6: Excerpt from measures documents _____	50
Figure 7: Number of people who reported they were following the advice (either already or since receiving the email), and if the advice prompted them to do it _____	52
Figure 8: What motivated those who tried the advice to do so _____	53
Figure 9: Reasons participants gave for not trying the advice _____	54
Figure 10: How easy or difficult respondents who tried them found the advice _____	55
Figure 11: Impact of fully loading washing machines and dishwashers for those who tried it _____	56
Figure 12: Impact of turning down radiator valves in unused rooms for those who tried it _	56
Figure 13: Impact of bleeding radiators for those who tried it _____	57
Figure 14: Impact of clearing radiator obstructions for those who tried it _____	57
Figure 15: Impact of turning down the thermostat for those who tried it _____	58
Figure 16: Impact of turning down boiler flow temperature for those who tried it _____	59
Figure 17: Overall satisfaction with advice _____	60
Figure 18: Responses to "To what extent would you agree with the following statements in relation to the roadmap..." (n=85) _____	68
Figure 19: When do you imagine you'll be living in a home running efficient, low carbon heating like a heat pump? _____	69
Figure 20: "When, if ever, do you think you might take the following steps to make your home more Net Zero Ready?" _____	71
Figure 21: "To what extent did the roadmap influence your plans on the steps that you mentioned (multiple choice)" _____	73
Figure 22: "When, if ever, do you think you might take the following steps to make your home more Net Zero Ready?" (n=86, those with roadmaps) _____	74
Figure 23: "When, if ever, do you think you might take the following steps to make your home more Net Zero Ready?" (n=510, those without roadmaps) _____	75
Figure 24: Suggested improvements to roadmaps _____	77

Figure 25: Illustration of PTG line fitting _____	81
Figure 26: Illustration of difference in difference _____	82
Figure 27: Change in mean HPLC from winter 2023/24 to winter 2024/25 (N = 429 homes, only including homes with sufficient data in winter 2024/25 before / without intervention) _	84
Figure 28: Change in mean HPLC between winter 2023/24 and after intervention winter 2024/25 compared with counterfactual (HfNZ, not SERL) for winter 2024/25 _____	84
Figure 29: Change in mean HPLC between before intervention winter 2024/25 and after intervention winter 2024/25 _____	85
Figure 30: Mean change in mean internal temperature before and after intervention, in winter 2024/25 in living rooms _____	87
Figure 31: Proportion of time a room was over threshold temperature in summer 2024 plotted against mean daily external temperature. _____	89
Figure 32: Householders' ability to maintain a comfortable temperature during the heatwave in 2024 _____	90
Figure 33: Householders' success in reducing temperature _____	90
Figure 34: Distribution of daily energy consumption for January 2024 in core group (N=850), compared to SERL observatory comparator group (N= 1,400), counts less than 10 suppressed _____	93
Figure 35: Mean monthly energy demand for core homes and SERL comparator group, November 2023 to March 2024 _____	93
Figure 36: Mean monthly energy demand for core homes and SERL comparator group, November 2024 to March 2025 _____	94
Figure 37: Comparison of UK population and core trial householders' awareness of Net Zero _____	95
Figure 38: Operating costs for tepeo ZEB by season (£/month) _____	99
Figure 39: Annual cost savings by heating technology (£/annum) _____	101
Figure 40: Duration of substantial charge events _____	104
Figure 41: Duration of substantial discharge events _____	105
Figure 42: Frequency of use of boost function _____	106
Figure 43: Heat delivered efficiency by season for tepeo ZEB _____	108
Figure 44: Proportion of household electricity use consumed by the tepeo ZEB _____	110
Figure 45: HfNZ data flow _____	114
Figure 46: High level architecture of the Living Lab _____	114
Figure 47: Tableau bridge architecture _____	115

Table of tables

Table 1: Types of activity in HfNZ _____	15
Table 2: Subsets and their combinations of measures and activities _____	16
Table 3: Initial and revised measures quantities _____	31
Table 4: Characteristics of heat battery technologies included in the trial _____	35
Table 5: Mean external temperatures in summer 2024 _____	88
Table 6: Statistical summary of available pollutant data in April 2025 for 69 sensors in core trial household living rooms _____	91
Table 7: Installation and maintenance costs for three heat battery types and ASHP counterfactual _____	96
Table 8: Methods utilised for recruitment of households into AEH trial _____	118
Table 9: Further methods utilised for recruitment of households into AEH trial _____	119

Executive Summary

Decarbonising domestic space heating and hot water has been recognised as one of the most difficult challenges on the pathway to Net Zero. It may not always be simple and straightforward for householders to replace their heating system with an efficient zero direct emissions alternative, with additional alterations to the heating system, or changes to the fabric of their home also required. The purpose of the Homes for Net Zero (HfNZ) project is therefore to better understand these challenges for householders. The objectives of HfNZ are:

- Develop a flexible home monitoring trial for a range of research priorities
- Better understand the opportunities and barriers for homeowners to transition to a Net Zero ready home
- Explore the role of alternative electric heating technologies to decarbonise heating in homes
- Explore the emerging issues and potential solutions to adapt homes to a changing climate

To understand these challenges, ~1,250 homes have been recruited to HfNZ trials. All homes have had their energy use and internal temperatures monitored to provide a detailed understanding of their heating use. Several hundred homes have had measures installed; these measures include changes to building fabric such as loft insulation, changes to heating systems such as radiator upgrades, or entirely new systems such as reversible air-to-air heat pumps (RAAHPs). Homes that have had measures installed have had additional and more advanced monitoring installed, such as a heat meter or room-by-room temperature controls, to better understand how these changes have affected heating use. Several surveys are used throughout the trials to understand consumer perspectives. Some homes are recruited to the trials that already have heat batteries in-place. Approximately a third of the homes are also having their internal air quality monitored. All monitoring is managed through the Energy Systems Catapult's Living Lab¹.

Due to small samples sizes it is not possible to draw wider conclusions at stock-level on energy savings from the results on low cost, low disruption efficiency measures. In the homes tested, the initial results did not find evidence of significant energy savings from these measures. Repeat analysis in future winters, will explore these results further.

Insufficient data is available in the project *yet* to make assessments of comfort taking, performance of combinations of measures, and performance of RAAHPs. Future reports will cover these research questions. However, where heat meters had been installed, it was found that mean boiler flow temperatures had reduced by over 6°C following a heating system MOT+ intervention; for homes to be Net Zero ready, the heating systems may need to operate at lower flow temperatures.

¹ <https://www.livinglab.energy/home>

Because the homes recruited to the heat battery trial already had them installed, a greater amount of analysis has been undertaken. Findings indicate heat batteries can provide space heating cheaper than other direct electric heating technologies (operational costs only), but more expensive than gas boilers or air-source heat pumps. Householders reported a high degree of satisfaction with the technology, a low-level of disruption during installation, and feeling comfortable.

An important aspect of getting homes ready for Net Zero is making improvements to occupant comfort, such as reducing occurrences of rooms being too cold or hot. In response to a survey undertaken shortly after a heatwave, most householders reported that they were rarely comfortable overnight despite making attempts at reducing internal temperatures. Data from temperature sensors has showed internal temperatures higher than 28°C, even when external temperatures dropped. Likewise, nearly half of respondents to a survey undertaken after a cold spell reported being uncomfortably cold in their bedroom overnight.

Nearly 250 householders have received different types of information about how they can get their home ready for Net Zero and reduce their energy use in the form of a bespoke Roadmap for their home or more generic behavioural advice. Roadmaps included detailed and tailored information about their home and included suggested measures to get their home ready for Net Zero. Behaviour change measures were easy-to-make low or zero cost changes that householders can adopt immediately, that both reduce their energy use and bills, and prepare a household for how their heating system may work in the future (e.g., reducing flow temperature).

Of those who received behaviour change advice, 63% responded to a follow-up questionnaire. Most people reported they found the advice they were sent 'easy' or 'very easy' to do. Most found that the advice was common knowledge and had tried it before, however many reported the advice was a reminder, and some used it as an opportunity to revisit how they'd previously looked after their home. The primary motivator for participants trying the advice was saving money on energy bills, followed by reducing environmental impact and then improved comfort. This highlights the importance of financial incentives in promoting energy-saving behaviours, with health and comfort being less influential. Analysis of energy data for those who had received the behavioural advice found it was not possible to identify a reduction in energy use.

Of those who received a roadmap, 57% responded to a follow-up survey. Most participants (64%) found the roadmap easy to understand, and over half (58%) said it clearly showed the changes they needed to make. Reiterating findings from the behavioural advice surveys, most participants reported their main motivations for improving energy use are cutting bills and staying warm, with climate concerns a lesser priority. Most recipients said their roadmap felt both helpful and relevant (74% reported being satisfied with it) and they appreciated the level of personalisation that made the advice feel grounded and trustworthy.

Some felt the roadmap prompted them to start acting, those in electrically heated households who had started to seek expert advice or review their tariff. Low-disruption, cost-effective upgrades appealed most. Solar PV panels appealed to many gas-heated households and a

good share of electric-heated ones, while invasive wall insulation was often seen as impractical or too costly.

1. Introduction

This section of the report describes the challenge of decarbonising domestic heat, provides a high-level overview of the approach taken in the project, and outlines the project's research questions.

1.1. The heat decarbonisation challenge

The UK Government has set a challenging target of meeting Net Zero emissions by 2050, that will mean decarbonising all sectors of the UK economy.

Providing space heating and hot water to the UK's nearly 30 million dwellings contributed 18% of the UK's greenhouse gas emissions in 2021². Providing householders with space heating and hot water contributes greenhouse gas emissions from the burning of gas or oil in boilers. About 80-85% of the UK's housing stock has a gas boiler, with 5-10% having an oil boiler. Most of the remaining 5-15% of dwellings have 'zero direct emissions' heating technologies, powered by electricity.

Decarbonising domestic space heating and hot water has been recognised as one of the most difficult challenges on the pathway to Net Zero (National Audit Office, 2024³). Replacing gas or oil boilers is often not a simple and straightforward heating source swap to a zero direct emissions alternative. For example, additional changes may be required to ensure that the householders are comfortable and can afford their energy bills. These additional changes may entail changes to other aspects of the heating system, such as pipework and radiators, or changes to the fabric of the dwelling, such as insulation and draught proofing.

Dwellings that already have a 'zero direct emissions' space heating and hot water system will most likely have something that can be replaced with a more efficient alternative. Older systems such as storage heaters are at best 100% efficient and can be replaced with alternatives that are at least 200-300% efficient if not more⁴. Making these changes reduces running costs for householders and frees up capacity that could allow more low carbon technologies to connect to the electricity network.

A small proportion of dwellings in the UK have already made the transition to high efficiency and zero direct emissions heating systems, such as air source heat pumps⁵.

² Decarbonising Home Heating, 2024, National Audit Office (<https://www.nao.org.uk/reports/decarbonising-home-heating/>).

³ Decarbonising Home Heating, 2024, National Audit Office (<https://www.nao.org.uk/reports/decarbonising-home-heating/>).

⁴ Systems that are 200-300% efficient utilise heat pumps that can extract "free" energy from the surroundings and upgrade this energy through a vapour compression cycle to achieve more output thermal energy than the electrical energy used to power the compression cycle. This is referred to as the co-efficient of performance.

⁵ Those supported by funding from Government schemes total just less than 125,000 over the period Q1 2018 - Q2 2024, around 0.5% of the UK housing stock. The English Housing Survey 2023-24 low carbon technologies fact sheet reports a figure of 276,000 in England, around 1% (<https://www.gov.uk/government/statistics/english->

1.2. Homes for Net Zero

The purpose of the Homes for Net Zero (HfNZ) project is therefore to better understand these heat decarbonisation challenges for householders. As noted, it has been recognised as one of the most difficult challenges on the pathway to Net Zero. It may not always be simple and straightforward for householders to replace their heating system with an efficient zero direct emissions alternative, with additional alterations to the heating system, or changes to the fabric of their home also required.

HfNZ is a project designed and funded by the Department for Energy Security and Net Zero (DESNZ) and delivered by the Energy Systems Catapult (hereafter referred to as *the Catapult*). HfNZ has the following objectives:

1. Develop a flexible home monitoring trial for a range of research priorities,
2. Better understand the opportunities and barriers for homeowners to transition to a Net Zero ready home,
3. Explore the role of alternative electric heating technologies to decarbonise heating in homes,
4. Explore the emerging issues and potential solutions to adapt homes to a changing climate.

Two types of home and heating system are of interest in HfNZ and meeting the project's objectives is therefore through two trials:

1. A 'core trial' focussing on solid wall homes with a gas combi-boiler,
2. An 'alternative electric heating trial' focussing on two types of electrically heated homes: direct electric heated flats and houses, and those with a heat battery.

Solid wall homes with gas boilers are of interest to DESNZ because they may be challenging to decarbonise due to their unique characteristics (solid walls can be expensive to insulate, combi-boilers provide hot water directly and therefore do not need to be paired with a hot water tank). Flats provide unique challenges as they typically have limited space and therefore reduced options for decarbonisation or energy efficiency, likewise, houses with direct electric heating may not choose an ASHP as it would entail installation of a full 'wet' heating system. Homes with heat batteries are of interest to understand how these technologies perform.

To understand these challenges and meet the project's objectives, ~1,250 homes have been recruited to HfNZ. All homes are having their energy use and internal temperatures monitored to provide a detailed understanding of their heating use.

From the cohort of ~1,250 homes, several hundred homes were selected to have measures installed to better understand the opportunities and barriers for homeowners transitioning to

Net Zero. These measures included changes to building fabric such as loft insulation refreshes and changes to heating systems such as radiator upgrades, or entirely new systems such as reversible air-to-air heat pumps (RAAHPs) that can provide cooling as well as heating. Some homes already have alternative electric heating technologies installed and are providing data on their performance.

Homes that were having measures installed also had additional and more advanced monitoring installed, such as a heat meter or room-by-room temperature controls, to better understand how these changes have affected their heating use. Approximately a third of the homes had their internal air quality monitored. All monitoring is managed through the Energy Systems Catapult's Living Lab⁶.

Up to 250 householders received different types of information about how they can get their home ready for Net Zero in the form of a Roadmap or reduce their energy use through behaviour change. Roadmaps included detailed and tailored information about their home, including suggested measures to get their home ready for Net Zero. Behaviour change measures were easy-to-make low or zero cost changes that householders can adopt immediately, that both reduce their energy use and bills, and prepare a household for how their heating system may work in the future (e.g., reducing flow temperature). Some surveys were undertaken after extreme weather events, such as a heatwave to understand how householders coped.

The intended outcome from HfNZ is therefore a robust evidence base built on the back of the data collected and analysed in the project, that answers the project's research questions (see Appendix 1). This project summary and initial findings report describes the progress made to date and the methods and approaches adopted and provides an initial analysis of some data.

1.2.1. Brief overview of project approach

In both trials, householders volunteered to participate. The recruitment process required householders to sign up to the trials, agree to the project's terms and conditions, provide access to their smart meter data and set up temperature and humidity monitoring equipment that was provided free of charge to them. Hundreds of homes were surveyed, with those meeting a project's requirements then selected to receive a 'measure'. A measure was a change to the dwelling that will progress the householder's transition to being a 'Net Zero ready' home. These measures varied from a low level of disruption such as improving the draught proofing of a dwelling to much more complex measures such as replacing the heating system. Some measures were paired with additional monitoring equipment to provide specific data streams. Some householders were provided with advice and information on how they may get their home ready for Net Zero.

In the core trial, the target was to recruit a cohort of 1,000 homes. As noted, these dwellings were built with solid external walls and have a gas combi-boiler. Decarbonising this type of dwelling is of particular interest due to it having solid walls and not having a hot water tank. Solid walls can only be insulated internally or externally (because there is no cavity to be

⁶ <https://www.livinglab.energy/home>

insulated); internal insulation is very disruptive, reduces room sizes and requires redecoration whereas external insulation is comparatively expensive, requires rendering and changes the look of the building. Having insulated external walls reduces heat loss and therefore makes providing space heating more efficient and affordable and increases occupant comfort, however Homes for Net Zero is seeking to understand how these homes can transition to being Net Zero ready without insulating external walls. The absence of a hot water tank introduces a further challenge (which may be explored in future phases of the programme); a home that transitions to being Net Zero ready will likely install a heat pump and therefore will need to find space to accommodate a hot water tank, space it may have previously had before a gas combi-boiler was installed, but has since been utilised for another purpose.

In the alternative electric heating (AEH) trial, the target was to recruit a cohort of ~250 homes. These dwellings were electrically heated and will be a mix of flats and houses. Approximately 200 of these will be electrically heated flats and houses; this type of dwelling is of particular interest due to the potential for it to benefit from a significantly more efficient heating system that does not require installation of 'wet' central heating plumbing and can also provide space cooling to prevent over-heating. The remaining 50 recruited were homes that have already installed a heat battery

Across the two trials, the cohort of ~1,250 homes were divided across several subsets according to the combinations of 'activity' that they will receive. A brief summary of the types⁷ of activity is shown in Table 1 with each of the subsets and their combinations of measures and activity shown in Table 2⁸. The number of homes receiving each intervention was a target.

⁷ A more detailed description of each type is provided in 2.6.

⁸ This is a revised list of numbers and combinations due to challenges encountered during surveys. These are documented and described in sections 2.5.4 and 2.5.5.

Table 1: Types of activity in HfNZ

Type		Brief description
Monitoring	Basic	Collecting half hourly data from electricity and gas smart meters, temperature and humidity sensors.
	Detailed	Collecting half hourly electricity or heat meter data from sub-metered equipment
	Air quality	Collecting data from indoor air quality sensors (CO ₂ , temperature, humidity, VOC's, PM1, PM2.5, and PM10)
Survey	PAS2035 survey	Fabric energy efficiency survey according to PAS 2035 standards.
	SAP heat loss survey	Room-by-room heat loss calculation
	Heat loss survey and system design	Room-by-room heat loss calculation and heating system design specification
Heating system intervention	Temperature controls	Thermostat and smart radiator valves
	Heating system MOT	Service boiler, power flush system, add magnetic filter and inhibitor, balance radiators, reduce flow temperature
	Heating system MOT+	As per heating MOT, but replace up to four radiators to increase emitter capacity and enable lower flow temperatures
	Reversible air-to-air heat pump (RAAHP)	Replace or supplement existing electrically powered heating system with RAAHP
Fabric energy efficiency intervention	Loft insulation refresh	Remove old loft insulation and replace with modern standard to recommended depth
	Draught proofing	Install draught proofing to meet PAS2035 standard
Behavioural	Behavioural advice	Provide householders with information on easy-to-make changes to reduce their energy consumption.
	Roadmaps	Provide householders with detailed, bespoke, information on how to make their home Net Zero ready
	Extreme weather	Understand how householders have coped with extreme weather events, such as heatwaves
	Interviews and surveys	Several surveys at various points during the project to understand householder perspectives

Table 2: Subsets and their combinations of measures and activities

Trial	Subset	Measures	Survey	Basic monitoring	Detailed monitoring	Temperature control	Air quality monitoring	Roadmap	Number			
Core	A	Heating MOT	Heat loss	Yes	Heat meter	Yes	Yes	Yes	10			
	B							No	58			
	C	Heating MOT+	Heat loss	Yes	Heat meter	Yes	Yes	Yes	10			
	D							No	20			
	E	Loft insulation refresh	PAS 2035	Yes	No	No	Yes	Yes	10			
	F							No	70			
	G	Draught proofing	PAS 2035	Yes	No	No	No	Yes	No	10		
	H	Heating system MOT, loft insulation	PAS 2035 + heat loss	Yes	Heat meter	Yes	Yes	Yes	10			
	I							No	0			
	J	Draught proofing, loft insulation	PAS 2035	Yes	No	No	No	Yes	1			
	K							No	0			
	L	Behavioural advice	No	Yes	No	No	No	Yes	10			
	M							No	90			
	N	Supplementary groups	No	Yes	No	No	No	Yes	Yes	40		
O	Yes							No	10			
P	No							No	651			
AEH	Q	Reversible air-to-air heat pump	Heat loss	Yes	Electricity sub-meter	No	No	Yes	No	30		
	R	Supplementary groups	None		No			No	No	No	Yes	50
	S				Electricity sub-meter						No	~100
	T	Heat battery owners	None		Electricity sub-meter			No	~50			

In the above subsets, the ‘supplementary groups’ are used as a counterfactual with which comparisons can be made with the ‘treatment’ groups that are receiving measures. Further comparisons are also being made with a counterfactual group recruited to the Energy Demand Observatory and Laboratory (EDOL) set up as part of the Smart Energy Research Lab (SERL⁹).

1.3. Research questions

The project is collecting a variety of data types related to the trials. These are used to answer a comprehensive set of research questions (see Appendix) across the project:

- High-volume, high-resolution quantitative data from sensors installed in trial participants’ homes (incl. smart meters) are used to analyse the effects measures have had on energy consumption and operational cost, observed occupant heating and cooling behaviour, and conditions within the home related to indoor air quality (IAQ) and

⁹ <https://serl.ac.uk/>

temperature. These data will also be used to compare the sample within HfNZ to the wider housing stock in England and Wales.

- Quantitative data from trial participant surveys are analysed to understand householders' lived experience with the measures and their installation, their attractiveness to consumers, and householders' perceived comfort within the home. They were used to gather feedback and evaluate impact of the roadmaps, and uptake of behavioural advice.
- Data from interviews are used to gain deeper insight into householders' experiences as above. Alongside focus groups, they have been used to gather iterative feedback from consumers to develop the roadmaps, and to refine the behavioural advice, as well as to understand their experiences of receiving/trying them.
- Furthermore, the trial has collected data about the practical aspects of installing the measures, such as the cost of installing different measures, or typical system designs.

Some of the research questions initially proposed at the project's outset will only be answered with a partial dataset; this is because measures will not be in place during all relevant months of interest for the research question to be answered. As an example, the use of reversible air-to-air heat pumps (RAAHPs) to provide summer cooling will be answered with a partial summer's data, as they will not be in place during all summer months during the (currently planned) project's duration. Future phases of the programme will aim to complete the analysis for these research questions.

1.4. Report aims

This document is a summary of the project and an interim report on findings to date from the first months of the project. The intention of the report is to document the methods being employed, describe the data being collected and analysed, and the insights intended to be developed, as well as provide initial insight for some research questions. A second interim report and a final report are due to be prepared later in the project, that will contain more insights gained from analysis of data seeking to answer the project's research questions.

This and subsequent reports will be of interest to civil servants in DESNZ, local authority officers with responsibility for retrofit projects and local emissions targets, and the wider retrofit industry, academics, as well as SMEs and innovators developing new technologies and services.

2. Project Approach

The approach undertaken for each of the various aspects of the HfNZ project is described in this section.

This report is written when many activities to set up the project have either been completed or are in-flight; what is described therefore reflects the progress made to date in setting up the project, challenges faced, decisions made and plans for analysis and reporting once sufficient data is collected, and initial insights for some research questions, where data and time periods of collection allow.

Two literature reviews have informed the approach taken in the project, a summary of both is included in 2.1. This is followed by a description of the approach taken to recruit households to the HfNZ project and enrol them in the trials in 2.2. When households join the trial, a huge amount of data will subsequently be collected from them; sections 2.5 and 2.6 describe the project's approach to basic and detailed monitoring respectively, before detailing the project's approach to managing the data that is collected in section 2.7.

Some of the homes recruited to the project were surveyed, and those that were suitable to receive technical measures that are akin to those a home might take to get 'Net Zero ready' or 'heat pump ready' were installed; the surveys and measures installed are described in 2.3 and 2.4.

As well as installation of technical measures, a number of approaches to providing information to householders to encourage them to understand their energy-related behaviours and take action to get their home net zero or heat pump ready were developed and tested. These included 'behavioural advice' and 'roadmaps' and are described in Chapter 3 alongside findings from providing this advice.

2.1. Literature review

At the outset of the project, a literature review was conducted by UCL, with input from the Energy Demand Observatory and Laboratory (EDOL¹⁰) teams at UCL and Oxford University and from the Catapult. The review is published alongside this interim report¹¹, and sets out lessons learned from previous energy measure monitoring studies to support planning to get the most out of the HfNZ project.

The literature review identified that very few studies of the scale of HfNZ have been carried out in the past. Most research has been undertaken as part of general policy evaluation with limited resource and few purpose designed studies have been undertaken. Major studies in the UK since 2000, and additionally examples from other countries and smaller scale studies, were assessed. Projects which simply observed energy use and temperatures in the home, and

¹⁰ <https://edol.uk/>.

¹¹ Homes for Net Zero: Home Energy Monitoring Studies - Literature Review

those that assessed energy efficiency measures, were both discussed as the learning from both is relevant for HfNZ. The design of these studies is described, as are the consequent monitoring strategies. Several options to calculate counterfactual energy use to assess energy savings from a measure were introduced.

The literature review identified that HfNZ provides a unique opportunity to design an intervention study that can avoid the pitfalls of previous projects. The key challenges faced by historical studies were identified as:

- Insufficient sample size to provide statistically significant evidence of energy saving¹².
- Limited monitoring instrumentation due to cost.
- Poor reliability of data. This includes lack of data about which measures occurred at what times, and poor collection of contextual data.
- Insufficient monitoring periods, if there is no pre-intervention monitoring.

HfNZ seeks to address these challenges as best it can, balancing robustness with breadth of study, practical concerns, costs and value for money. Specifically, it is recruiting a cohort of ~1,250 households, installing basic monitoring in every home and detailed monitoring in several hundred homes, and has a long monitoring period that extends to three years for some homes and data sources.

A second literature review was conducted, that assesses the existing knowledge base about IAQ. IAQ is included in HfNZ to establish a baseline understanding of IAQ and determine factors that affect it. The literature review highlighted the lack of knowledge and dearth of studies undertaken in the UK to date, identified the common pollutants monitored by in home devices, described analysis and assessment of data and made recommendations for future trials that seek to understand IAQ levels. HfNZ aimed to address these challenges by deploying 500 sensors in homes across the UK for several years.

2.2. Recruitment

As noted, a total of ~1,250 homes have been recruited to the project's trials. The purpose of this section is to describe the recruitment and onboarding process.

2.2.1. Recruitment plan

Recruiting ~1,250 homes was a significant challenge and required identifying homes from multiple sources and routes into the project.

The Catapult already had a Living Lab of over 2,300 homes in 2023 before HfNZ commenced; homes that met either the core or alternative electric heating trial's eligibility criteria were invited to join the HfNZ trials. To supplement these, in the core trial E.ON recruited from their pool of existing customers, and beyond through several channels. In the alternative electric

¹² Compared to preceding studies, HfNZ will build a much larger cohort of monitored homes with a richer dataset. However, as highlighted in this report, some groups remain too small to provide tests of statistical significance.

heating trial, Roots Research recruited homes from an existing panel of householders and a social media outreach campaign. Subsequently, Further Afield have been contracted to assist with recruitment, as Roots were unable to find sufficient householders who met the criteria through their channels. When recruiting homes with a heat battery already installed, Original Equipment Manufacturers (OEMs) were tasked with recruiting the homes from their existing customers.

In terms of eligibility, the following criteria were followed:

- Owner-occupiers (both freehold and leasehold)
- Solid walls (core trial)
- Gas combi-boiler (core trial)
- Electrically heated (alternative electric heating trial)
- Preference for flats although houses allowed (alternative electric heating trial)
- Pre-existing heat battery (alternative electric heating trial)¹³
- (Preference for) SMETS 2 standard smart meters¹⁴
- Living in the dwelling for 13+ months
- Wi-Fi
- For the core trial, homes were initially recruited from the Midlands only¹⁵. This was later expanded to the north of England.

2.2.2. Recruitment routes

Several routes were identified for recruiting households to the project's trials.

2.2.2.1. The Catapult's Living Lab

As noted, households were recruited to the trial from the Catapult's Living Lab. The Catapult's Living Lab has been in operation for many years, building from an initial cohort of 100 homes in 2016 to more than 5,000 in 2025. Homes in the Living Lab have signed up to participate voluntarily, often on an ad-hoc basis but sometimes in response to recruitment drives to meet a specific requirement. Homes that join the Living Lab are invited to answer questions about themselves and their home and can join trials as and when they become available, subject to meeting eligibility criteria.

For the core trial, the eligibility criteria reduced the pool of eligible homes to fewer than 100. These homes were emailed a 'trial offer' inviting them to join the HfNZ trial; approximately 30 joined the trial.

¹³ Allowances were made for OEMs to participate if they had upcoming planned installations.

¹⁴ Smart Metering Equipment Technical Specifications (SMETS) 2 meters have greater compatibility characteristics than SMETS 1 meters

¹⁵ It was important for homes to be clustered in regions to ease organising and completing measure installations.

Only two suitable candidates were recruited from the Living Lab for the alternative electric heating trial, due to the restrictive selection criteria. Neither of these had heat batteries.

2.2.2.2. E.ON's customer base and beyond (core trial)

As well as recruitment from the Catapult's Living Lab, E.ON recruited homes to the trial. Initially these homes were recruited from their customer base, but this was also broadened to non-E.ON homes. Several campaigns were launched to raise awareness and direct people to join the trial, including:

- invitations sent to E.ON's 'Next' customer base;
- campaigns launched on social media platforms;
- targeted direct marketing;
- project information pages on the E.ON and Catapult webpages;
- relationships with existing partners promoting the project;
- indirect, such as word of mouth and repurposing leads from other campaigns.

Many of these campaigns reached hundreds of thousands of people, and so take-up rates were naturally modest. The best performing of the direct campaigns was the invitations sent to E.ON's Next customer base, with a conversion rate of just over 1%¹⁶.

2.2.2.3. Recruitment by Roots and Further Afield (AEH trial – electrically heated flats and houses)

Roots Research were contracted to recruit householders for the alternative electric heating trial. They contacted their existing pool of research participants, as well as carrying out a social media campaign to reach new participants. Roots used a screener questionnaire developed by the Catapult to select suitable householders for both subsets of the trial: homes suitable for the installation of RAAHPs, and homes receiving monitoring only. Due to the restrictiveness of the criteria on the trial, a second recruitment agency, Further Afield, was later contracted to extend the reach of the recruitment effort.

2.2.2.4. Recruitment by heat battery OEMs (AEH trial – heat battery homes)

At the outset of the heat battery part of the AEH trial, DESNZ contacted and worked with all heat battery OEMs (as of October 2024) and the heat battery trade body, Thermal Storage UK. OEMs were asked to participate in the trial by contacting their historic customers, describing the HfNZ trial, and inviting them to join.

2.2.3. Recruitment challenges

Recruitment to the trial was a challenging task for several reasons (see also Appendix 4).

¹⁶ Conversion here means that the householder applied to the trial, not that they joined.

2.2.3.1. Core trial criteria

The criteria for recruitment meant most homes are ineligible for the trial. The following statistics provide an indication of the proportions excluded by each criterion for the trial. The total number of homes remaining eligible for the trial after all the criteria are applied is unknown, however it is likely to be a small proportion and likely to be less than 5%.

- It is estimated that 20-25% of the UK's housing stock has solid walls and a gas boiler¹⁷.
- 2021 Census data¹⁸ shows that 44% of the housing stock of England and Wales is within the areas recruited from (Midlands and north of England) , and of these 59% are owner-occupiers.
- At the end of 2023¹⁹, 58% of domestic electricity meters and 49% of domestic gas meters in Great Britain were smart and operating in smart mode.
- In 2020, 96% of households had internet access²⁰. However, more recent statistics and whether internet access is with Wi-Fi are unknown.
- The requirement for householders to have been in their property for at least 13 months will have meant some applicants were ineligible, but the proportion is unknown.

2.2.3.2. AEH trial criteria

The need to find owner-occupied flats with electric room heaters rules out the vast majority of the housing stock, thus makes recruitment challenging. Owner-occupied flats using storage heaters or electrical room heaters constitute only 1.3%²¹ of the housing stock.

Discussions were held with DESNZ around separating recruitment criteria into essential and desirable aspects, to relax the criteria and widen the range of eligible candidates. The selection criteria were expanded to include houses to significantly increase the number of suitable properties, eliminate the hurdle of obtaining freeholder permission to install, but not compromise the project's ability to gather learnings about the use of RAAHP technology in homes.

Expanding the criteria to include homes with central heating was also discussed, but this would create the need either for costly and disruptive removal of plumbing, or complex integration of the RAAHP with the central heating controls and so is unlikely to be viable for this project. Other options discussed but not progressed included targeting social housing and private landlords, the RAAHP manufacturer's list of leads from website interest, and homes which already have RAAHPs installed.

¹⁷ Approximately 20% of the housing stock is built pre-1919, the majority of which will have solid walls and a gas boiler. The next dwelling age band is 1919-1944, the majority of which will have been built with cavity walls; the exact ratio of solid:cavity walls in this age band is unknown. Data from [English Housing Survey 2022-23](#).

¹⁸ [ONS Census data](#), 2021.

¹⁹ [Smart Meter Statistics in Great Britain, Q4 2023, DESNZ](#). Published March 2024.

²⁰ [ONS, 2020](#).

²¹ English Housing Survey, 2016.

For expansion of the criteria for supplementary candidates, homes with less than a year of smart meter data were agreed to be brought into the inclusion criteria, while non-homeowners were discussed but not progressed.

Homes with solar panels present a challenge for the required analysis, because self-consumption within the home of electricity generated by the solar panels will not show up in smart meter data, meaning total energy usage for heating cannot be determined. This prevents accurate comparisons to heating use over the previous winter, as well as making it difficult to determine the usage of any supplementary heating used alongside the RAAHP, unless it is sub-metered. Fortunately, the preference for focussing on flats for the trial results in a low occurrence of solar ownership in the eligible group; however, expanding the criteria to include houses has increased the likelihood of this problem.

2.2.3.3. Incentives

Participation in trials is attractive for some householders on the basis of informing research and future policy but is not sufficient for everyone. To compensate householders for their time and efforts a small incentive was paid. This is paid in two instalments: firstly, upon completing all recruitment and onboarding tasks and secondly at the end of the trial. The minimum total incentive per household was set at £30. This is much lower than is typically offered for trials in the Catapult's Living Lab. A more generous incentive may have meant completing the trial's recruitment goals was easier, and that retaining householders for the full duration of the trial was made likely.

For the alternative electric heating trial, additional incentives were introduced, including a monthly prize draw for continued participation, intended to minimise the rate of drop-off after initial onboarding.

An extension to the project's timelines in spring 2025 meant householders were asked to remain in the trials for another 12 months. Additional incentives were paid to keep householders in the trials provided that they met basic requests, such as continuing to provide data and keeping equipment plugged in. These were paid in instalments during the 12 months.

2.2.4. Recruitment results

2.2.4.1. Core trial

Around 1,250 homes were recruited to the core trial by the end of October 2024. As homes sometimes choose to leave the trial, due to external factors beyond the project's control (i.e., moving home), the number remaining in the trial by the end of August 2025 had reduced to around 930. Those that leave the trial are not replaced by recruiting new homes due to concerns such as value for money and data quality.

2.2.4.2. AEH trial – electrically heated flats and houses

As of the end of August 2025, 142 householders have been recruited as potentially suitable for RAAHP installation (of the targeted 30), with a further 325 recruited into the supplementary group. Of the households potentially suitable for installations, 51 have signed up to the Living

Lab and connected their smart meters, and 148 of the supplementary group have done the same. Of the 51, 28 have reported that they have direct electric heaters (including one with electric underfloor heating and one using plug-in heaters) while 23 have storage heaters. Monitoring equipment has been issued to a total of 205 homes (some of which have since left the trial), of which 172 have been connected; 45 of these are RAAHP installation candidates.

Roots Recruitment exhausted their pool of potential candidates before meeting the recruitment targets, so the Catapult contracted an additional recruitment agency, Further Afield, in order to reach a greater pool. Several methods were utilised by the Catapult in order to recruit households into the AEH trial (see Appendix 4).

2.2.4.3. AEH trial – heat battery

A total of 52 households were recruited to the trial (See also Appendix 5 and Appendix 6). These 52 are as follows:

- 50 that have a tepeo heat battery,
- 1 with an Eskimo CLive heat battery,
- 1 with a Sunamp Thermino heat battery.

A fourth OEM was intending to recruit a household to the trial but could not do so in the required timelines. All households with a tepeo heat battery had them before the trial commenced, whereas the Eskimo and Sunamp households had them installed during the recruitment phase of the trial. These two households therefore cannot provide historic heat battery consumption data.

2.2.5. Representativeness of the HfNZ sample

Neither of the HfNZ trials sought to recruit a representative sample of homes across the UK. To the contrary, the trials were seeking to collect data about retrofit measures within segments of the housing stock which are particularly complex to decarbonise. Furthermore, recruitment and measure installation requirements led to a further limitation in the geographical scope of the project.

Nonetheless, the project has summarised the distribution of energy consumption within the monitored sample of homes and compared it to a representative sample of gas heated homes in England and Wales which exists within the Smart Energy Research Lab²² (SERL).

For gas heated homes in the core trial, the monthly gas, as well as the combined gas and electricity demand, for the months of November, December and January of the years 2023 and 2024 were established. For all months analysed, the degree-day normalised energy demand will also be calculated. These distributions are plotted to aid comparisons (see Figure 34, Figure 35 and Figure 36 in section 3.7 that describes the profile of the homes in the trials). The same statistics were derived for the nationally representative sample of gas heated homes within SERL (England and Wales only), to which the core trial sample was compared.

²² <https://serl.ac.uk/>.

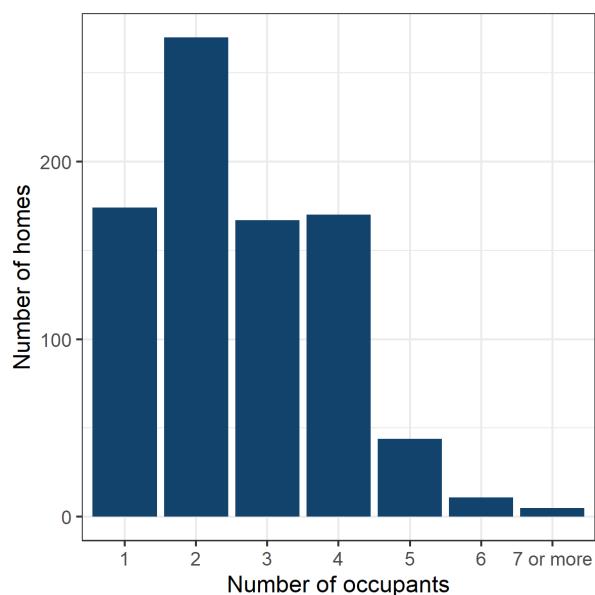
Furthermore, the homes within the trial were compared to the wider housing stock based on household and home characteristics (i.e., occupancy, tenure, energy efficiency according to EPC rating, heating systems and construction). This was achieved by comparing the contextual data gathered from trial householders to the English Housing Survey (EHS).

RQ 3.3: How does the sample of trial homes compare to the wider population of England and Wales in terms of:

- Occupancy
- Tenure
- Level of energy efficiency
- Heating systems
- Construction

In this section, statistics for 850 core trial homes for which energy data was available is analysed. An analysis of the representativeness of homes in the AEH trial will follow in future reports. Figure 1 shows the proportions of different household sizes in the core trial. The mean number of occupants is 2.64, compared with 2.36 average household size in UK²³; 20.8% of the homes have a single occupant, compared to 30% of all households in the UK¹. The higher number of multi-person households is likely the result of the programme’s focus on houses rather than typically lower occupancy flats.

Figure 1: Distribution of number of occupants across core project homes

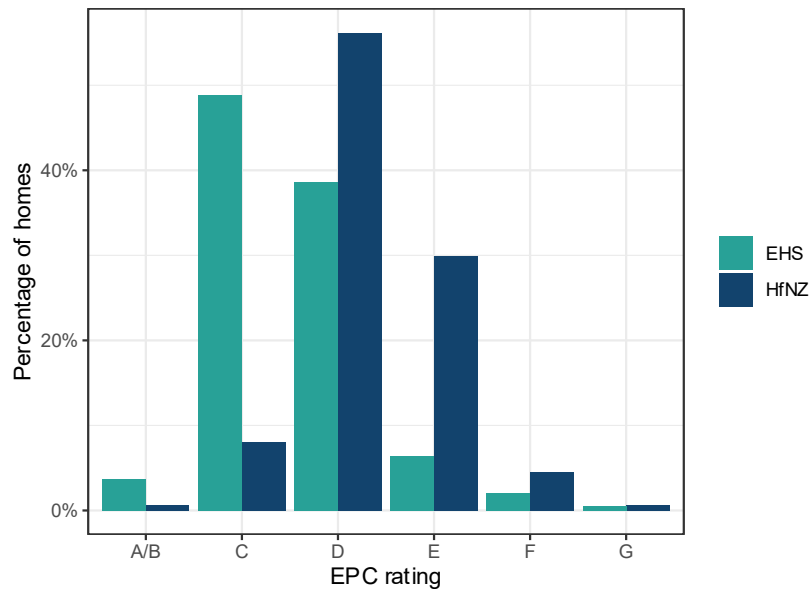


Of the households, 99.4% are owner-occupied (the focus of the trial is owner-occupied properties, so this is as expected). This compares to 65% owner-occupied households in

23
<https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2023>

England, 19% private rented, and 16% social rented²⁴. Figure 2 shows the breakdown of EPC ratings for 539 homes that have EPC certificates compared to that found in the English Housing Survey (EHS), 2023. As would be expected for this group of solid wall homes, there is a much higher proportion of ratings D to G than in the EHS.

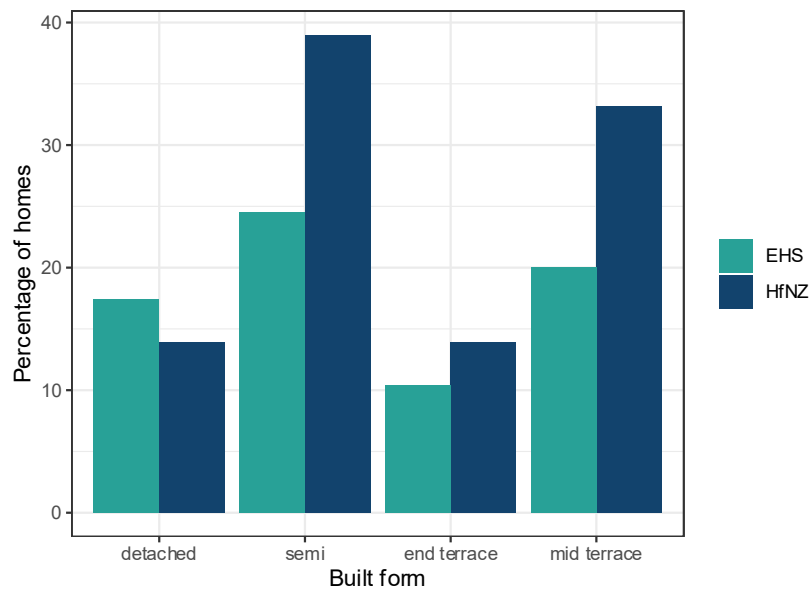
Figure 2: Percentage of households at different EPC ratings compared with EHS (2023)



Of the 539, 93.4% have solid brick walls, with 5% having stone construction (sandstone, limestone, granite or whinstone). All have gas central heating (again, a project criterion), compared with 84% of homes as recorded in the EHS (2023). Figure 3 shows the distribution of built form compared to that in found in the EHS (2023). As expected, given the age of the homes recruited in HfNZ, a greater proportion are terraced compared to EHS (2023) data.

²⁴ EHS 2022-23 report (https://assets.publishing.service.gov.uk/media/657c3ff691864e001308bdba/2022-23_EHS_Headline_Report.pdf)

Figure 3: Distribution of built form in core group compared with EHS (2023)²⁵



2.3. Technical surveys

To facilitate the delivery of measures, technical surveys of homes were carried out to assess suitability and understand exact requirements. Each home assigned a measure first had one of three types of survey:

- PAS2035 survey (core trial)– to technically assess a home’s suitability for energy efficiency retrofit measures such as loft insulation refresh and draught proofing.
- SAP heat loss survey (core trial)– to technically assess a home’s heat loss and understand the performance of the heating system.
- Heat loss survey and practical installation assessment (AEH trial) – to technically assess home suitability and inform design for the installation of an RAAHP.

The following sections provide a brief overview of each type of survey. The numbers of surveys achieved, and the challenges associated with these surveys and assigning homes to measures, is described in 2.3.4 and 2.3.5.

Homes in the heat battery part of the AEH trial were not surveyed, as they either had heat batteries installed before being recruited to the trial, or installations already planned (i.e., two homes) that continued without any HfNZ intervention (e.g., such as a technical survey).

2.3.1. PAS2035 survey (core trial)

PAS 2035 is a comprehensive standard introduced in 2019 as part of the UK government’s commitment to improving energy efficiency in buildings. A PAS2035 survey follows the

²⁵ Showing only the built forms in EHS that match those recruited in HfNZ

requirements of the British Standard²⁶, and is undertaken to identify best practice fabric energy efficiency improvements suitable for a 'whole house' retrofit.

Homes that had a PAS2035 survey could then be assigned to have one of the following technical measures installed:

- loft insulation refresh;
- draught proofing;
- combination: draught proofing and loft insulation refresh;
- combination: draught proofing, loft insulation refresh, and heating MOT (if combined with a SAP heat loss survey).

2.3.2. SAP heat loss survey (core trial)

A 'SAP heat loss' survey entails undertaking a SAP assessment of a home, assessing room-by-room heat loss and heating system design. The purpose of this assessment is to understand if the boiler's flow temperature can be reduced (ideally to below 60°C) and indicate how suitable the home is for a heat pump. It is different to EN12831 that the MCS use, in that it is simpler to complete but robust enough for the intended purpose and was a compromise to support delivery of the trial.

The heat loss calculations consider the dimensions of the home; the materials used in its construction and their properties. The assessment of the heating system design considers the boiler's characteristics such as type and output, pipework and radiator characteristics such as pipe diameters and radiator outputs.

Homes that had a SAP survey could then be assigned to have one of the following technical measures:

- Heating MOT
- Heating MOT+
- Combination: draught proofing, loft insulation refresh, and heating MOT (if combined with a PAS2035 survey)

2.3.3. Heat loss and RAAHP suitability survey (AEH direct electrically heated flats and houses trial)

The survey for installation of an RAAHP was primarily a heat loss survey, allowing selection of heat pump units of a suitable power for the home's requirements. Additionally, practical aspects of the home's suitability for installation were assessed. These included electrical capacity to connect an additional circuit, suitable location for the outdoor unit (considering

²⁶ <https://www.bsigroup.com/en-GB/insights-and-media/insights/brochures/pas-2035-retrofitting-dwellings-for-improved-energy-efficiency/>.

distance from neighbours' windows), pipe and cable routes, suitable location for a hot water cylinder (if required), and compatibility of showers with the hot water cylinder (if required).

The survey was also a point of contact with the householders that provided an opportunity to gather information for analysis. The installer filled out a data gathering template prepared by the Catapult, covering aspects such as existing heating systems, cookers (for air quality purposes), and reasons for the householder's interest in receiving the installation.

2.3.4. Results

A total of 394 surveys were undertaken (assumed need was 365). This included:

- 210 PAS2035 surveys.
- 177 SAP heat loss surveys.
- 42 heat loss and RAAHP suitability surveys (this may increase as RAAHP installations are still in progress, and further surveys may be required).

2.3.5. Technical survey challenges

Whilst it was always expected that the number of surveys required would exceed the number of homes having a measure installed – as some homes surveyed would not be suitable for a measure – the total number of surveys required was more than anticipated at the outset of the project.

Two main reasons are behind this, both related to the PAS2035 surveys. Firstly, homes were frequently assessed as having sufficient draught proofing already in place, and therefore would not benefit, or would not benefit beyond a marginal improvement, from having a draught proofing measure installed. During the process of phone surveying and seeking to identify homes suitable for draught proofing, householders in the trial were called and asked if they thought they would benefit from draught proofing, to try to increase uptake.

Secondly, many homes who were offered and accepted a loft insulation refresh later pulled out when they understood what was required of them. Householders were required to complete some or all the following tasks: empty loft contents, remove boarding, replace boarding in a way that does not compromise the new loft insulation's performance, put contents back. These additional tasks were not covered in the costs for replacing loft insulation, as the contractors were not prepared to accept the liability for handling householders' possessions.

2.4. Technical measures

Many of the ~1,250 homes had a technical measure installed during the project. The following sections describe the measures installed, selection and quality assurance processes, challenges faced, and lessons learned.

2.4.1. Technical measures (core trial)

As noted, core trial homes selected to receive a technical measure upon successful survey outcome were assigned to receive one of the following:

- **Draught proofing:** identify and carry out improvements to prevent unwanted ventilation, including trimming the underside of external doors and fitting draught proofing, installing trickle vents on windows and doors, installing extraction fans, blocking chimneys. Unwanted ventilation reduces internal temperatures and therefore increases heat demand; reducing heat demand helps a home move towards being Net Zero ready.
- **Loft insulation refresh:** replacing loft insulation that has been in place for at least 20 years, or topping up, in both cases bringing the total to 300mm depth; associated works might include altering the loft hatch size, insulating the loft hatch, adding 2m² of loft boarding and ladder, insulating water tanks, and ventilating the loft space. This measure was included to understand whether the performance of loft insulation degraded over time; removed loft samples were sent away for testing in a laboratory. If the loft insulation's performance degrades over time, this increases heat demand; getting a home ready for Net Zero may mean replacing old loft insulation.
- **Heating MOT:** service boiler, power flush, check for leaks, check valves and balance system, install magnetic filter, add inhibitor, reduce flow temperature below 60°C²⁷. Getting a home ready for Net Zero might mean that an air source heat pump (ASHP) is installed in place of the gas boiler; ASHPs work more efficiently at lower flow temperatures, hence the inclusion of this measure and the Heating MOT+ measure (next bullet).
- **Heating MOT+:** as per heating MOT but also to include replacing up to four radiators and pipework to facilitate reducing flow temperature. New radiators had higher outputs than those replaced, were identified during SAP survey in rooms that would need larger emitters to provide the same heat at lower output temperatures, and again were replaced as part of attempt to reduce flow temperature below 60°C.
- **Combination I:** draught proofing and loft insulation refresh.
- **Combination II:** draught proofing, loft insulation refresh, and heating MOT. Combinations of measures are included to understand whether the benefits of each individual measure stack up when combined with other measures.

Due to the issue of finding homes suitable to receive draught proofing, the numbers of each type of measure to be installed, and the combination of measures were subsequently changed (e.g., draught proofing was removed from combinations almost entirely). Table 3 shows both initial and revised quantities of each type of measure.

²⁷ A heating system power flush is a deep clean that pumps water and cleaning solution through your radiators and pipes to remove built-up sludge and help the system heat your home more evenly and efficiently. A magnetic filter traps tiny metal particles in your heating system before they cause blockages or damage, helping it run more reliably for longer. An inhibitor is a special liquid added to the heating system water to prevent corrosion and scale build-up, protecting pipes and radiators over time.

Table 3: Initial and revised measures quantities

Intervention	Initial number	Revised number
Heating MOT	40	68
Heating MOT+	20	30
Loft insulation refresh	80	80
Draught proofing	80	10
Draught proofing, loft insulation refresh	40	1
MOT, draught proofing, loft insulation refresh	20	0
MOT, loft insulation refresh	0	10
Total	280	199

A selection process was required to identify homes most suitable to have a measure installed or would benefit most from a measure. The selection process took a combination of feedback from householders, EPC records, as well as outputs from the aforementioned surveys.

The installation of measures was overseen by E.ON with their existing sub-contractors. Before the measures began to be installed, several training sessions were held to ensure sub-contractors understood requirements and had a chance to ask questions. Upon a measure being installed, forms and photographs were completed and submitted to E.ON for their quality assurance processes. In addition, the flow of data from installed equipment (e.g., a heat meter) was checked shortly after installation to quickly identify any issues, and to provide another quality assurance check.

2.4.2. Results

Core trial measures may be considered to be ‘typical’ in the sense that they are not novel or innovative and instead represent actions that households have to some extent been undertaking themselves for decades (e.g., boiler service, radiator replacements) and sometimes have been part of government or energy supplier funded schemes (e.g., loft insulation). However, the approach taken in HfNZ was novel. For example, loft insulation wasn’t simply installed or topped up but instead old insulation was removed and a completely new, best practice, insulation was installed; changes to heating systems are often carried out individually whereas in HfNZ ‘packages’ encompassed several changes in combination. Challenges in delivering core trial measures have largely been limited to typical challenges such as householders and installers making arrangements, and minor technical difficulties during installations.

The following was completed, largely in line with plans:

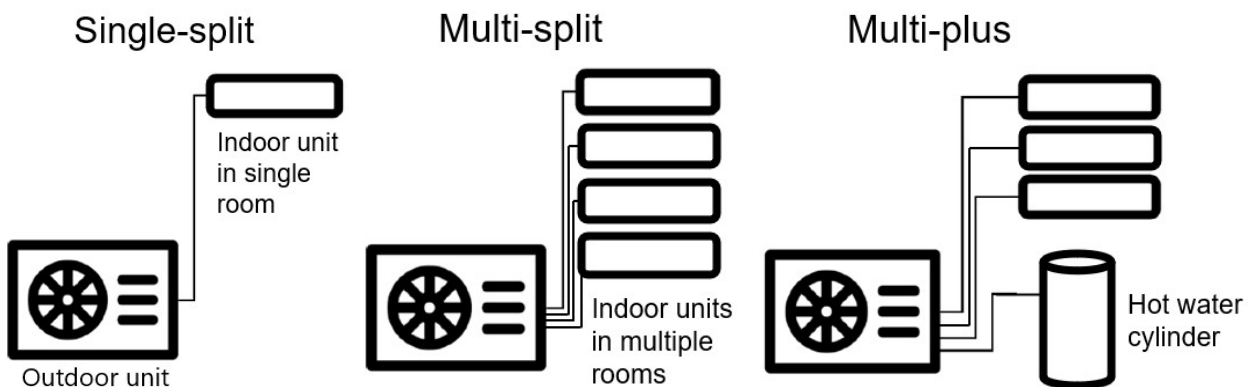
- 68 heating MOT
- 30 heating MOT+
- 80 loft insulation refresh
- 10 draught proofing
- 10 heating MOT, loft insulation refresh

- 1 draught proofing and loft insulation refresh

2.4.3. RAAHP installation (AEH trial)

In one aspect of the AEH trial, the focus is on the installation of RAAHPs in 30 electrically heated homes. RAAHPs are a type of air source heat pump which heat a home without the use of water-based radiators and plumbing. Instead, one or more air blower unit(s), typically wall-mounted, transfer heat directly from a refrigerant heat exchanger into the indoor air with the assistance of a fan. Since no radiator plumbing is required, this type of heat pump can be a less disruptive and more cost-effective way for homes without existing central heating to transition to a heat pump. RAAHPs are also capable of dehumidification and cooling; many people are already familiar with their use to provide “air conditioning”, commonly used in commercial buildings. Because of the dramatically higher efficiency of heating with a heat pump compared to conventional electric resistive heating (e.g., direct room heaters and storage heaters), the installation of RAAHPs is expected to bring about significant energy savings for the householder. A range of system types will be installed for the trial, including: “single-splits” which provide heating and cooling to one room only, “multi-splits” which provide heating and cooling to up to four rooms, and “multi-plus” systems which provide heating and cooling to up to three rooms, as well as domestic hot water supply from the heat pump, via a hot water cylinder. Single and multi-split units will use an alternative source to provide domestic hot water, mostly a standalone electrically heated cylinder. Figure 4 shows each system’s schematics.

Figure 4: Schematics of RAAHP system types



2.4.3.1. Planning Permission

Before June 2025 the installation of RAAHPs was delayed by difficulties navigating the planning permission requirements for the technology. Although heat pumps are covered by The Town and Country Planning (General Permitted Development) (England) Order 2015, there are conditions that RAAHPs were unable to comply with. These were:

G.1 Development is not permitted by Class G unless the air source heat pump complies with the MCS Planning Standards or equivalent standards.

and

G.2 Development is permitted by Class G subject to the following conditions—

(a) the air source heat pump is used solely for heating purposes.

The MCS planning standard is a noise calculation procedure which helps to ensure heat pump installations do not cause a noise nuisance to neighbours. However, the standard prior to June 2025 (MCS020) also contained the following wording:

3.1 The MCS Planning Standard for air source heat pumps is as follows:

(a) The air source heat pump product shall be certified in accordance with MCS 007;

(b) The air source heat pump shall be installed by an MCS Contractor in accordance with MIS 3005.

This linked the noise assessment with other MCS standards relating to performance, design and accreditation, which have been designed for air-to-water heat pumps, so cannot currently be met by RAAHP installations. For this reason, the condition of permitted development intended to prevent noise nuisance had, perhaps inadvertently, ruled out the use of RAAHP technology. This is despite the outdoor units of RAAHPs being virtually identical in noise emissions, appearance, and likely location to air-to-water heat pumps, as can be seen in Figure 5.

At the end of May 2025, the planning requirements for RAAHPs changed and they are now covered by permitted development so long as certain criteria are met (e.g., noise levels). This is expected to reduce the timelines for installations by avoiding the need for an approximately 8 week wait for the planning application to be assessed. Shortly before, MCS020 was superseded by MCS020a which no longer links to MCS007 and MIS3005. Consequently, RAAHPs can now be installed under permitted development, although there remains a requirement for installation contractors to hold an MCS licence in order for the installation to comply, which many installers of RAAHPs are unlikely to.

Figure 5: Example of typical outdoor RAAHP unit appearance and positioning from manufacturer marketing material



The use of RAAHPs solely for heating is difficult to guarantee due to their multifunctional nature and furthermore removes a key advantage and appeal to householders of the transition to a heat pump: the ability to improve summer comfort by cooling.

Before changes to permitted development, the Catapult tendered for planning consultants to carry out planning permission applications for each installation. The process is ongoing for some installations (e.g., those that don't meet permitted development requirements) and is delaying installations. These difficulties may highlight a need for a 'technology-neutral approach' in planning and standards in order to assist meeting Net Zero goals.

2.4.3.2. Freeholder permission

As many flat owner-occupiers are not the freeholders for their building, they face the hurdle of having to obtain permission from their freeholder to install equipment on the outside of the building. In some cases, freeholders have requested a fee for processing an application for permission, without guaranteeing that permission will be granted.

Information packs have been produced by the Catapult for building freeholders, to expediate and encourage the granting of permission to leaseholders to proceed with installations. A lesson learnt from this process has been to anticipate the need to engage building freeholders, with communications prepared in advance and project allowances made for the time required to obtain permissions. The Leasehold and Freehold Reform Act (LFRA) 2024 will make it "cheaper and easier for leaseholders in houses and flats to [...] buy their freehold"²⁸, which may provide an easier route for some flat owners to install an RAAHP.

2.4.4. Heat battery technologies

The project defined heat batteries as devices that can absorb and retain heat for later use. The energy can be stored as:

- Latent heat - where the heat energy causes a change in phase of the storage material (for example, changing from solid to liquid state as occurs with ice and water at 0°C).

²⁸ <https://commonslibrary.parliament.uk/leasehold-reform-in-england-and-wales/>

- Sensible heat – where the heat energy causes a change in temperature of the storage material (for example, heating a water from 1°C to 20°C).
- Both latent and sensible heat – where both a phase and temperature change occur (for example, heating ice from -5°C to water at 20°C)

They can then discharge this heat as required whilst retaining the heat storage material within the heat battery. This can enable the increased use of off-peak (or alternate lower-priced time-of-use) tariffs or renewables.

For this trial, the in-scope heat batteries are storage devices heated using electricity as primary fuel (including use of air-to-water heat pumps) which are connected to the main central heating system. Table 4 provides a summary of the characteristics of the heat batteries included in the trial.

Table 4: Characteristics of heat battery technologies included in the trial

OEM, Product	<i>Comparison: Hot water tank (250 L)</i>	tepeo, ZEB	Sunamp, Thermino xPlus / ePlus	Eskimo, CLive
Product status	Generic	Production	Production for hot water, niche / not commercialised for space heating	Prototype (Note, in production figures may change)
No. participants in HfNZ Heat Battery Trial	N/A	50	1	1
Heat storage medium and type	Water (sensible)	Solid core (largely sensible)	Phase change material (largely latent)	Phase change material (largely latent)
Max storage capacity	5-6 kWh space heating 10-15 kWh hot water	40 kWh	24 kWh (12 kWh per unit, variable)	10 kWh (2.5 kWh modules)
Built-in charging	Yes (electric resistive immersion heater)	Yes (electric resistive)	Yes (electric resistive)	No (charged by external heat pump)
Max charge/discharge power	3 kW charge, water-flow discharge	9 kW charge, 15 kW discharge (via water-flow)	5.6 kW charge (2.8 kW per unit), water-flow discharge	Water-flow charge and discharge

Functions	Generally hot water only. Space heat numbers provided for comparison.	Space heat and indirect hot water	Space heat and indirect hot water	Space heat
Mass	~60 kg (empty), ~310 kg (full)	375 kg	466 kg (233 kg per unit)	~280 kg (70 kg per unit)
Size	0.39 m ³ 65 L/kWh space heating capacity	0.39 m ³ 9.75 L/kWh space heating capacity	0.44 m ³ (0.22 m ³ per unit) 18.33 L/kWh space heating capacity	~0.35 m ³ (0.086 m ³ per unit) 34.65 L/kWh space heating capacity

2.4.4.1. tepeo ZEB explained

The following provides a summary of characteristics of the tepeo ZEB:

- Eighteen electric resistive heating elements work together to heat what is known as the core, located inside the ZEB. The core can reach temperatures of up to 800°C.
- The core can store approximately 40 kWh of heat energy.
- As cold air passes through the block, it is heated up and transfers the heat stored in the core to water.
- The water is heated up to a temperature between 35°C and 80°C and supplies the installed heating system.
- As the maximum flow temperature of a designed system is 80°C, when the core is 80°C or below, the amount of useful heat provided (for space heating) is restricted by the design flow temperature.
- The ZEB unit is designed as a "heat only" boiler, intended for retrofitting, and does not include a pump or a pressure vessel. tepeo advises to use a hot water cylinder, which can be heated indirectly by the ZEB or directly by an immersion heater. Alternatively, hot water can be provided by a separate PCM heat battery.
- Two modes:
 - **Smart Charging mode:** In the smart charging mode, the user can choose between "carbon optimisation" and "cost optimisation" or a mix of the two. The charging algorithm uses weather forecasts to forecast the heat demand and uses this to set the target state of charge.
 - **Custom mode:** In the custom mode, the user manually sets a target state of charge at different times of the day. The custom mode does not adapt to the expected home heat loss based on weather forecast, instead the user must make manual adjustments.

2.4.4.2. Sunamp Thermino explained

The Sunamp Thermino system used in this trial is a prototype system set up using commercially available heat batteries. It is installed in one home only. The following provides a

summary of characteristics of the Sunamp Thermino and the heating system which uses it in this trial:

- The system uses two Sunamp Thermino 300 units in parallel (one ePlus and one xPlus).
- These units are currently widely used and marketed to provide domestic hot water. The trial system is designed and installed as a Combined Primary Storage Unit heating system to provide both space heating and domestic hot water. It is therefore considered a prototype system set up.
- Each of the Thermino units contains a 2.8kW electric resistance heater so the total charging capacity is 5.6kW.
- Each of the Thermino units is designed to store 12kWh of useful heat at 50°C flow temperature so, the total storage capacity of the system is 24kWh at 50°C flow temperature.
- The Sunamp Thermino units store both sensible and latent heat as they undergo a phase change. The Plentigrade phase change material melts (and freezes) at 58°C, this process stores most of the heat in the Thermino heat batteries.
- Due to the thermal performance of the home the system is intended to operate at 40°C flow temperature. Therefore, the system will likely provide more than 24kWh useful heat output.
- The Thermino xPlus has four pipework connections whereas the Thermino ePlus has two. Therefore, the xPlus, will operate as the primary unit and will be used for heating and hot water and the ePlus, will provide additional heating storage capacity when the weather requires it.

The Sunamp system is not evaluated in detail throughout this report as the installation was completed following Winter 24/25. Further analysis will be provided in future reports.

2.4.4.3. Eskimo CLive explained

The Eskimo CLive system is a prototype system set up which uses prototype heat batteries. It is installed in one home only. The following provides a summary of characteristics of the Eskimo CLive system:

- The system uses four 2.5kWh CLive heat battery modules, providing a combined total of 10kWh heat storage. These work alongside an air source heat pump which charges them using heated water. The number of modules can be tailored to the individual house requirements.
- Both the heat batteries and the system are a prototype and are not commercially available.
- The heat batteries in the system store heat for space heating only. Hot water is provided by a separate hot water cylinder which is charged by the same heat pump.

-
- The CLive heat batteries use a phase change material which changes phase between 40°C and 50°C, as such they can provide useful heat up to and above 40°C.

The Eskimo system is not evaluated in detail throughout this report as the installation was completed following Winter 24/25. Further analysis will be provided in future reports.

2.5. Basic monitoring

Basic monitoring of HfNZ households is managed in the Catapult's Living Lab. Basic monitoring involves the collection of energy consumption data from participants' smart meters, and temperature and humidity data from self-installed sensors. All ~1,250 homes recruited to the project have basic monitoring.

2.5.1. Smart meters

When a householder connected their smart electricity and gas meters to the Living Lab, the Catapult used a connection to a smart meter data provider, Hildebrand, who obtained the data on the Catapult's behalf from the smart meter data communications company (DCC) who has access to smart meter data from homes across Great Britain. The DCC will supply, on connection, up to 13 months of historical consumption data, if it is available.

To link a smart meter, users could either simply enter a code from their smart in-home display (IHD) into the Living Lab website or download and install the 'Bright' phone app by Hildebrand from an app store. This gave the Catapult access to details about a meter such as Meter Point Administration Number (MPAN), Meter Point Reference Number (MPRN), and its sensors, and well as the energy usage data in watt-hours.

The initial intention of the core trial was for E.ON to provide 13 months of historical data; however, households were recruited from beyond E.ON's customer base and as such the Catapult upgraded its interface with Hildebrand to be able to provide historic data.

Smart meters are often reliable data sources but sometimes face challenges that mean that data is not always collected. Data is continuously monitored and where necessary, issues identified and resolved as soon as possible by the Catapult.

To ensure individual trial householders are supplying data regularly, Tableau²⁹ reports have been created that count the number of individual readings received in the Catapult's (Vertica) database daily, with the expectation that each meter reports half hourly, (i.e., 48 readings/meter/day). Because of the volume of data, a report monitoring the previous two weeks of data is used and is reviewed twice a week. If a meter records no data incoming for the previous few days, an investigation is triggered. If the meter has lost connectivity to the Smart Meter Wide Area Network (SMWAN) and is no longer reporting usage to the DCC, this had to be resolved by the user's own energy provider. The Catapult contacts the householder and alerts them to the issue and provides guidance and support to get reconnected.

²⁹ <https://www.tableau.com/en-gb>

2.5.2. Temperature and humidity sensors

To monitor temperature and humidity in homes, all households were sent a tado° monitoring pack which consists of three tado° temperature monitors that are mounted on walls. These record temperature and humidity and send data to the Living Lab in near real-time as temperatures or humidity changes for each sensor (or every 20 minutes, whichever is sooner).

Installing the devices is a simple process of self-install and all kits were sent with detailed installation instructions. The Catapult's operations team were on-hand to assist if required. Linking a tado° account to the Living Lab is also simple, requiring only that the user entered their tado° username and password onto a tado° hosted web page consenting to the linking. Thereafter, the user specifies which room each of the devices was in. Data stored in the Vertica database is referenced by home, device, sensor, and room.

2.5.3. Basic monitoring - details

It is the project's intention that 'basic monitoring' data will be collected from *all* households recruited to the trials. Basic monitoring includes:

- Data from gas and electricity smart meters:
 - half-hourly intervals;
 - up to 13 months before the household joined the trial;
 - recorded in watt-hours every 30min;
 - UTC timestamp associated with each reading;
 - Data imported one day at a time one day in arrears (e.g., approx. 02:00 every day).
- Data from tado° temperature and humidity monitoring equipment:
 - Temperature:
 - measured once per minute;
 - reporting interval subject to there being a change of +/-0.1°C or 20-minutes maximum if no change measured;
 - UTC timestamps are associated with each reading.
 - Humidity:
 - measured once per minute;
 - reporting interval subject to there being a change of 1% RH or 20-minutes maximum if no change measured;
 - UTC timestamps are associated with each reading.
 - Other:
 - operation supported via established tado° network includes emails to householders for issues such as low battery;

-
- householders can see their data on the tado° app. Support information (e.g., low batteries, failed sensor) is provided directly from tado°. In normal operation, the sensor temperature display is blank, making the monitors very unobtrusive in the home environment.
 - All tado° data is sent to the Living Lab 'Data Integration Platform' (DIP) continuously in near real-time.

2.6. Detailed monitoring

In addition to the electricity and gas smart meter data and temperature and humidity monitoring described as basic monitoring, the project is also conducting detailed monitoring of specific aspects of interest. As per Table 2, only specific households will have detailed monitoring kit, and each household will not get all types of detailed monitoring. Detailed monitoring is:

- monitoring of IAQ (CO₂, temperature, humidity, VOC's, PM1, PM2.5, and PM10);
- monitoring of room-by-room temperature *control* devices (core trial only);
- monitoring of heat from the boiler (core trial only);
- submetering of RAAHP electricity consumption (AEH trial only);
- submetering supplementary electrical heating devices (AEH trial only).
- collecting data from already installed submetering that is monitoring heat batteries (AEH trial only)

2.6.1. Indoor air quality

Five-hundred households are in the process of being supplied with Lascar WEM+ IAQ sensors, across both trials. The Lascar devices monitor CO₂, temperature, humidity, VOC's, PM1, PM2.5, and PM10 at 1-minute intervals and upload to the Lascar cloud every 30 minutes.

The sensors are linked to the online Lascar EasyLog Cloud service, allowing users to see their air quality in graphic or data form. There is not an automatic interface between the Lascar Cloud and the Living Lab DIP; however, Lascar has an interface that allows the Catapult to download IAQ data for analysis.

All households that are selected to receive a measure have received an IAQ sensor (this accounts for about two-thirds of the 500); the remaining sensors will be distributed to households not receiving a measure in due course.

Data from Lascar IAQ monitors:

- Temperature (°C)
- Humidity (%RH)
- Particulates (PM₁₀)

-
- Particulates (PM_{2.5})
 - Particulates (PM_{1.0})
 - Volatile organic compounds (VOCs)
 - Pressure (hPa / millibars)
 - CO₂ (ppm)

2.6.2. Room-by-room temperature control devices (core trial)

Room-by-room temperature control is via a tado° control kit; a tado° control kit is an upgrade of the tado° monitoring described in 'basic monitoring'. In addition to the temperature and humidity monitors, householders have up to six smart radiator thermostatic valves (SRTV) installed in place of their existing thermostatic radiator valves (TRV). These link to a control device which is wired to the home's boiler and allow the householder, via an app, to individually schedule and control the heating in each room (e.g., to avoid heating an unused bedroom).

Data received by the DIP and Vertica include not only temperature and humidity but the set-point schedule too, allowing an assessment of actual temperature against desired temperature.

Each of the households having a heating MOT or MOT+ has had up to six SRTV (tado° control devices) installed.

Data from SRTV - tado° temperature *control* equipment (core trial only)³⁰ includes:

- Temperature:
 - measured once per minute;
 - reporting interval subject to there being a change of +/-0.1deg°C or 20-min max if no change measured;
 - UTC timestamps are associated with each reading.
- Humidity:
 - measured once per minute;
 - reporting interval subject to there being a change of 1% RH or 20-minutes maximum if no change measured;
 - UTC timestamps are associated with each reading.
- Temperature set point:
 - schedule of temperature set points;
 - 0.5°C settings;
 - based on UTC timestamp.

³⁰ This list is like the list for tado° temperature and humidity monitoring equipment, but not identical.

-
- Other:
 - operation supported via established tado° network includes emails to householders for issues such as low batteries within any device;
 - householders can see their data on the tado° app. Support information (e.g., low batteries, failed sensor) is provided directly from tado°. In normal operation, the sensor temperature display is blank, making the monitors very unobtrusive in the home environment.

2.6.3. Heat monitoring (core trial)

Heat monitoring in the Living Lab is via an integration with Meterpoint. Heat meters have integrated temperature sensors, flow rate monitors and are attached to pipework from boilers and heat pumps, to calculate energy use by assessing flow and return water temperatures and water flow rates. They are installed in compliance with EN-1434-2. The parameters reported by the heat meters installed in HfNZ are listed in 2.6.6.

The Catapult has access to a portal owned and operated by Meterpoint that allows visibility of all Living Lab Meterpoint installations. Each entry in the portal contains 'keys' to allow - in near real-time – download of all device data directly into the Living Lab / Vertica database. Installations are starting to be linked allowing data to be seen flowing into the Living Lab.

The same households that had a heating MOT or MOT+ have had a heat meter installed. Heat metering in the core trial includes:

- Power (W)
- Volume (m³)
- Cumulative heating energy (Wh)
- Cumulative cooling energy (Wh)
- Flow (m³)
- Flow temperature (°C)
- Return temperature (°C)

2.6.4. RAAHP sub-metering (AEH trial)

Homes receiving a RAAHP installation have had sub-metering of the RAAHP's electricity consumption installed. These sub-meters integrate with the Living Lab via Meterpoint for remote data collection. It is not practical or cost-effective to measure the heat output of RAAHPs in-situ³¹, so no heat metering will be carried out. Up to three supplementary space heating and hot water circuits per household receiving a RAAHP install are sub-metered.

³¹ In lieu of direct measurement of RAAHP efficiency, a model of the power temperature gradient (PTG) of each home will be used to analyse energy use for heating before and after the installation of the RAAHP. The PTG describes the relationship between outdoor temperature and energy consumption of the home, meaning that

RAAHP electrical submetering includes cumulative import energy (kWh) only.

2.6.5. Heat battery monitoring (AEH trial)

In the heat battery aspects of the AEH trial, tepeo (data from other heat battery companies was provided separately and is discussed in future reports) provided two sets of data for each ZEB in the trial from heat meters installed at the time the heat batteries were installed:

- **5-min interval readings:** These readings are from various sensors inside the ZEB and are used to optimize its operation. The most important values for this project are:
 - Combined electricity consumption of the heating elements
 - Heat output, determined by the flow rate and temperature difference between flow and return water
 - An estimate of the heat stored. This estimate is based on an algorithm considering the electricity and temperature, material, and shape of the core. This algorithm is frequently updated by tepeo as part of new firmware releases.
- **Monthly summary:** The ZEB stores aggregates for incoming and outgoing energy internally. For each month, these aggregates are reported in a coverage sheet, together with the number of measurements successfully submitted.

The 5-min intervals readings are the primary data source. The monthly summaries are used as consistency checks and for handling missing data in the 5-min readings.

2.6.5.1. Heat meter calibration

The following describes calibration of the installed heat meters:

- The ZEB measures the flow rate and temperature of the flow and return water.
- Due to variations in the electronics and sensors, each ZEB is individually calibrated against an industry standard Class 2 heat meter in the temperature range of 50°C-80°C.
- tepeo identified that the ZEB under-reports heat output at water temperatures below 50°C, in particular if the temperature difference between flow and return water is small.
- tepeo estimates that if the under-reporting of heat flow was corrected, the average ZEB's efficiency in this trial would increase by around 3%.
- How much an individual ZEB would be affected by the recalibration depends on how much time it operates at temperatures below 50°C. While some ZEBs would be hardly affected by the recalibration, it is estimated that the efficiency for other ZEBs would increase by more than 10%.

varying weather between different comparison periods is controlled for. By analysing the gradient between baseload energy consumption when no heating is need and increased usage for heating, it separates energy used for heating from other uses. Comparing the PTG before and after the installation of the RAAHPs will give an indication of the RAAHPs' impact on household energy use for heating.

-
- For this analysis, raw values which have not been adjusted for this heat meter calibration issue are used. As such, the heat output may be under-reported. We have aimed to flag which results this could impact.

2.7. Data management

This section provides an explanation of how the data from inside and outside the Living Lab is received and stored, and subsequently shared and processed securely within the Catapult, with project partners, and DESNZ.

2.7.1. Receiving and storing data

The 'Living Lab System' is a combination of three databases, application components, interfaces and three web sites running within a secure Amazon Web Services (AWS) environment (see Appendix 2 and Appendix 3 for schematics).

Householder's sign-up to the Living Lab via a publicly accessible 'offering portal' which then grants them access to a password secured 'participant site' within which they are asked and encouraged to both provide static data about their home and link certain smart devices (e.g., smart energy meters, temperature monitors, EV chargers, energy monitors, and heat pump controllers).

Static data and details about the linked devices (i.e., such as what sensors they contain) are stored in a Postgres database referred to as the 'Data Integration Platform' (DIP). The device and sensor details are used within software components called "Adapters" to call, or be called by, 3rd party interfaces to fetch time series data (e.g., energy use, temperature, humidity, etc.) which is stored in a Vertica database, by sensor.

Additional functionality, such as the ability to record that a user is on a trial, or to send automated emails, has been developed in-house by the Catapult and is stored in a third Postgres database called the Next Generation Living Lab (NGLL) database. The Catapult uses Tableau as its main participant data reporting tool and regular extracts of key data are taken from the various databases.

All systems are subject to technical monitoring which consists of several key checks at various levels to ensure the application is functioning correctly³². These include:

- **AWS Cloudwatch** which monitors application and server components, responds to performance changes, provides insights into operational health and generates alerts.
- **Icinga monitoring agents** which, via a dashboard, provide a more detailed layer of component monitoring and alert to events such as an adaptor failure, expired tokens for

³² See appendix for a high-level architecture of the Living Lab system.

individual smart device links, non-discovered devices following a linking event, disc space, system load and memory issues, etc.

- **Nagios** email notifications based on icinga events.
- Daily reviews of application logs for error messages.
- **Tableau** reports on the number of householders on trial and with smart devices linked.

When required, DIP data is extracted by way of Tableau reports and converted to comma-separated or Microsoft Excel files. Tableau reports can easily be constructed to extract data such as building archetype, age, wall and insulation type, device and sensor types and identifiers, and room types, etc. These are forwarded on to the Catapult's Data and Analytics team for processing.

Vertica time series data can consist of many millions of rows of data. For example, a single tado° device could produce up to 2,880 readings per day for *each* sensor. With at least three devices per home, data for a single home for one year could easily surpass a million rows of data. Since it is stored in a separate database, extracted time series data is linked to static data via a common home identifier and is also available for processing.

2.7.2. Processing data

To process data from its initial raw format into a cleaned, joined and pseudonymised dataset ready for analysis, the Catapult has built a repeatable pipeline in Python. Raw data extracts from the Living Lab, including smart meter and tado° monitoring and control data are performed at regular intervals, saved to a secure, access restricted server and run through the pipeline to produce up-to-date datasets. Additional data, including from IAQ sensors and historic smart meter data, are combined with the Living Lab data to create a single dataset for all data. Contextual data about householders and their homes is extracted via Tableau, cleaned and added to the dataset on the secure server.

The next step was to pseudonymise all the data by removing any remaining personal identifiable information from the dataset and mapping new IDs to the homes. Data is then aggregated where necessary. During this step, flags were added to the data to indicate anomalous values or timestamps and counts of the number of missing readings per day are performed. It was agreed with UCL, who are providing detailed statistical data analysis for the project, not to remove any data or interpolate any gaps at this stage; since different types of analysis will be performed to respond to the research questions, each therefore will require a specific treatment of the data. Data quality metrics are then calculated across the entire dataset to assess what proportion of the expected data has been captured over the course of the entire trial (this is done to supplement the weekly operational monitoring of the data via Tableau, which was described in section 2.7.1). The finished dataset is then shared securely with UCL via the uSmart platform along with a project specific data dictionary that explains what the data means and how it was gathered. UCL then carry out their analysis in their data safe haven (DSH), an access controlled secure research environment. The Catapult has access to the DSH for the purpose of reviewing analysis and providing feedback. The dataset has been developed iteratively between UCL and the Catapult to allow additional features to

be added when the need for them is identified (e.g., location-specific weather data and data from EPCs has been added from external data sources). The flows of data in the project are depicted in the Appendix.

The output dataset is predominantly stored as parquet files and is over 193 million rows and 3.68 GB (up to 30/04/2025).

3. Analysis and findings

This section provides a summary of the analysis techniques employed alongside initial findings from analysis of the data collected to date. Further details of the quantitative analysis methods can be found in the appendix. Some of these findings will be updated in future reports as more data becomes available.

3.1. Analysis of behavioural measures

This section describes the methods being employed to analyse quantitative and qualitative data collected via consumer research to assess the project's behavioural measures (i.e., behavioural advice, roadmaps, experience of measures and home improvements).

Qualitative data collected from interviews is transcribed, and themes related to the research questions identified using an approach informed by thematic analysis³³. Several survey questions allow open answers; answers to these are grouped by theme for reporting.

Quantitative data collected via surveys is analysed in the following main ways:

- summary statistics is used to present householder demographics and initial views on topics of interest (e.g., age, income level, openness to different retrofit measures, views on behavioural measures);
- if there is an expected effect of treatment on outcome – e.g., improvements in heating outcomes for people who received measures vs. those who did not affecting changes in Net Zero awareness over time - cross tabulation with these variables will be used to explore findings;
- if appropriate, CHI-squared analysis followed by post-hoc analysis with pairwise proportion tests to identify which proportions are significantly different will be used to identify significance of effect (pre-post measure x group (treatment vs. control)).

The relation of HfNZ householder's Net Zero awareness to government measures is ascertained via correlational analysis. This will help to contextualise findings in terms of views of the general population.

In the core trial, householders were asked several questions via a survey to assess their baseline views and experiences, Net Zero awareness, and attitudes to energy and home improvements. These included their understanding of the concept of Net Zero, as well as awareness of what that will mean for them and their home, and any efforts they have already made to improve the energy efficiency of their home.

At the end of the trial these questions will be asked again, as well as the government's Net Zero awareness indicator question (below), to understand change over time and how

³³ Clarke, V., & Braun, V. (2017). Thematic analysis. *The journal of positive psychology*, 12(3), 297-298.

representative the householder's attitudes are of the wider population³⁴. The UK government's Net Zero awareness question is:

"The UK government is aiming to reduce UK greenhouse gas emissions to 'Net Zero' by 2050. This will involve significantly reducing emissions produced by our industries, transport, food, and homes. Any remaining emissions will be balanced by actions that reduce greenhouse gases already in the atmosphere, such as planting trees." Before today, how much were you aware of the concept of 'Net Zero'?

All householders have been asked via a survey to report their ability to maintain a comfortable temperature in their home, and any issues they experience (e.g., to do with damp or mould), any changes they have made to how they heat their home over the last year, and whether they have tried any of the energy saving tips recommended as part of the behavioural advice. Householders were asked at the start of the trial which measures they might be interested in, or not, and why, and this will be followed up towards the end of the project. Finally, a quick survey was sent out following the heat wave in summer 2024, the cold spell in winter 2024, and again following a heat wave in summer 2025 to understand how householders manage to keep comfortable during extreme weather situations.

Householders receiving measures were asked via surveys and interviews to report any changes they have noticed in their home because of the measures, whether they experienced any disruption in having it done, how satisfied they were with it, and whether they would choose to have it done if they had to pay for it.

For the alternative electric heating trial, householders were asked about their satisfaction with their current heating at the start of the trial, and what motivated them to have the RAAHP installed. Following installation of the RAAHPs, householders will be asked via surveys and interviews to report how they found the experience, how easy they find it to maintain a comfortable temperature in their home with the heat pump compared to before, and any impact its installation might have had on air quality or other things (e.g., damp/mould) in their home.

In the AEH trial, householders were also asked to answer the government Net Zero awareness indicator question. This will be repeated at the end of the trial to see if awareness has changed amongst those who had a heat pump installed.

3.2. Behavioural advice

A set of behavioural advice, or 'energy saving tips' were created to share with 100 of the HfNZ 'core trial' householders. These tips are all 'low- or no-cost' actions that householders can easily take in their homes immediately to improve their home's energy efficiency and potentially reduce their energy bills. The aim of this stream of research was to:

- understand willingness to try the different behavioural advice presented;

³⁴ <https://www.gov.uk/government/statistics/desnzs-public-attitudes-tracker-spring-2024/desnzs-public-attitudes-tracker-net-zero-and-climate-change-spring-2024-uk>.

-
- evaluate how easily householders manage to implement behaviours/changes proposed;
 - evaluate which behaviours/changes householders tend to continue and which are often abandoned – and why;
 - Learn about the experience/impact of the behavioural advice.

3.2.1. The advice

A total of six tips were identified; two tips were each given to half the cohort only, as follows:

- **lower your boiler flow temperature:** householders were given instructions on how to reduce their boiler flow temperature to 60°C;
- **lower your thermostat temperature:** householders were asked to consider reducing their thermostat temperature by up to 2°C;

The remaining four tips were sent to all 100 householders:

- **bleed radiators:** householders were given instructions on how to bleed their radiators;
- **clear any radiator obstructions:** householders were given advice on how and why to keep radiators clear;
- **turn down radiator valves in unoccupied rooms:** householders were given guidance on how to adjust individual radiator temperatures;
- **fully load washing machines/dishwashers:** householders were advised that filling devices before running them can save energy.

Figure 6 is an excerpt from the behavioural advice documents.

Figure 6: Excerpt from measures documents

Tips for saving energy in the home



1 Lower boiler flow

The "boiler flow" temperature indicates how warm the water circulating through your heating system will be. Most boilers are set to high temperatures, around 70–80°C. **Reducing your flow temperature to 60°C can result in up to 8% gas savings.**

Your home should still be warm if you do this, it may just take the house a little longer to heat up.

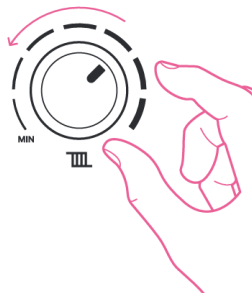
This might not work for all boiler types, or your boiler might already have a lower temperature set.

You can access an online tool to help you, using the link below. This tool will help you understand whether your boiler is suitable and (if so), navigate the process.

moneysavingboilerchallenge.com/walkthrough

How to reduce boiler flow temperature

1. **Find the boiler flow temperature control.**
This is usually a dial or knob on the boiler itself, sometimes labelled "flow temperature" or "heating flow".
2. **Once you have found the control, reduce the temperature to 60 °C.**



Tips for saving energy in the home



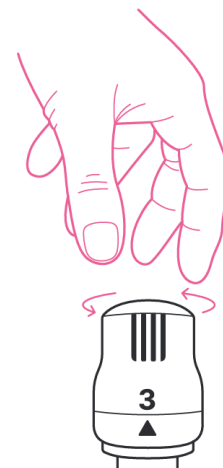
4 Turn down radiator valves in unoccupied rooms

Turning down radiator valves in unused rooms can save around 4% gas yearly.

You can direct warmth where it's needed most and save energy everywhere else.

How to turn down radiator valves

1. **Locate the individual radiator valves** – these are usually located at the **bottom or side of each radiator**.
Note: If you don't have a valve on some or all of your radiators you won't be able to make this change.
2. **Close valves in unused rooms.**
Turn the valve handle clockwise until it stops, without forcing it.
3. **Adjust as needed** – If you find a room getting too cold with the valve closed, adjust it slightly to allow some heat flow.



More detailed instructions are below:
yourrepair.co.uk/blog/how-to-turn-a-radiator-off

3.2.2. Pilot findings

The behavioural advice was piloted from February to March 2024. Twenty non-trial participants were recruited and emailed with a link to a document with clear advice and step-by-step instructions for following the tips. They were then asked to complete a short survey to gather feedback on the tips they tried (i.e., why they tried a tip or why not) to help evaluate the method and materials. Five of the 20 were invited to interview. Findings were:

- the tips and advice were easy to follow;
- householders had already heard of, and had already tried, most of the tips;
- they were hoping for something new.

As a result, it was agreed that no changes were made to the advice offered in the full roll out, though small changes were made to the emails inviting participants to engage with the advice (i.e., a summary of the tips was not included in the body of the first email sent), and the feedback survey design.

3.2.3. Full trial research approach

100 householders were selected to receive the behavioural advice. These 100 had expressed interest in receiving this kind of advice when they signed up to the trial and had not been selected for another type of measure. The tips were administered as follows:

-
- they received an email from E.ON informing them they had been selected to receive this advice;
 - they received an initial email from the Catapult telling them about the advice and sharing a link to a document containing it that they could read or print;
 - one week later the Catapult sent a reminder email containing a summary of the tips, and another link to the advice;
 - one week after that they were offered a £5 voucher to provide the Catapult with feedback on the tips via a survey.

The survey asks:

- if householders have read the advice;
- if they are currently doing any of the tips;
- if the advice was what prompted them to do so.
- for some feedback on why they are/are not currently doing each of the tips;
- how effective they think the tips are;
- any impact they have had in their home;
- and how easy/difficult they are to follow;
- a bit more about what people did around changing their boiler flow and reducing their thermostat temperatures (e.g., temperatures set before and after, and whether they ever adjust these).

Additional questions will be asked to evaluate measures in the final survey (see 3.10).

3.2.4. Engagement with behavioural advice

Of the 100 participants that were sent the advice:

- 95 participants opened at least one of the emails (47 who were sent the advice including to reduce boiler flow temperature, and 48 who received the advice to reduce their thermostat temperature)
- 75 participants clicked on the link to read the PDF advice (34 who were sent the advice including to reduce boiler flow temperature, and 41 who received the advice to reduce their thermostat temperature)

3.2.5. Findings

Of the 100 respondents who received the survey, 63 filled it out.

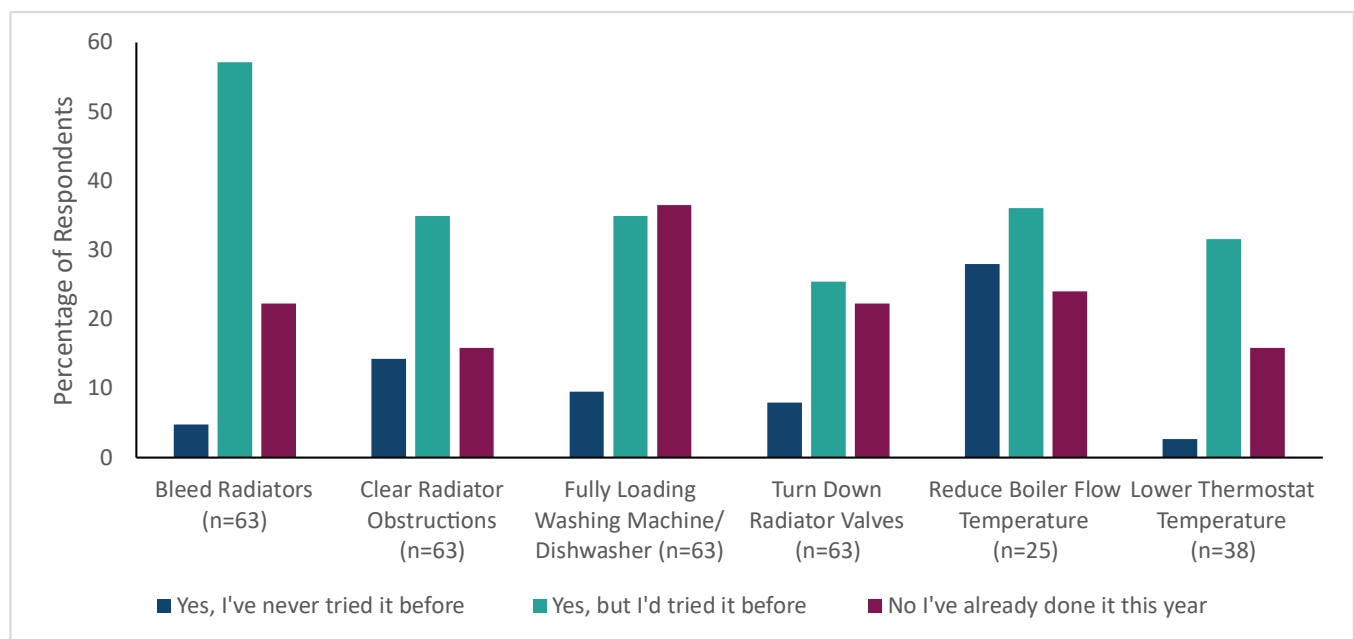
- 25/63 responses to the survey came from those receiving advice on lowering their boiler flow.
- 38/63 responses to the survey came from those receiving advice on turning down their thermostat temperature.

- Four of the participants who received the guide were interviewed about their experience of trying the advice, and their feedback on any outcomes experienced so far.

3.2.6. Willingness to try the advice

Most of the advice given was common knowledge and participants had mainly tried it before (Figure 7). However, many people told us they were prompted to action by our reminders, and some used this as an opportunity to revisit how they'd previously approached the advice and treated the guide as an example of best practice.

Figure 7: Number of people who reported they were following the advice (either already or since receiving the email), and if the advice prompted them to do it



The three pieces of advice most commonly being followed were:

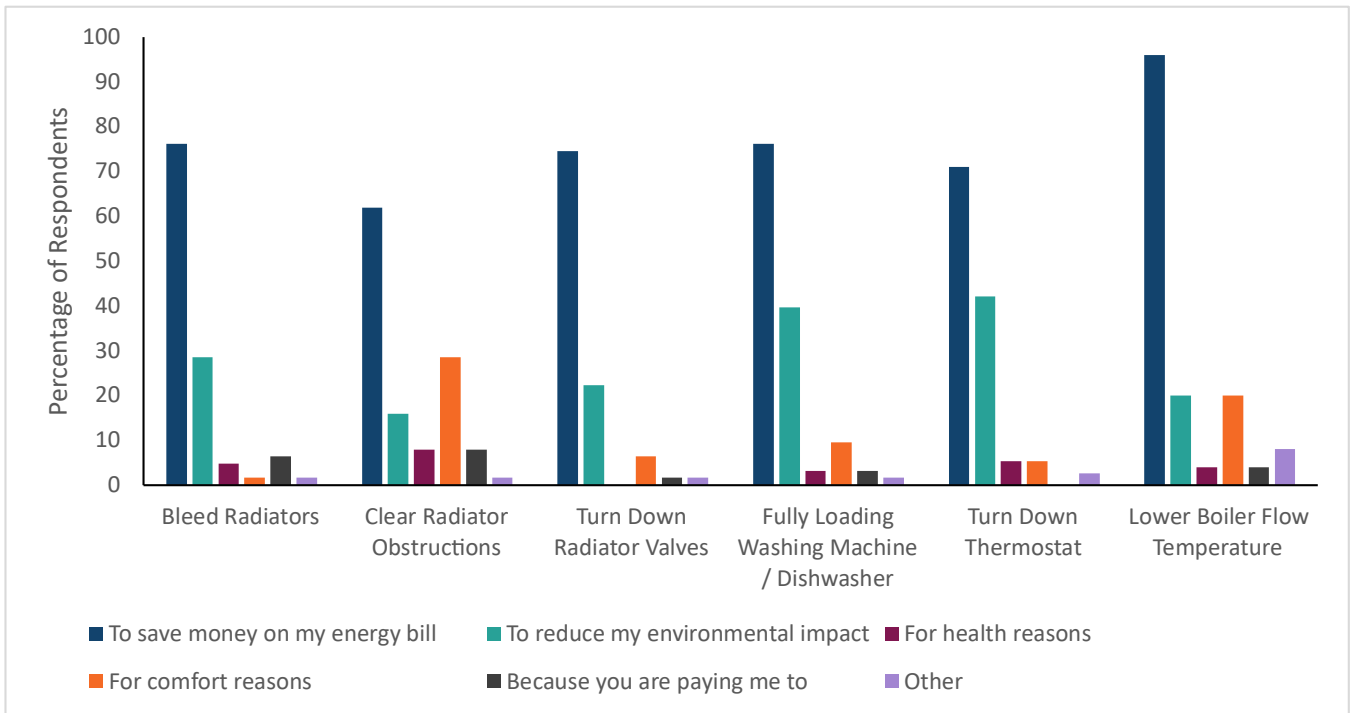
- Reducing their boiler flow temperature (88% of those who received the advice)
- bleeding their radiators (84%) and,
- fully loading their washing machine/dishwasher (81%).

Of those that reported they were doing each of the tips, 92% of those who said they'd lowered their thermostat and 92% of those who said they'd bled their radiators had already tried it. Despite this, the advice prompted 62% of respondents who received the advice to bleed their radiators again. It also prompted 64% of respondents who got this advice to lower their boiler flow temperature and 49% of respondents to clear obstructions from in front of their radiators. The tip that fewest people had tried before was reducing their boiler flow, with 28% of respondents who received this tip (32% of those who did it) trying it for the first time following the advice. Also, 14% of respondents (22% of those who tried it) tried clearing radiator obstructions for the first time.

The primary motivator for participants trying the advice was saving money on energy bills, followed by reducing environmental impact and then improved comfort (Figure 8). This

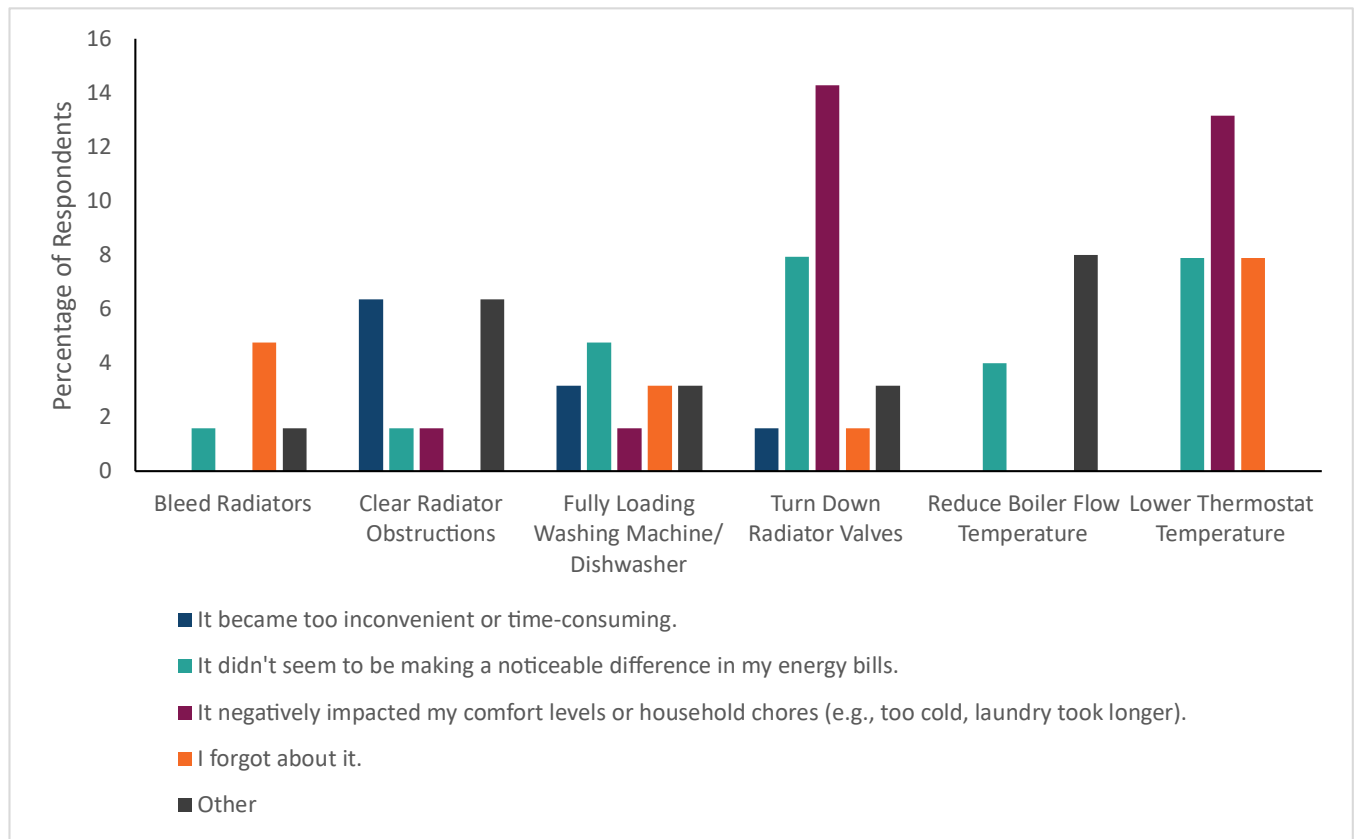
highlights the importance of financial incentives in promoting energy-saving behaviours, with health and comfort being less influential.

Figure 8: What motivated those who tried the advice to do so



People who didn't want to try the advice and had never tried it before reported this was for a variety of reasons, including not being sure how to (i.e., especially around bleeding radiators), concerns about how it might impact their comfort, or not feeling like it would make any difference (Figure 9). Advice such as removing radiator obstructions, changing their boiler flow temperature, bleeding radiators and turning down radiator valves were not always felt to be practical or possible. Some participants added that their *"best tip for energy saving is just not to use it"*.

Figure 9: Reasons participants gave for not trying the advice



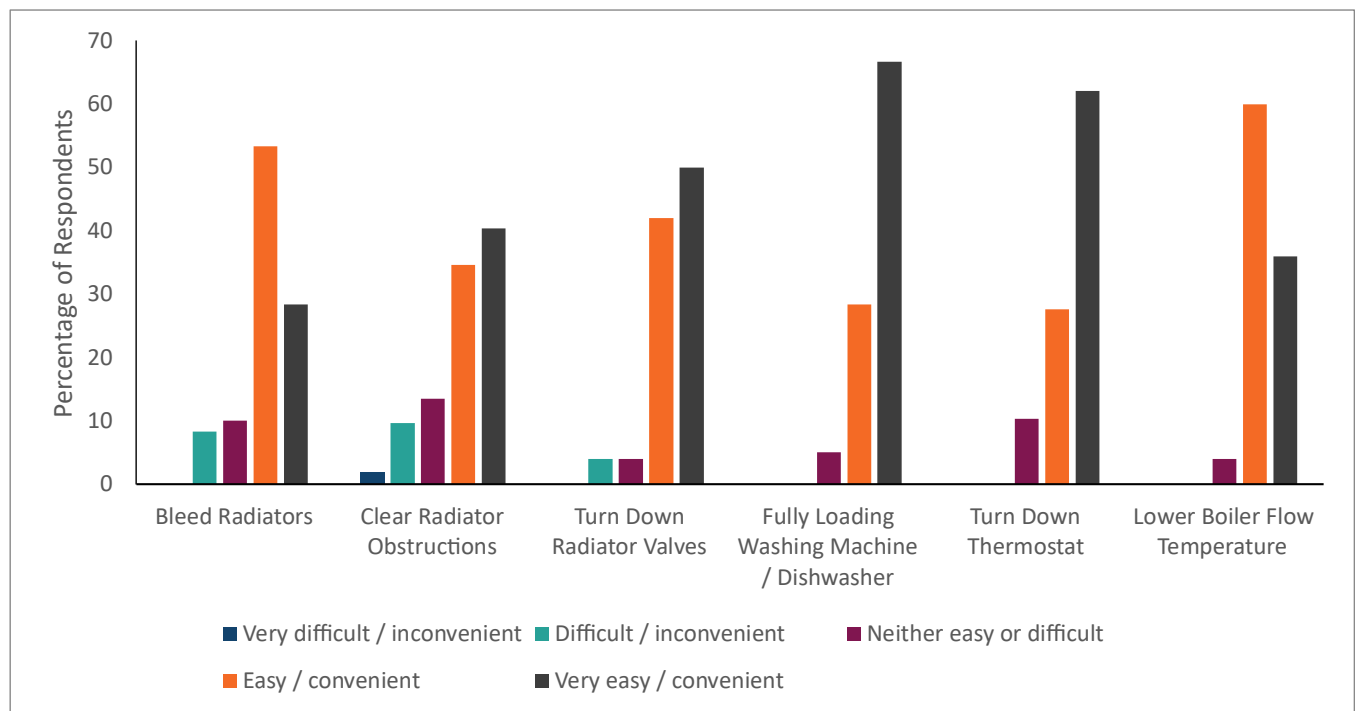
People gave up on advice they had tried before because it was inconvenient (e.g., especially clearing radiator obstructions), they didn't think it made much difference, it negatively impacted their comfort (e.g., especially turning down radiator valves in empty rooms) or they simply forgot about it. Other reasons they mentioned included finding themselves cold in their home or being unable work out how to bleed new types of radiators.

3.2.7. Ease of following the advice

Most people reported they found the advice they were sent 'easy' or 'very easy' to do (Figure 10). Respondents listed fully loading machines and the dishwasher and lowering boiler flow temperature as easy to do.

However, although easy for most, those who hadn't done some measures such as bleeding radiators and removing radiator obstructions found it difficult. Participants reported that removing radiator obstructions was difficult or not always practical due to their home layout.

Figure 10: How easy or difficult respondents who tried them found the advice



A few people found bleeding radiators difficult and some required help from family and friends to do this. Participants said they lacked information or knowledge about how to do it, even after the behavioural advice was sent to them. One person reported they wanted more hands-on assistance as they'd never attempted this before. Almost 5% hadn't done this previously, despite the benefits of this tip reported by many others (see next section).

3.2.8. Impact of measures

Some participants felt some of the measures had little, or a negative impact, on their homes (Figure 11 to Figure 17). For example, some participants felt running a full washing machine or dishwashing cycle or turning down radiator valves in unused rooms impacted warmth, temperature consistency, air quality, draughts and damp in their home. Only a few felt these actions reduced their energy bills.

"House is damper when fuller loads are being dried"

"I tried it [turning down radiator valves in unused rooms], and I didn't enjoy it, so I've not definitely, with the drafts in the house, it just made it worse. So, yeah, I've not done it again."

One respondent mentioned their plants didn't like it. However, one participant told us this worked well for them as they had smart controls:

"The smart thermostats and altering the temperature in the rooms has made a difference. I would say we're saving about a third of the bills."

Figure 11: Impact of fully loading washing machines and dishwashers for those who tried it

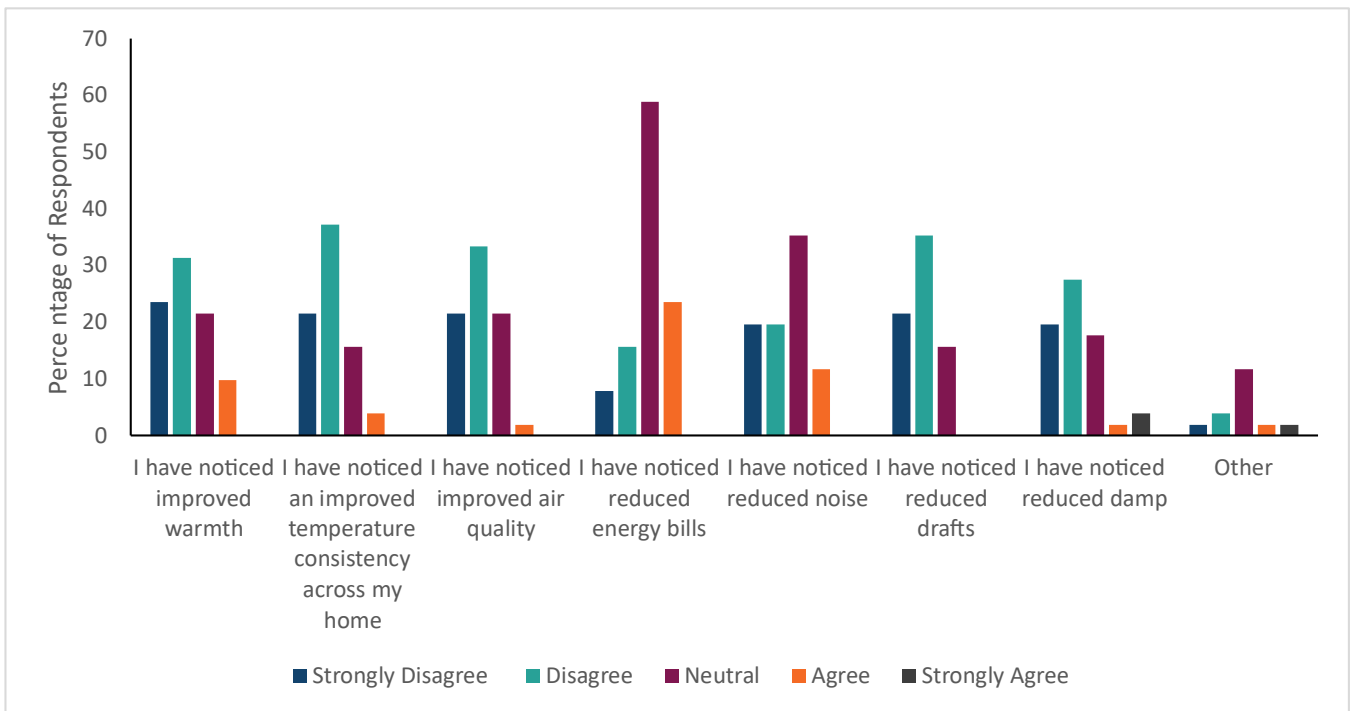
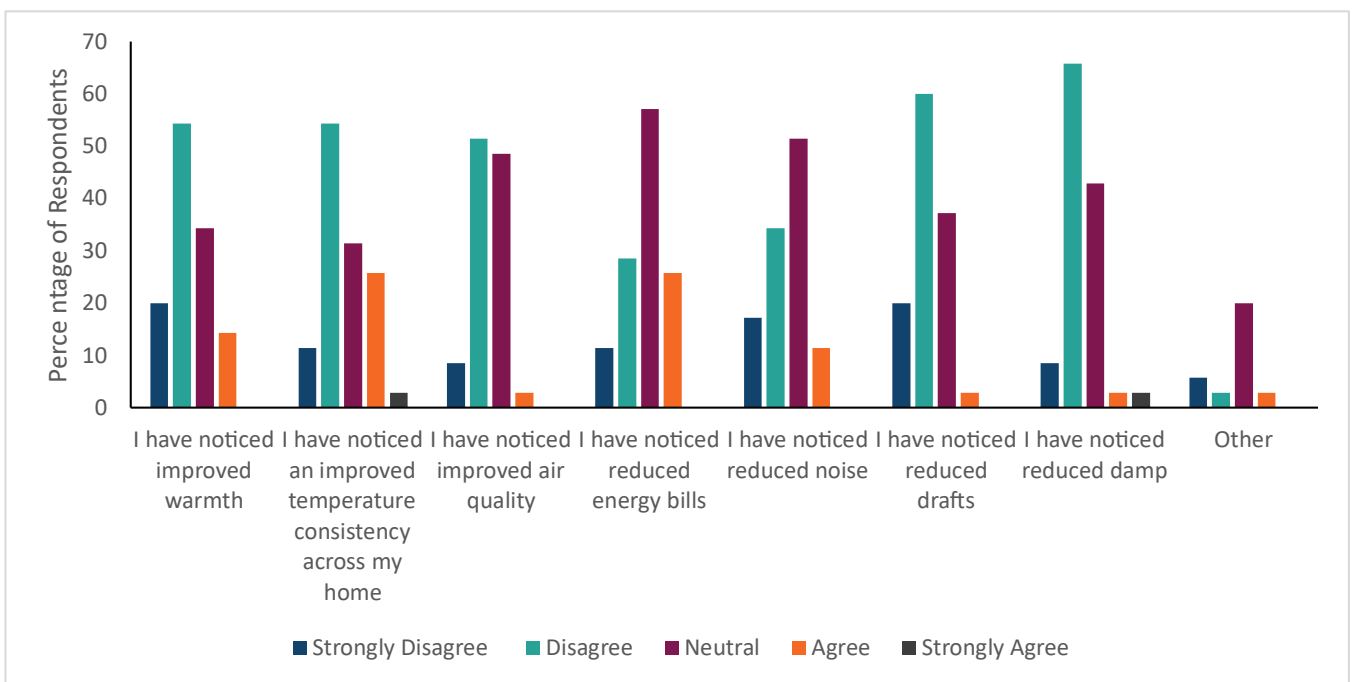


Figure 12: Impact of turning down radiator valves in unused rooms for those who tried it



In contrast, many were positive about the impact of bleeding radiators, with many agreeing that they have noticed improved warmth, an improved temperature consistency across their homes, and reduced noise. However again, they didn't feel it reduced their bills. Given people who hadn't tried it struggled with this, more interactive help and guidance is needed for those who haven't managed to bleed their radiators previously or have access to in-person support to do this. Clearing obstructions was felt by some to improve warmth and consistency of temperature around the home, but not a reduction in bills.

Figure 13: Impact of bleeding radiators for those who tried it

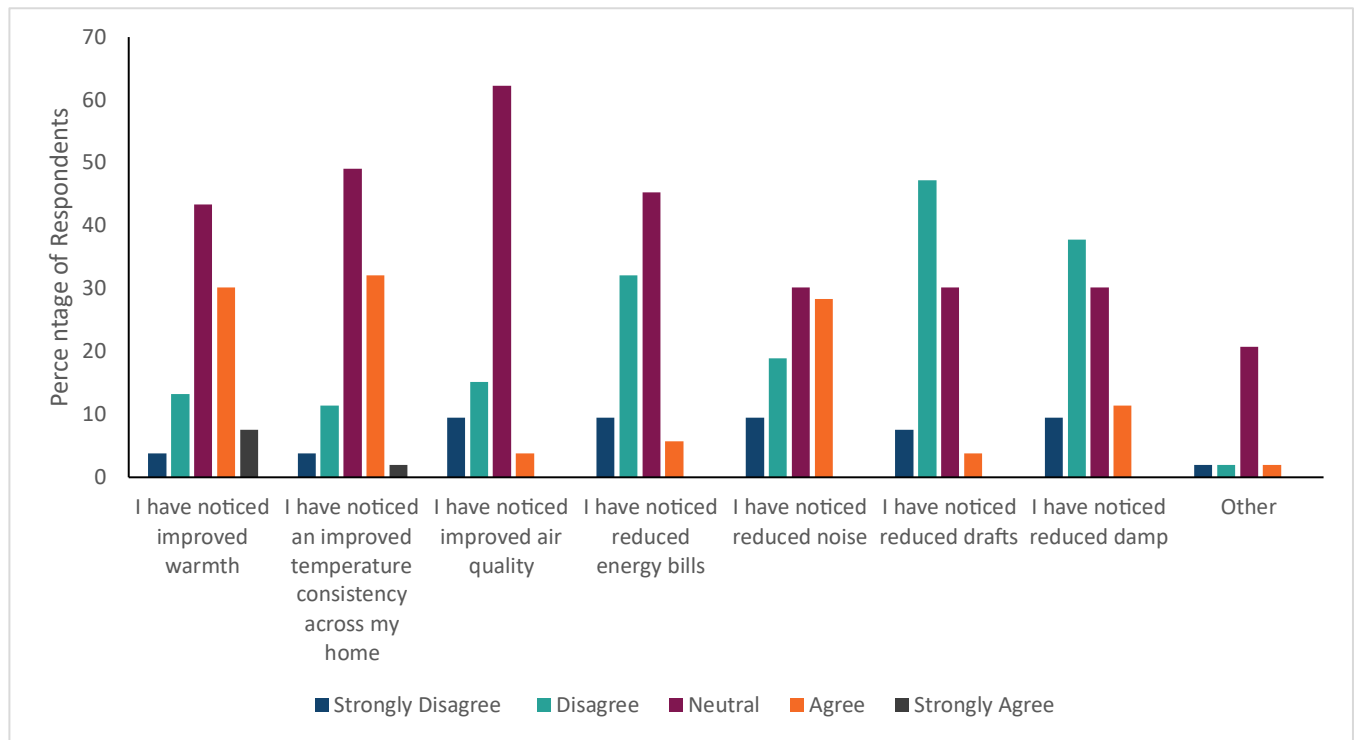
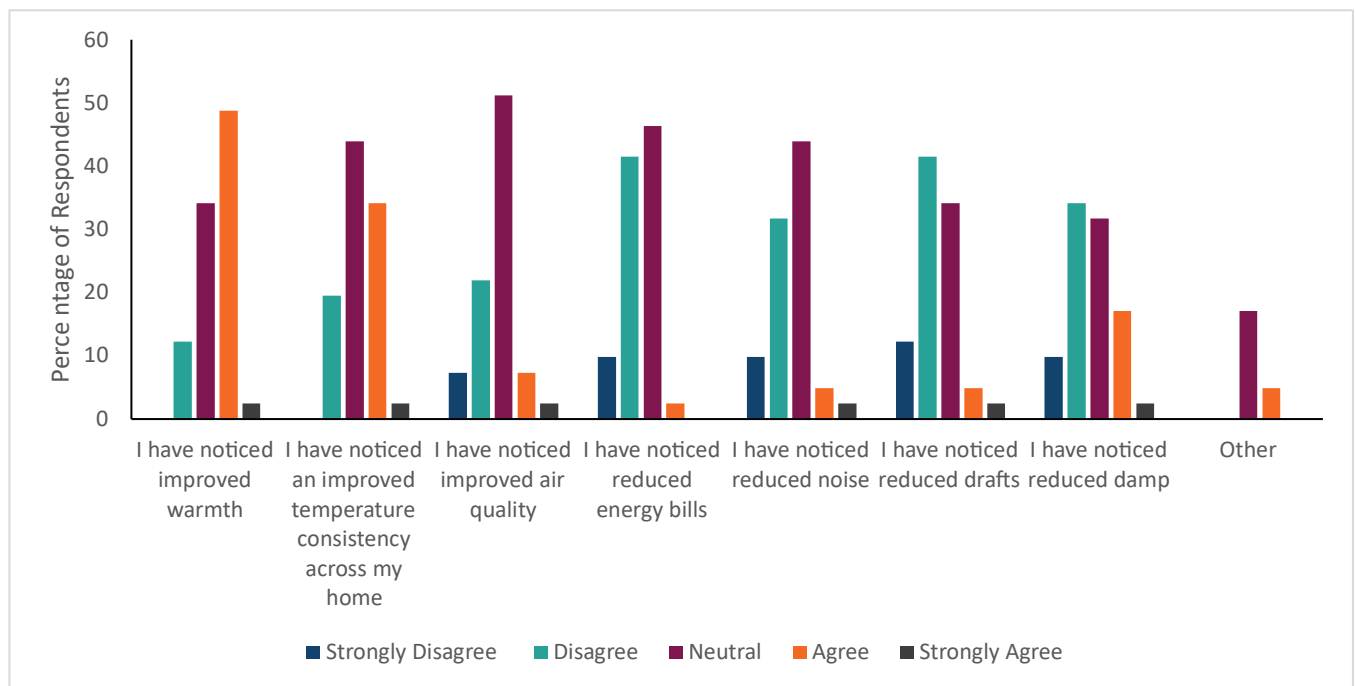


Figure 14: Impact of clearing radiator obstructions for those who tried it



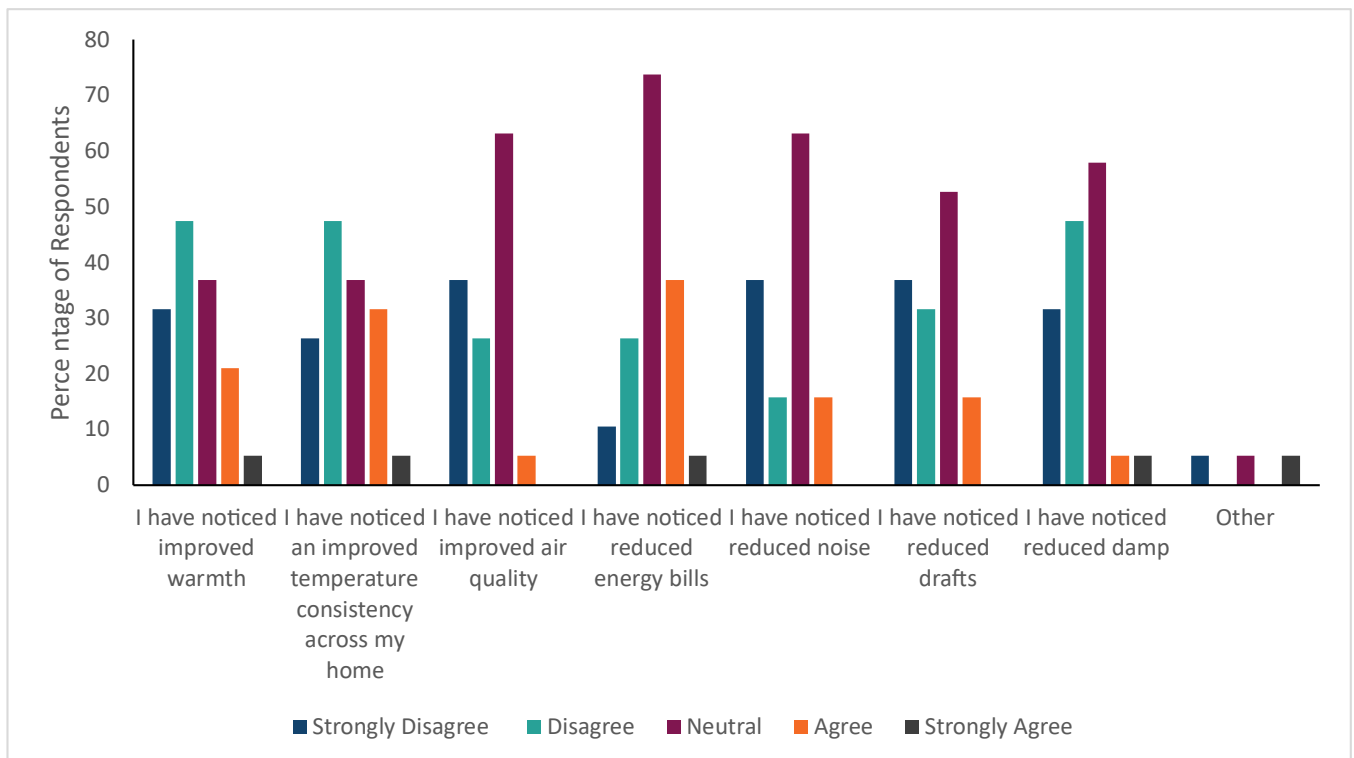
3.2.8.1. Lowering thermostat temperatures

While turning down thermostats led to householders noticing a reduction in their bills, some found this was at the expense of comfort. Most respondents found turning down their thermostat temperature easy, had previously turned it down and said they continue to do so. Nearly 3% did this for the first time because of the advice. Those who followed the advice turned them down from an average of 20°C (from temperatures between 17 and 25°C) to an average of 18°C. However, just over two-thirds turned their thermostat back up again at some

point (69% of respondents turned their thermostat temperature back up again during the winter, with 38% doing this multiple times).

Whilst some participants felt lowering thermostat temperatures improved comfort and reduced bills, a larger proportion of people mentioned discomfort, damp, and drafts. Some said that it impacted others in their homes. Overall satisfaction with this was low at 55%. Despite some feeling like turning down their thermostats reduced their bills, which encouraged them to do it, others felt it was too inconvenient to continue doing it.

Figure 15: Impact of turning down the thermostat for those who tried it



3.2.8.2. Turning down boiler flow temperatures

Most participants who tried were able to adjust their boiler flow, but the results of this varied.

Turning down their boiler flow temperature was the advice that most (88% of those sent it) had tried before. Whilst most respondents who had tried turning down their boiler flow found it easy, some reported needing help from friends and family in order to do this.

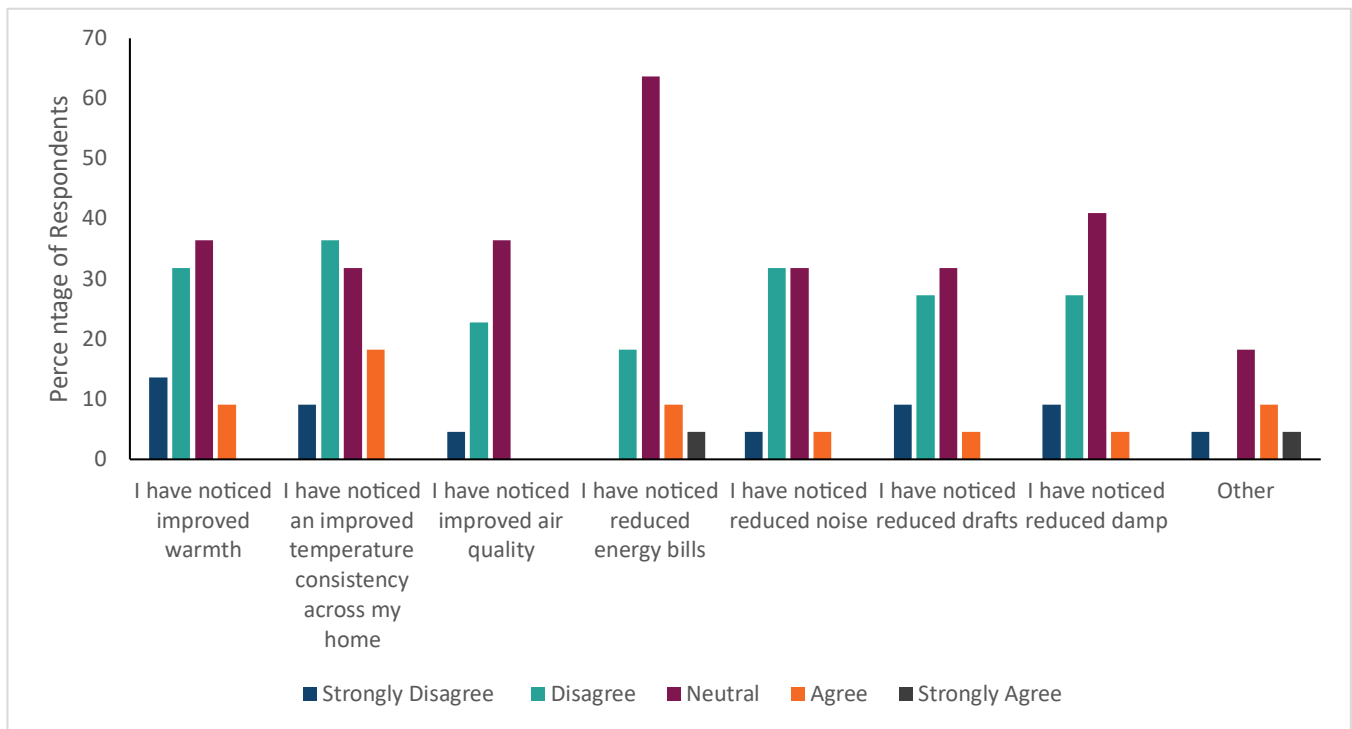
Others could not act on the tips as they lacked support from others and shared a lack of knowledge and control over their boiler system. They had no visibility of their boiler flow temperature and were not willing to try adjusting the flow with the concern that this approach might increase their bills.

Householders told us they reduced their boiler flow temperature from an average of 70°C (ranging from 62°C to 87°C) to an average of 60°C (ranging from 55°C – 67°C). On average, householders reduced their boiler flow temperature by around 10°C.

Whilst some people thought doing this improved temperature consistency throughout their home, warmth, and felt it reduced energy bills, a larger proportion disagreed or were neutral about this. Many reported feeling cold and just under a third (31%) of respondents turned the flow temperature up again in winter (11% of these did so multiple times).

"I'm noticing this year as well, the house is colder than I was used to."

Figure 16: Impact of turning down boiler flow temperature for those who tried it



3.2.8.3. Advice homeowners were most satisfied with and likely to continue

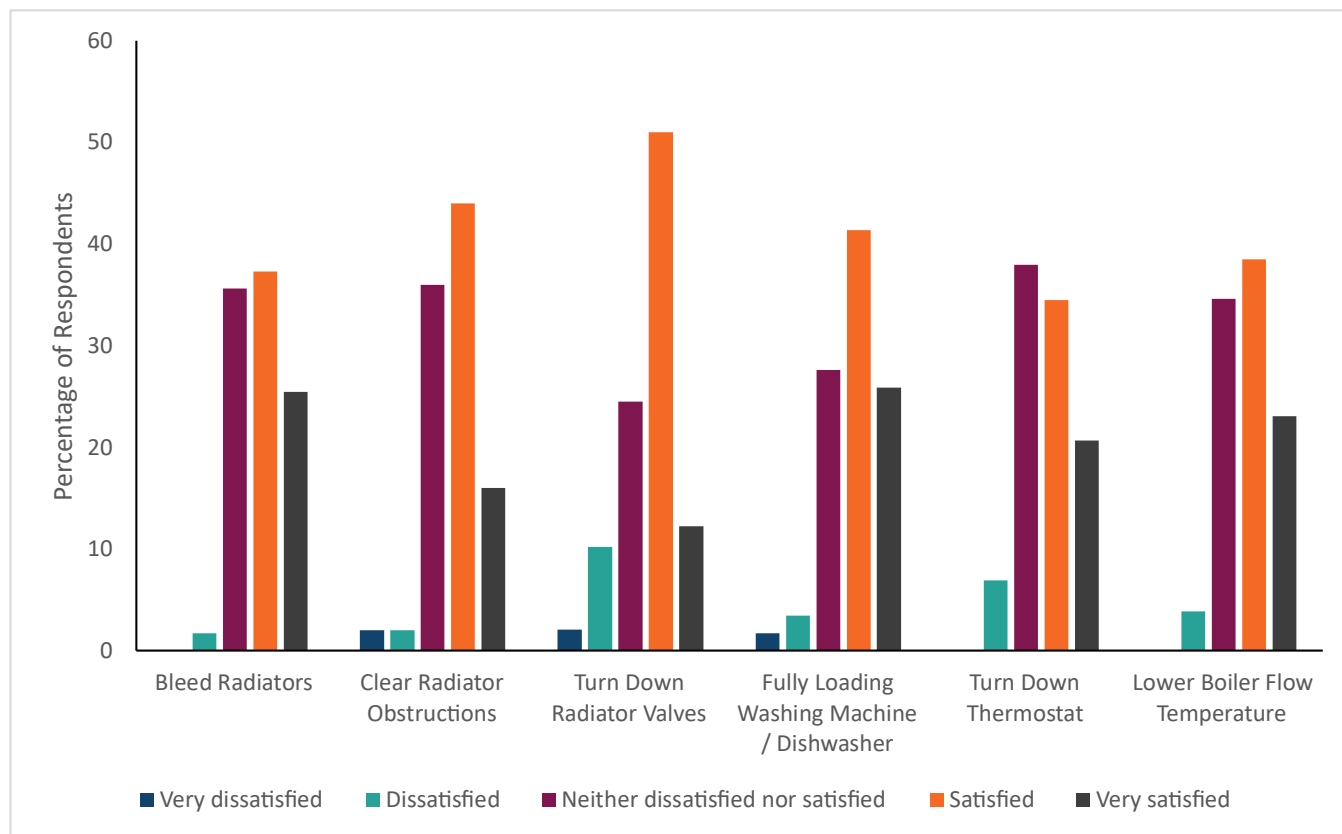
Overall, most participants were either satisfied or neutral about the advice.

For tips that participants managed to implement successfully, such as loading the dishwashers and washing machines, bleeding radiators and removing obstructions, people were happy to continue doing these, even despite a lack of perceived or experienced benefits at times. Advice like removing radiator obstructions were not always practical to implement due to different housing designs.

Others that tried advice such as turning down their radiator valves, and either turning down their thermostat or boiler flow temperature had to turn these back up. Some found that turning down thermostat temperatures resulted in other issues at home, causing them to stop doing it. While some noticed improvements in warmth and temperature consistency, others did not observe significant changes in energy bills or comfort levels.

Advice regarding tips participants hadn't tried before, or that caused other challenges or discomfort were difficult to continue with, therefore, participants were more likely to continue with advice they found easy to do, despite a lack of experienced benefits. They reported that the guide served as a useful tool to remind them to carry out advice that they usually do and were happy to do as advised even if they don't always notice a difference.

Figure 17: Overall satisfaction with advice



3.2.8.4. Effectiveness of providing behavioural advice

The behavioural advice guide was useful for participants in various ways, with scope for future improvement.

- Many participants had already tried this advice in the past, indicating a high level of pre-existing awareness. While advice is well-known, the function of the guide as a reminder was valuable to maintain engagement.
- The guide was well-received and used by participants, with it being passed on to family members to share the potential benefits and to share knowledge with relatives.
- Additionally, smart controls could help users follow many of these recommendations such as turning down thermostats and radiator valves.

3.3. Development of roadmaps

The aim of the roadmaps workstream was to design and test a process which provides householders with an understanding of the likely changes required to their home to become Net Zero ready and to outline potential routes for achieving this. Net Zero ready is loosely defined, but for the purposes of the roadmaps it entailed a (relatively) energy-efficient home with efficient zero direct emissions heating (i.e., probably a heat pump).

This was achieved by developing and testing comprehensive roadmaps for householders in the two types of homes of interest (solid wall gas heated home, and electrically heated flats or

houses). The roadmap outlined clear incremental steps that householders can follow, creating a structured path toward decarbonisation and the electrification of heating systems to achieve this. The intention being to give people the chance to plan and make changes at their own pace rather than undertake a whole house approach in one.

A total of 150 roadmaps were created. Of these, 100 were for householders currently in solid wall gas heated homes and:

- helped householders understand why they will need to transition to a Net Zero compatible home – for the purposes of this trial, defined as a (relatively) energy efficient home with zero direct emissions heating;
- helped householders understand that in the future they will have to switch to zero direct emissions heating (i.e., they will not be able to replace their gas boiler with another gas boiler);
- helped householders understand what they will need to do to their home;
- provided relevant, (tailored) advice;
- framed this in a positive way that encourages people to start to act or be ready to in the future.

The remaining 50 were for householders currently in electrically heated flats and houses and will meet the same goals as the 100 roadmaps in solid wall gas heated homes, with the following exception:

- help householders understand that there may be more efficient electric heating systems suitable for their homes than the electric heating that they have currently got (in place of advice about replacing their gas boiler).

Approximately half of the roadmaps went to householders who, in other surveys, have been identified as having 'high' Net Zero awareness, with the other half going to those identified as having 'low' Net Zero awareness.

The roadmaps will test the hypothesis that:

A roadmap outlining to homeowners (both those with high and low Net Zero awareness) what they will need to do to their home in order for it to be Net Zero compatible is an effective tool for supporting them in taking steps towards that goal.

3.3.1. Approach to development

The roadmaps were created via an iterative process incorporating feedback from various stakeholders including householders, retrofit experts, the project steering group, and DESNZ.

The steps taken were:

- Evaluation of existing approaches:

-
- A search for different types of advice available to consumers to help them understand what they could do to improve the energy efficiency of their home was conducted and advice categorised.
 - Focus groups were then run with householders and Catapult retrofit experts to provide feedback on features of these existing approaches, in terms of helping consumers understand what they needed to do their home and how to go about it.
 - User requirements gathering via iterative prototyping:
 - A series of interviews with householders were conducted around draft prototypes of possible roadmap features/approaches.
 - User needs gathered and initial solution ideas were presented to DESNZ and the steering group for feedback.
 - This resulted in a final refinement of the project roadmap goals.
 - User needs, goals and ideas were then fed into the E.ON Wren design sprint³⁵.
 - E.ON Wren design sprint.
 - E.ON lead a design sprint to develop an interactive prototype of a potential roadmap app. The process involved design and delivery experts from E.ON and researchers from the Catapult. It involved two rounds of development and testing with householders.
 - Kuppa³⁶ prototype development.
 - Kuppa was enlisted to generate the individual roadmaps for trial householders. They already have a service that produces retrofit advice based on an intelligent energy model that draws on numerous relevant data sets. For this project, their model generated tailored advice to householders considering (if available), the home's EPC, survey data, and smart meter data. This model was used to select suitable measures to recommend to householders, and to provide feedback on expected costs, energy, and carbon savings. Outputs of the previous rounds of roadmap development were used to structure Kuppa's outputs to produce roadmaps that are formatted to meet the project requirements and aims.

The final roadmap outputs shared with householders were in document format.

3.3.2. Roll out and evaluation of roadmaps

Before the final roll out of the roadmaps to the selected householders, a pilot of the roadmaps was undertaken with six households. The pilots were evaluated via interviews to explore householders' understanding and opinions on features of the roadmaps, and their thoughts and response to the information and advice provided. Following integration of feedback from

³⁵ The 'design sprint' developed an early prototype of the roadmap that helped define requirements early on.

³⁶ <https://www.kuppa.co.uk/>.

the pilot research and DESNZ's review of the pilot roadmaps, Kuppa generated individual tailored roadmap documents. Roadmaps were then emailed out.

Two sets of roadmap evaluation questions were included in the householder surveys. The first set of questions went out to only those householders who received a roadmap. These questions explored how easy householders found the roadmap to understand, how tailored and useful the advice was, whether they felt it helped them understand what needs to be done (and how) for their home to be more energy efficient, and whether it has prompted them to take any action. It also asked if householders felt it was valuable, and their views on how it could be improved.

The second set of questions will go out to *all* householders in the core trial and those who received a roadmap in the alternative electric heating trial. This will enable a comparison between treatment (those who receive a roadmap) and control (those who do not) groups. These questions will ask about a householder's plans to make changes to their home to make it Net Zero ready, their understanding of Net Zero and the changes it would require them to make in their home, and their barriers to acting.

Ten householders were invited to interview to provide more detailed feedback on their experiences with the roadmaps.

3.4. Roadmaps

A template was created for each of the two types of roadmap, and Kuppa's model was used to generate content tailored to each address based on this template and data available about the home. These produced PDF roadmaps for each participant.

The data available to tailor the roadmaps was different for different homes:

- All electrically heated home roadmaps were tailored based on EPC data.
- Gas heated home roadmaps were tailored based on EPC data³⁷, smart meter data (where Kuppa had permission to use this), and home survey data (where this had been collected as part of the trial and was relevant to the roadmap advice).

To address the brief and test the hypothesis, the roadmaps were structured as summarised below.

3.4.1. Context setting (pages 1-3)

The first three pages of the roadmap explained what the roadmap is and does, who the organisations are that were responsible for delivering it and messaging around the need to get to Net Zero and what homes have to do with it.

For electrically heated homes this messaging was around upgrading electricity networks, opportunities to save money by improving energy efficiency, and becoming less reliant on peak

³⁷ Homes without EPC data were not selected to receive a roadmap.

energy. For gas heated homes it was about switching away from gas heating and availability of grants to install heat pumps to future proof homes.

Finally, a 'Net Zero ready home' was defined, the benefits to the householder for having one were explained (e.g., keeping cosy in winter, cool in summer, producing own power to reduce bills, accessing grants), some information about grants was provided, and the data that was used to inform the roadmap was explained (tailored to each individual case).

3.4.2. Roadmap summary (page 4)

The fourth page showed an overview of where their home is now (i.e., in terms of estimated annual energy bills and carbon footprint), and where it could get to, plus a summary of the recommended actions to get there, broken into three steps. These steps were tailored to each home:

- **'Get started here'**: easy to achieve or recommended actions to improve energy efficiency and prepare a home for a heat pump were included here. This included recommendations (where relevant) such as topping up loft insulation, installing solar panels and batteries, DIY quick wins like reducing boiler flow temperature, setting a heating schedule or checking the tariff (e.g., electric homes only).
- **'Consider next' to get to Net Zero Ready**: participants were recommended a heat pump suitable for their home – for gas heated homes this is an air-source heat pump, for electrically heated homes this is a RAAHP.
- **'Go even further'**: included other recommendations that would improve the energy efficiency of participants' homes but are more difficult to do and aren't strictly needed for a home to be considered Net Zero ready.

The order in which to present recommended actions as part of a roadmap was considered carefully during the development of the roadmaps. The goal was to get people to understand what was needed for their home to be Net Zero ready and to start to act. Early user testing showed that large and expensive measures with very long payback periods (e.g., solid wall insulation) were unappealing and can lead to disengagement. However, some of these actions should be taken before others, if they are going to be done. If the roadmap was ordered in terms of what should be done first, it may list some of these most expensive and unappealing measures first (that may be less necessary to achieve a Net Zero ready home). Therefore, the roadmaps were organised in terms of the order that people should consider the actions to take, considering a combination of both priority and ease/appeal. Information about the order in which recommendations should actually be carried out in the home was given in the detailed roadmap advice pages.

3.4.3. Detailed advice

The largest section of the roadmap provided detailed advice to the householders. It included a title page for each of the three aforementioned stages followed by detailed information about each of the measures recommended within that stage. The title pages explained what could be

achieved by considering the measures in that stage, as well as total cost, expected bill and carbon savings of implementing those measures.

Each recommendation included up to three pages of detailed information about the recommendation, including what it is, why it is worth doing, the benefits, expected costs, expected savings, payback time, and disruption. It also contained information about what it might involve, how ready their home is for the measure (i.e., informed by EPC and/or survey data where available) and some information on next steps to get started. Icons and colour coded checklists were used to make the information easy to digest.

3.4.4. Final pages

The final two pages of the roadmap provided participants with a legend for understanding the measures used in the roadmaps, and some links to help them take the next steps (e.g., links to organisations that can help them find out more about grants and heat pumps).

3.4.5. Technical specification and FAQs

A set of FAQs were created for householders and sent to them with the roadmaps. This document included information about how the advice was generated and included assumptions used in the process. A more detailed version of this document was also created for DESNZ to explain in more detail the rationale behind the roadmap design and selection of advice to share with households, in addition to some information about the underlying model used by Kuppa to generate the recommendations.

3.4.6. Distribution of roadmaps

In the core trial, the roadmaps were distributed to 100 homes as follows:

- 16 to households that have received measure(s) and have low awareness of Net Zero
- 24 to households that have received measure(s) and have high awareness of Net Zero
- 27 to households that have not received measure(s) and have low awareness of Net Zero
- 33 to households that have not received measure(s) and have high awareness of Net Zero

In the alternative electric heating trial, the roadmaps were distributed to 50 homes as follows:

- Low awareness of Net Zero - 28
- High awareness of Net Zero – 18
- Unknown awareness - 4

Each roadmap was sent via personalised link within an email, that also included a link to a FAQs document (e.g., a different version for gas and electrically heated homes). Within the first two months after sending, the emails were opened by 89% of recipients, with most opening in the first week after receipt in March 2025.

3.5. Evaluation of roadmaps

Both interviews and surveys were used to evaluate the roadmaps.

3.5.1. Interviews

Ten households (five from gas heated homes and five from electrically heated homes) took part in interviews to evaluate the roadmaps, approximately two weeks after they had received them. Interviews lasted approximately 30-45 minutes and took place in April 2025.

The interviewed participants were selected to be a mix of higher and lower Net Zero awareness, genders, dwelling types, as well as some who received physical measures, and some who didn't.

3.5.2. Surveys

All core trial households were sent a survey that included a set of questions to evaluate the effectiveness of the roadmaps. This was administered at the end of April 2025, at which point there were 953 households in the core trial (the number in the trial is not fixed as households sometimes leave the trial and are not replaced). All participants were asked about their plans on making their home Net Zero ready and to gauge their understanding of Net Zero. In addition, those who had received roadmaps were asked for feedback on their roadmap and any impact it had on their future plans. Additionally, the 50 households that were sent a roadmap that are in the alternative electric heating trial were sent the questions as a standalone survey. Of the 150 people who received a roadmap, 86 completed the survey:

- 56 responses from the 100 households in the core trial.
- 30 responses from the 50 households in the alternative electric heating trial.

The following sections describe the findings from analysing responses to the survey.

3.5.3. Roadmaps outcomes

The effectiveness of the roadmaps is not covered by any of the project's research questions, but survey responses from recipients have been collected and analysed and provide useful insights described here. The survey was administered in April 2025 and went to all HfNZ participants; during analysis and reporting, responses are sometimes grouped as follows:

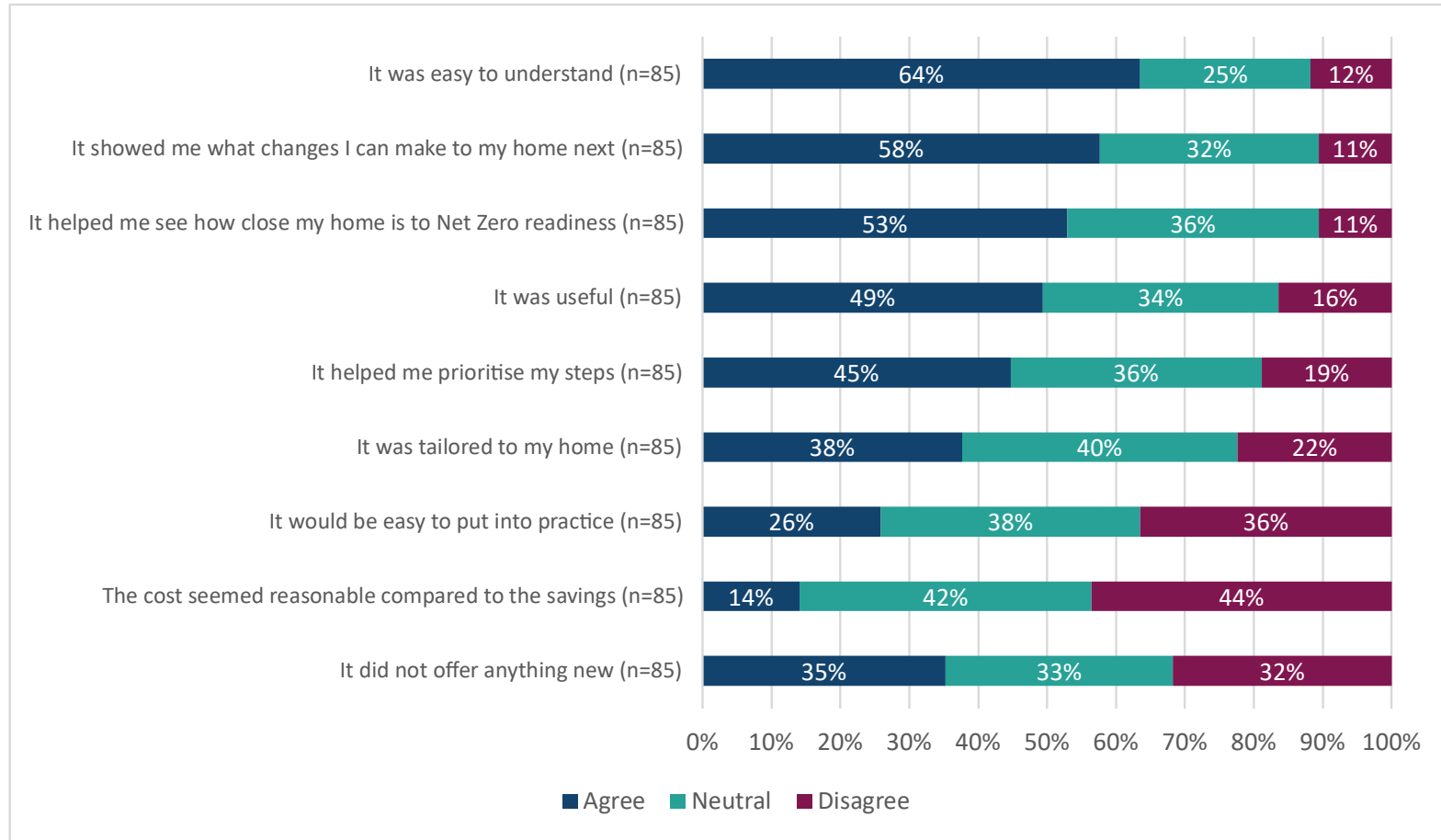
- Completed survey, but did not receive a roadmap: n=510
- Completed survey, received a roadmap, core trial: n=56
- Completed survey, received a roadmap, AEH trial: n=30

3.5.3.1. Roadmaps helped people understand what Net Zero might mean for them

Most participants (64%) found the roadmap easy to understand, and over half (58%) said it clearly showed the changes they needed to make (Figure 18). Electrically heated households found it particularly useful, saying it helped them see how close their homes already were to being Net Zero ready.

Alongside greater awareness, many felt more prepared to act. Nearly half said the roadmap helped them prioritise the steps they might take (45%) and found it broadly useful (49%). Again, people with electrically heated homes said they found the roadmap helpful as it made clear what steps to take next and how to prioritise them.

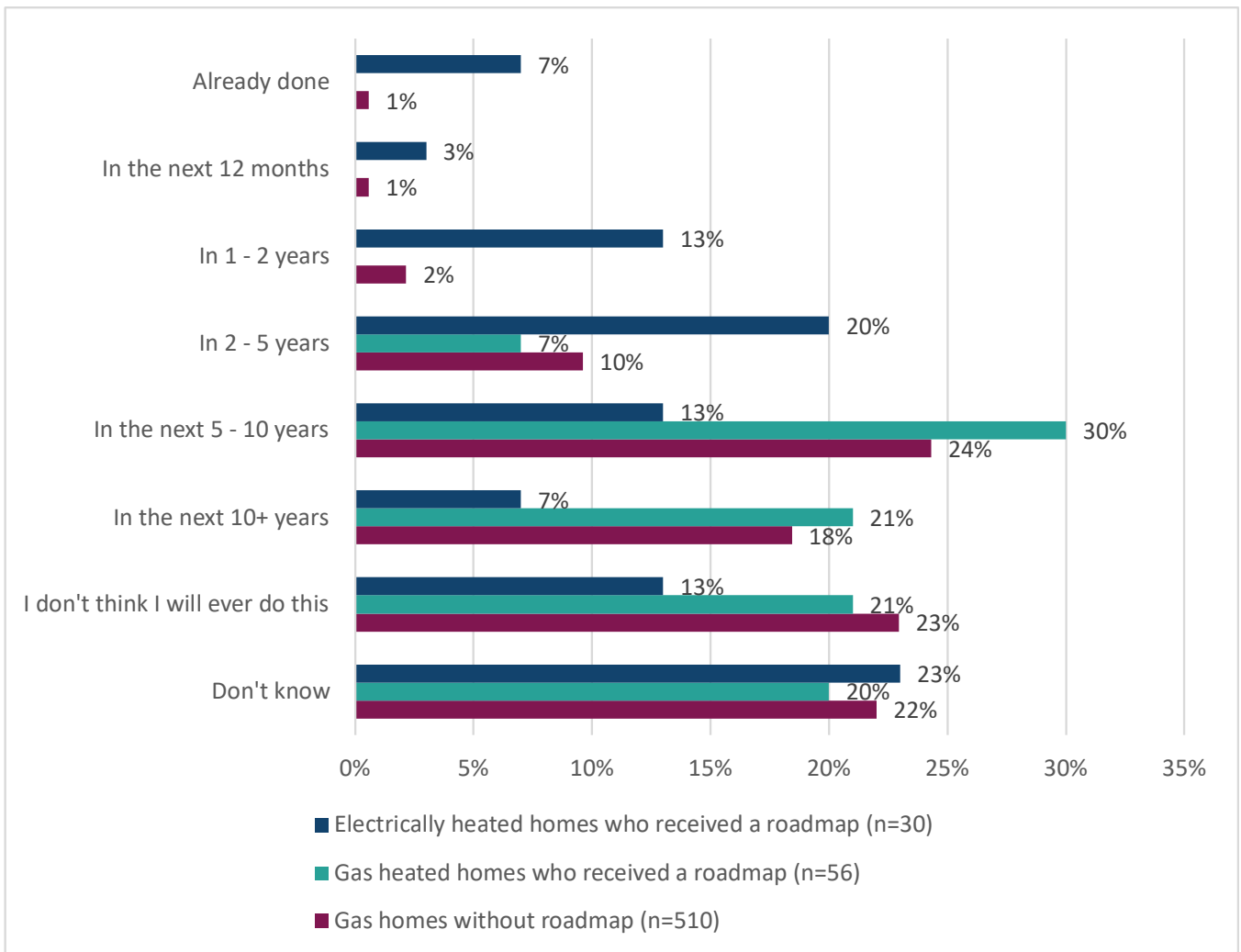
Figure 18: Responses to “To what extent would you agree with the following statements in relation to the roadmap...” (n=85)



The roadmaps also may have increased some participants’ acceptance or understanding that in the future, homes in the UK, including their own, might be heated using more efficient low carbon heating, like heat pumps³⁸. An exploratory analysis suggests that roadmaps may have helped a few participants to consider they would be living in a home with efficient heating at some point in the future, that this might happen sooner rather than later, and less likely to think it would never happen (Figure 19). However, sample sizes were too small to draw strong conclusions.

³⁸ We asked participants ‘When do you imagine you’ll be living in a home running efficient, low carbon heating like a heat pump?’

Figure 19: When do you imagine you'll be living in a home running efficient, low carbon heating like a heat pump?



Similarly, exploratory analysis suggested that, of those who received roadmaps, those with electrically heated homes may be more likely to imagine they'll be living in a home with low carbon heating at some point in the future than those in gas homes and to think this would happen sooner (e.g., in the next 5 years).

3.5.3.2. Many still see Net Zero as low priority for them

Many people told us they understand the importance of Net Zero. In interviews, some spoke about doing their part for Net Zero:

“Everyone needs to be part of the net zero energy use.”

“Definitely, even future proofing, especially for my daughter.”

“Most people ought to be looking at that, not just the experts.”

However, most participants interviewed about the roadmaps said their main motivations for improving energy use are cutting bills and staying warm. Climate concerns are a lesser priority.

“High bills are what got me thinking – not climate stuff.”

Some found the concept of Net Zero too abstract to act on. They wanted clearer explanations of everyday benefits; like how Net Zero upgrades could help keep homes cool in summer and warm in winter.

The roadmap still does not overcome many of the barriers people face to installing low carbon heating. People are still held back by high costs, long payback times and a fear of making the wrong decision. Participants said they might consider upgrades in the future if they receive a grant or other financial help. A few also had questions around gas (e.g., not being sure if it would be phased out completely, or whether they'd still have a choice in using it). More information about the future of gas in homes would help address this.

Therefore, roadmaps may have increased participants' awareness of Net Zero and helped some to realise that low carbon heating was likely to happen. But for most people, Net Zero does not figure as a major motivator to making energy efficient improvements to their home.

3.5.4. Transition to low carbon heating

3.5.4.1. Those in electrically heated homes are more likely to consider installing low carbon heating

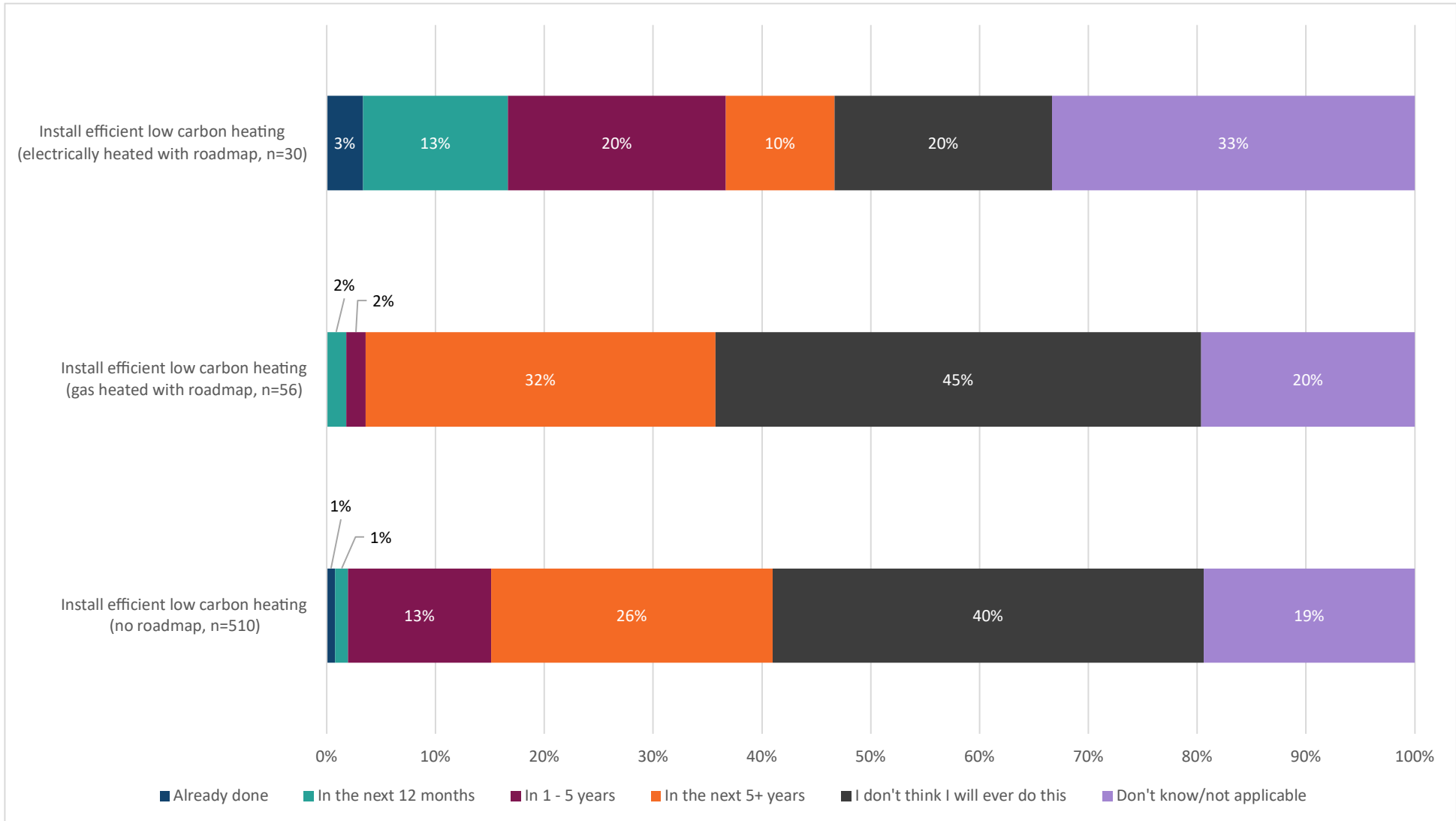
The roadmap helped 43% of those who received it feel more ready to switch to low carbon heating (Figure 20). Of those who said they would consider switching to low-carbon heating, 70% of those living in gas heated homes said it had at least some influence on their likeliness to switch (though 40% only slight) whilst 79% of those in electrically heated homes considering the switch said the roadmap influenced them, 57% saying it had a moderate influence.

However, looking at when people said they might make the change, there is limited evidence that the roadmaps influenced how soon, if ever, people felt they'd make the switch. If anything it looks like those with gas heating who received the roadmap were more likely to say they'd never switch, or to suggest that if they did, it'd be further in the future than those in the core trial who didn't receive one, suggesting that providing information such as in a roadmap might actually put people off low carbon heating for those in gas heated homes. However, more data would be required to confirm this or understand it further, as those without a roadmap were from gas and electrically heated homes (it could be that electrically heated homes were more positive thus making a comparison to gas heated homes with a roadmap less relevant).

However, there may be a difference between intentions of those living in electrically heated homes and intentions of those living in gas heated homes, though again, sample sizes are small. Of those who received a roadmap, those in electrically heated homes were more likely to say they'd install low carbon heating within the next 5 years, than those in gas homes³⁹ (33% vs. 4%, $Z=3.94$, $p<0.05$). Those in electrically heated homes were also less likely to say they'd never consider installing a heat pump in the future than people in gas heated homes (20% vs. 45%, $Z=-2.3$, $p<0.05$). A large proportion of responders remained unsure.

³⁹ It should be noted that those in the AEH trial joined on the basis that they might be eligible to receive a RAAHP.

Figure 20: "When, if ever, do you think you might take the following steps to make your home more Net Zero Ready?"



Therefore, whilst participants told us the roadmap influenced them in terms of how likely they were to install a heat pump in the future, we have limited evidence that it will (e.g., because it didn't seem to increase likely uptake in those living in gas heated homes). Although we know that those living in electrically heated homes that received a roadmap were more positive about installing low carbon heating in the future, we can't say what influence the roadmap had on this.

3.5.5. Other energy efficiency recommendations

3.5.5.1. People felt the roadmap prompted them to act

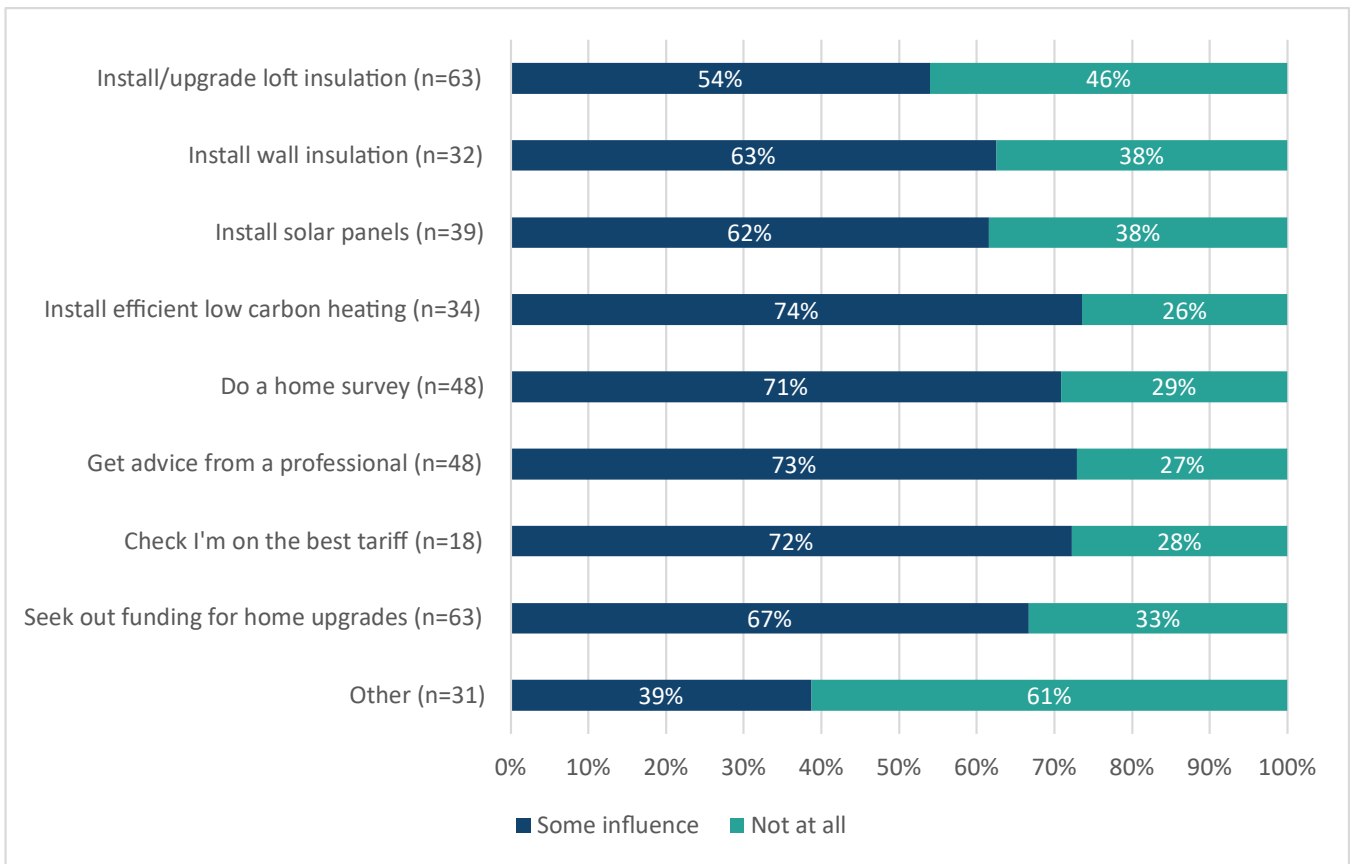
Among those in electrically heated homes, many found the roadmap useful for planning practical steps (Figure 21). More than a third (37%) said it prompted them to get advice from a professional and a third said it encouraged them to get a home survey done. Nearly half reported it nudged them to check whether they were on the best electricity tariff for their needs.

Those living in gas heated homes felt the roadmaps influenced them to consider getting advice from a professional (43%, three people saying the roadmap was fully responsible for this) and looking into getting a home survey done (43%, seven people saying it significantly or completely prompted this).

Although wall insulation wasn't popular – only 38% of participants in gas heated homes (who were more likely to have been recommended it) thought they might do it, 76% of them said the roadmap influenced them to consider it.

There was a lot of interest in looking into funding options for both those living in electrically heated homes and gas heated homes: 73% of participants were interested in funding available, and 67% of them said the roadmap prompted them to look.

Figure 21: "To what extent did the roadmap influence your plans on the steps that you mentioned (multiple choice)"



3.5.5.2. Intention to act

As well as people feeling roadmaps prompted action, they may have had a small impact on encouraging people to consider acting sooner, though not an overall likelihood to act (Figure 22 and Figure 23). Sample sizes are too small to confirm, but across many of the energy efficiency actions recommended in the roadmaps, it looks like roadmaps could have slightly influenced people to plan to take actions such as considering getting a home survey, getting advice from a professional or looking into funding for home upgrades sooner (e.g., in the next 12 months). It may also have made them less willing to rule out ever taking these actions in the future.

Figure 22: "When, if ever, do you think you might take the following steps to make your home more Net Zero Ready?" (n=86, those with roadmaps)

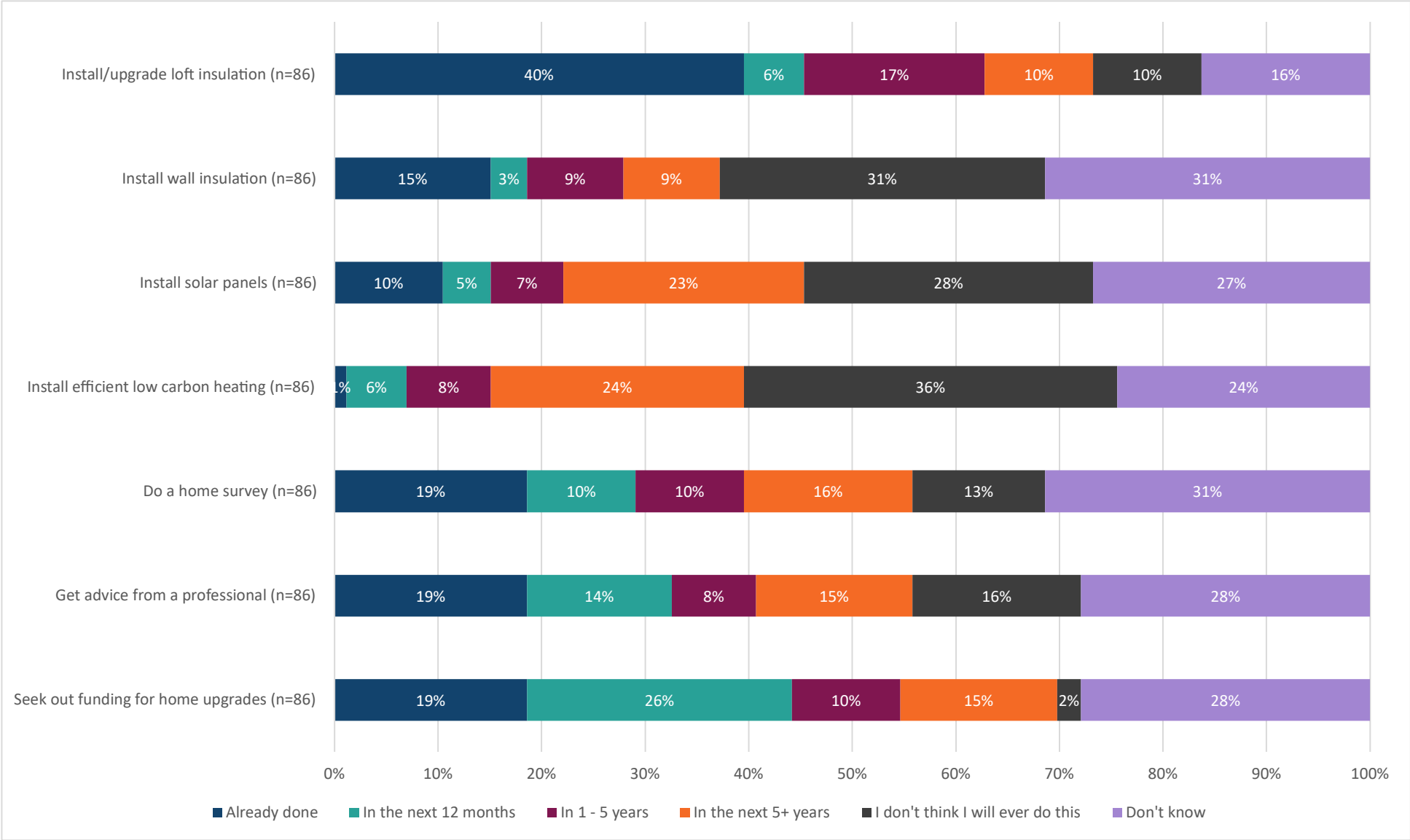
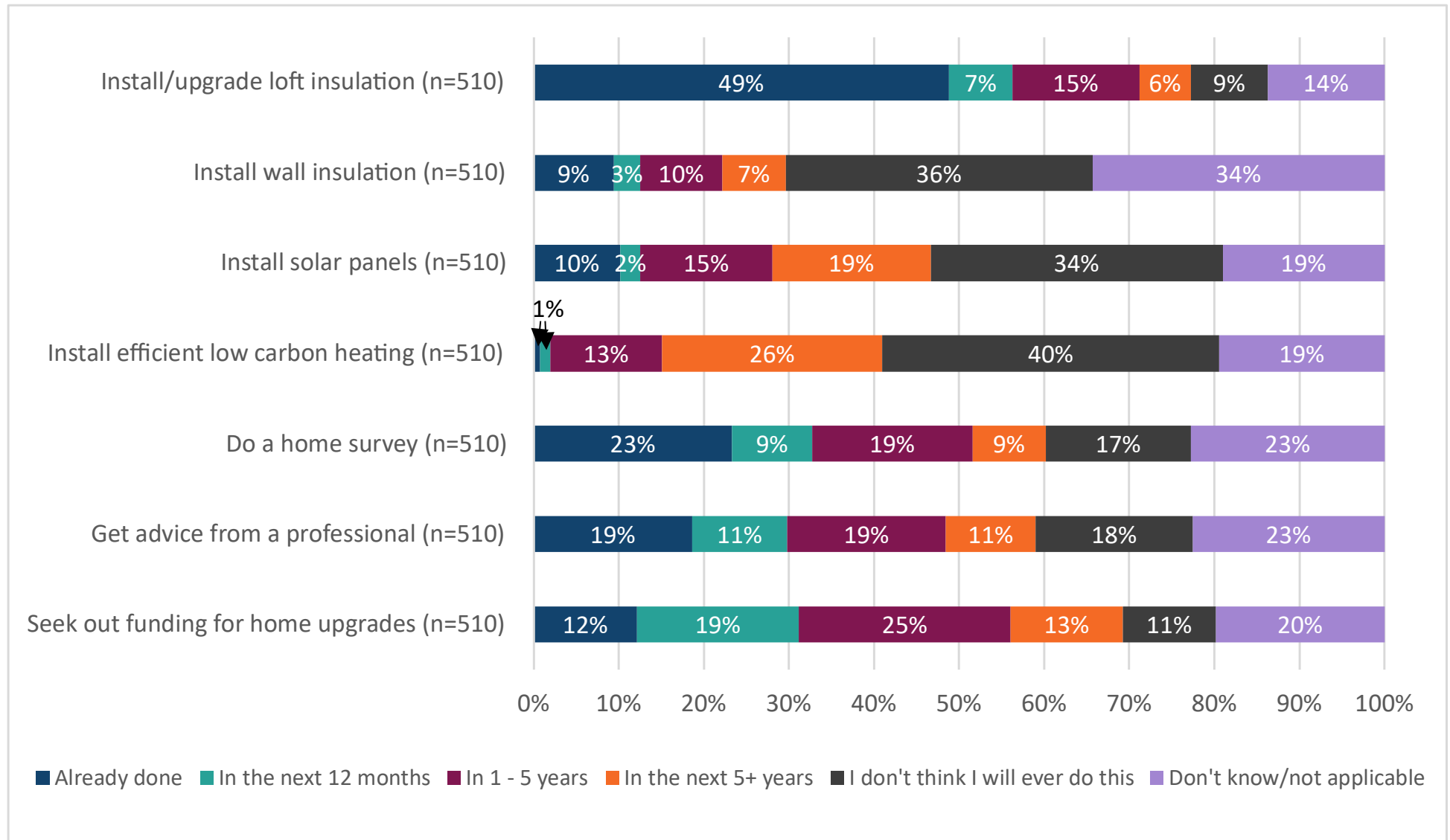


Figure 23: "When, if ever, do you think you might take the following steps to make your home more Net Zero Ready?" (n=510, those without roadmaps)



3.5.6. Roadmap usability

3.5.6.1. Many people found the roadmaps useful and felt they were tailored to their homes, but there was room for improvement

Most recipients said their roadmap felt both helpful and relevant; 74% reported being satisfied with it. They appreciated the level of personalisation. The roadmaps reflected key features like flooring type, energy usage, and current heating systems. This made the advice feel grounded and trustworthy. As one participant with electric heating summed it up, the roadmap felt “as personal as you can get without collecting more data.”

3.5.6.2. Solar panels: a popular first step

When it came to upgrades, solar PV panels proved the most popular first step, especially for gas-heated homes. About 44% of people in gas heated homes (and 28% of those in electrically heated homes, many of whom are in properties which would not be suitable for solar PV) said they planned to install solar PV panels. For many, the appeal lay in how straightforward installation is and how little it disrupts daily life.

“Solar panels are easiest, least disruption, so most sensible to start with” noted a participant in a gas heated home. People with high electricity use were particularly keen on solar, seeing it as a smart way to cut bills and future-proof their home energy.

Battery storage generated interest, largely among those already considering solar PV. The promise of storing energy and reducing reliance on the grid was attractive. Yet, uncertainty about sizing, compatibility, and real-world performance held some people back.

“I looked at a battery, especially with the cost of electricity... but I don’t know what size I’d need”

3.5.6.3. Providing more detailed cost information

Despite roadmaps providing information on estimated costs of installing measures and payback time, some respondents fed back that they wanted more detailed information on the costs and the return on investment. Some respondents were unsure about whether some measures were financially viable.

3.5.6.4. Everyday changes were the most appealing

By far, the most appealing changes to adopt were the simplest and cheapest, such as small behaviour shifts or minor DIY fixes. These everyday improvements topped the list because they were practical, low-cost, and doable without professional help. Across all upgrades, the financial information in the roadmaps stood out as a key takeaway. Seeing estimated costs and potential savings helped people judge what was worth pursuing:

“I liked how it showed how long it would take to make the money back”

Still, many asked for more detail, such as clearer guidance on funding options, precise payback periods for each upgrade, and regular updates on grants or support schemes.

Wall insulation was one of the least embraced suggestions, though 27% living in gas homes considered it and 7% said they already had some. Although most participants understood its benefits, concerns over disruption, cost, and feasibility in older or non-standard homes often outweighed the gains. For many, the idea of tearing into walls simply felt too invasive to be worth it.

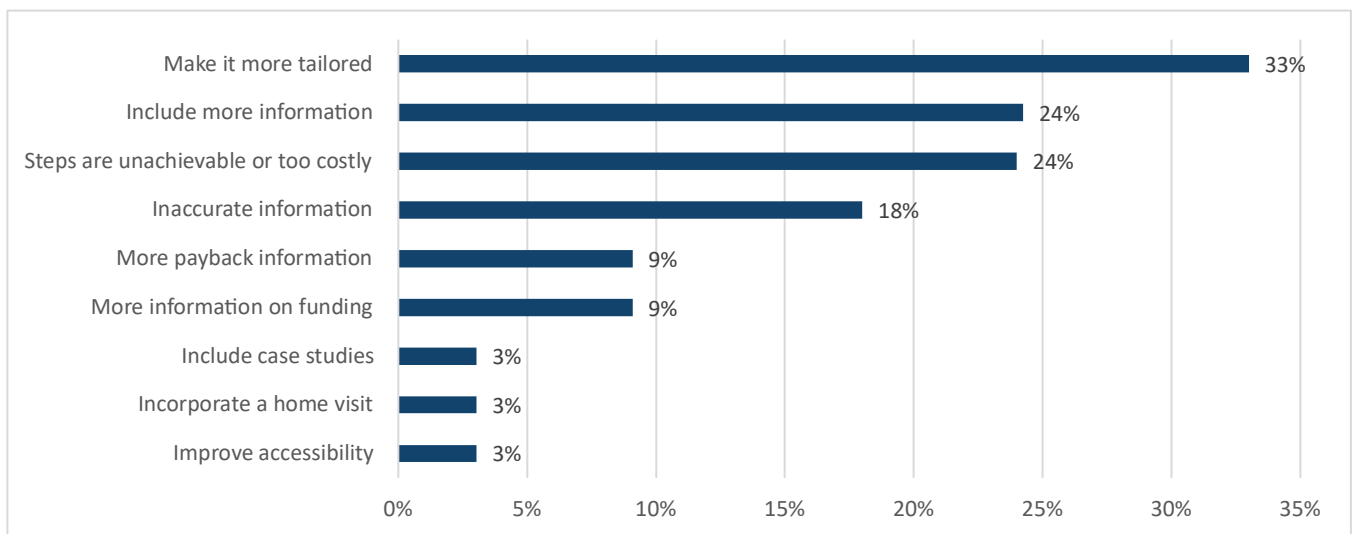
3.5.6.5. Some felt the roadmap didn't reflect their home well

However, some people felt the advice didn't fully match their circumstances (Figure 24). This was particularly true for those living in flats, leaseholds, or older homes with limited upgrade options. Suggestions like rooftop solar or floor insulation simply weren't realistic for them.

About one-third of these participants said the roadmap needed to better reflect apartment living. Others pointed out that past upgrades - such as already having solar PV panels - weren't acknowledged, leaving them frustrated at advice that told them to “do things twice.”

If roadmaps are to be used in the future, the householder having the opportunity to review before they are finalised would help alleviate concerns around the advice not being sufficiently tailored.

Figure 24: Suggested improvements to roadmaps



3.5.6.6. Roadmaps may have been more positively received by those who understood Net Zero concepts

Our exploratory analysis shows that among participants with higher Net Zero awareness in April 2025, 69% ($n=34$) agree that the roadmap showed them what efficient changes they can make to their home next, whilst 42% ($n=15$) of those with lower awareness thought so. This trend is held true across other measures as well: better-informed users were more likely to grasp the roadmap's content and feel that it was more useful for them.

3.5.7. Roadmaps - key takeaways and recommendations

3.5.7.1. Key takeaways

- Participants' Net Zero awareness has increased since the start of the trial. Roadmaps may have influenced this in those who received them and helped them understand what it would mean for them and their home.
- They felt it informed them about low carbon heating options, especially participants living in electrically heated homes who were more likely than those in gas heated homes to say they'd consider installing a heat pump sooner.
- People felt the roadmap prompted them to start acting. Many electrically heated households set out to seek expert advice or review their tariff, while a sizeable share of gas-heated homes began exploring funding options and arranging energy surveys.
- Those who received roadmaps may have been prompted to consider taking actions, like getting professional advice or exploring funding options sooner, and less likely to say they would "never take action."
- Those familiar with Net Zero were more likely to feel they benefited, finding the roadmap easier to understand and more useful compared with people who had lower awareness of Net Zero.
- Low-disruption, cost-effective upgrades appealed most. Solar PV panels appealed to many gas-heated households and a good share of electric-heated ones, while invasive wall insulation was often seen as impractical or too costly.
- Most people felt the roadmaps were tailored to them, but some still wanted more detail on costs and returns on investment, and those living in flats, leaseholds, or already-retrofitted properties felt some recommendations did not fit their circumstances.

3.5.7.2. Recommendations

- Tailor roadmaps to home type

The advice must feel relevant to the person reading it. People in flats or leaseholds sometimes received suggestions they couldn't act on, which made the roadmap feel less trustworthy or useful. Roadmaps should be as tailored as possible to housing type and tenure and only suggest options that can be realised.

- Allow people to update their home details

People didn't appreciate being given advice to do things they've already done. Users should be able to check and update information about their home before their roadmap is generated.

- Highlight easy first steps people can take immediately

Most people were positive about simple, practical actions like checking their electricity tariff, looking for advice, or booking an energy assessment. Roadmaps should spotlight a handful of low-barrier steps people can do right away, and link directly to the tools, websites, or local services that make follow-through simple.

-
- Provide information on costs and other benefits

People focused on and valued cost estimates and payback timelines and wanted more detail. Therefore, information on this that is as accurate as possible is valuable, along with advice on how to find out about financial support.

Care should also be taken when presenting options with unattractive pay-back period. Methods should be found to clearly justify the other benefits of these and/or they should not be presented before other actions more likely to engage.

RQ 2.2: Which measures, of those offered, are more or less attractive to consumers?

Core trial householders were asked which energy efficiency measures they were interested in having in their homes (only measures offered in HfNZ were options):

- Almost 3 in 4 householders were interested in draught proofing (74%), a heating MOT (72%) or heating MOT+ (74%);
- loft insulation attracted the least interest from householders (57%), for reasons such as already having the measure or it being inconvenient to install.

In addition, most people were interested in receiving advice about what to do in their home:

- 85 % of householders were interested in having a Home Energy Efficiency (HEE) survey (i.e., the PAS2035 survey);
- Similarly, 84% wanted a Heat Pump Sizing (HPS) survey (i.e., the SAP heat loss survey).

Householders were asked to give reasons why any measure or survey was unappealing. Aside from already having the measures offered or surveys implemented, which was predominantly found for loft insulation and draught proofing, some common reasons for not being interested in the measures were a lack of understanding of the practicalities and benefits. Those who were not interested in the boiler MOT and MOT+ either reported having these measures already or did not “understand what it is or how it would work.” These initial findings indicate some uncertainty about what having these measures entails, or a failing by the contractor to adequately explain them.

Regarding the HPS survey, of those who did not want a HPS survey, five out of fifteen respondents resonated with the statement “I do not think it is worthwhile/offers any real benefit to me,” indicating a lack of interest in the measure due to a lack of perceived benefit, despite being free.

This question is not repeated in future reports.

3.6. Quantitative data analysis methods and findings

University College London (UCL) is providing detailed quantitative data analysis for some data in the project. A summary of the methods that are being employed is presented alongside the

relevant initial findings for some of the project’s research questions. Latter reports will cover other methods and other research questions. See also Appendix 7 for further method details.

3.6.1. Research questions

A complete list of research questions posed by both trials can be found in the appendix to this document. Research questions from both trials have been grouped together in this section to highlight the different types of data analysis methods that will be employed by the project to answer them.

Due to the timelines of the project some research questions originally posed as part of the original scope of the project may not be answered or may not be answered conclusively in this phase of the programme. Delays with recruitment and measure installations, as well as data quality issues caused by incorrect installation or operation of monitoring equipment are likely to further impact on the quality of the analysis that can be achieved. Lessons learnt from previous monitoring studies have been taken to mitigate these issues (e.g., by choosing linear modelling techniques that do not rely on high percentages of data completeness).

3.6.2. Analysis of energy savings from installed measures

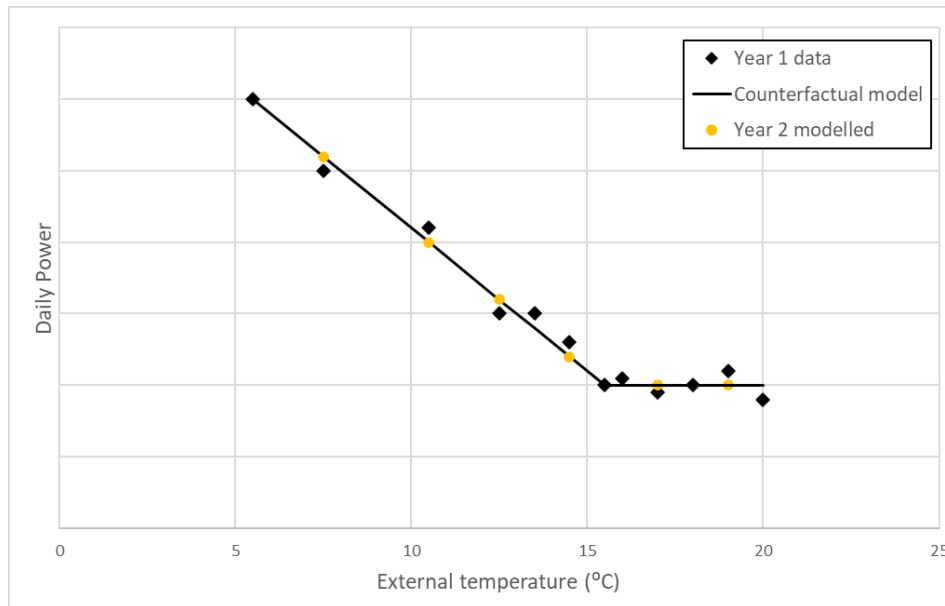
One of the key research questions for both trials is the comparison of energy consumption prior to and after installation of individual and packages of measures, as well as the impact novel heating technology can have on energy consumption in homes. Central to this analysis will be the difference-in-difference (DiD) approach which allows changes in energy demand due to measures to be distinguished from those happening because of other factors (e.g., changes in energy prices).

First, energy consumption and external temperature data from winter 2023/24 are used to develop a model that will be used to predict energy demand in winter 2024/25. The “Power-Temperature Gradient” (PTG) is a linear regression with external temperature data as the independent, and daily energy demand as the dependent variable (depending on the building and heating system type this could be gas only, gas and electricity combined, or electricity only). This model assumes that no energy will be used for heating above a certain, fixed (external) “balance temperature”⁴⁰, meaning that all energy used during such warmer periods represents “baseload” of the home from activities such as cooking, heating hot water, or running of household appliances. By establishing the baseload, both primary and secondary heating demand of the home can be identified. When temperatures fall below the balance temperature, the model assumes a linear relationship between temperature and gas usage of the home.

⁴⁰ A balance temperature is calculated for each home.

The PTG method, shown in Figure 25, was chosen for its simplicity, widespread use (including as basis for some remote SMETER techniques) and consistency with Domestic Energy Monitoring via SERL (DEMS) project (winter 2023-24) for DESNZ⁴¹⁴².

Figure 25: Illustration of PTG line fitting



The difference between the weather-corrected, predicted energy consumption in winter 2024/25 (i.e., counterfactual), and the actual energy consumption of homes during this period will be partially attributed to the retrofit measures installed.⁴³

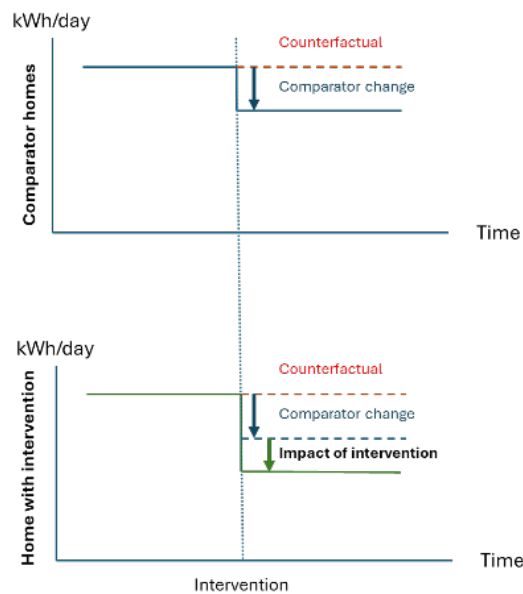
Additionally, the analysis must account for systemic changes to how homes consume energy: hence, the homes receiving the measures will be matched to homes within a comparison group that did not receive any measures. This will be done using characteristics of the dwellings and households within the trial. Figure 26 illustrates how the comparison group methodology enables us to differentiate the savings from energy efficiency measures from systemic shifts in energy consumption that also affected the comparison group.

⁴¹ Elwell, C.A. *et al.* (2015) 'Determining the impact of regulatory policy on UK gas use using Bayesian analysis on publicly available data', *Energy Policy*, 86, pp. 770–783. Available at: <https://doi.org/10.1016/j.enpol.2015.08.020>.

⁴² McKenna, E. *et al.* (2024) Smart Energy Research Lab: Energy use in GB gas heated domestic buildings during the 2022/2023 heating season.

⁴³ Due to delays with recruitment and the installation of measures, the sample will contain homes where measures were installed during, not prior, to the winter 2024/25 heating season. For these homes, the data for the PTG model will be split in accordance with the actual measure installation dates, to accurately represent energy consumption prior to and following installations taking place.

Figure 26: Illustration of difference in difference⁴⁴



Given the relatively small sample sizes of the groups receiving measures, and the relatively small, expected energy savings from each measure, it is anticipated that the energy savings from the chosen measures will not be statistically significant. This issue is likely to be further exacerbated by the delays in recruitment and data collection encountered by the project. Nonetheless, statistical testing will be carried out to establish whether the mean percentage change in energy demand for each group is significantly different to the mean for the matched control groups, using a t-test or non-parametric equivalent. Uncertainty metrics about the savings achieved as well as the confidence in the PTG model will furthermore indicate the robustness the analysis achieved.

RQs 1.1: What are the energy savings of individual measures?

The key variable for assessment of changes in energy demand is the Heating Power Loss Coefficient (HPLC) which combines fabric and heating system efficiencies and allows periods with different external temperatures to be compared. Higher values of HPLC indicate higher heat loss, with lower values indicating a more efficient home.

The calculation of change in energy demand was complicated by the wide date range of the measures installations at different points during winter 2024/25. The HPLC was calculated for three periods for all homes where sufficient data was available (which requires 50 days of data during the heating season and 50 days during the summer, with the exception of Period 3):

- Period 1: “Winter 1 Summer 1” (W1S1) HPLC (i.e., the HPLC before intervention), based on dates for the period 1/11/23 to 31/8/24. Applicable for *all* core trial homes.
- Period 2: “Summer 1 Winter 2 Before” (S1W2B) HPLC. This is the HPLC calculated for the period 1/5/24 to 31/3/25. It is applicable for *all* core trial homes, however, for those that had a measure installation, any data after the installation date is not used. For the

⁴⁴ CF. RetroMeterWP2-Methodology Development [report](#).

core trial households that did not have a measure install, this is the only Summer 1 Winter 2 HPLC.

- Period 3: “Summer 1 Winter 2 After” (S1W2A) HPLC. This is the HPLC calculated for the period 1/5/24 to 31/3/25 but excluding all Winter 2024/25 data before intervention (the inclusion of Summer1 is necessary to give a baseline since no summer data is available after the intervention). This is only applicable for homes that have a measure install; in this case the filter for winter data is a minimum of 20 days post intervention. This low minimum limit allows inclusion of some of the homes where the intervention was later in the winter.

The change in mean HPLC between the two winters for all those homes without interventions (Period 1 to Period 2) is shown in Figure 27. Although the trend appears to be upward, the change in the mean is within the variation indicated by the standard error of the mean error bars (i.e., there is no evidence of overall change).

Figure 28 shows the mean before and after intervention for W1S1 to S1W2A for five interventions (Behavioural Measure (BM), Draught Proofing (DP), Loft Insulation (LI), Heating System MOT (MOT) Heating System MOT+ (MOT+)) where there are sufficient households with post-intervention data. For all five interventions, the error bars overlap when comparing before-after-counterfactual, suggesting no change in energy consumption. The mean HPLC for homes that had Draught Proofing is higher than for homes that had other measures; this is related to small samples sizes, and, with the HPLC not adjusting for floor area, a higher heat loss due to larger homes. Figure 29 shows the mean before and after intervention for S1W2B to S1W2A for two interventions (LI, MOT) where there are households with sufficient data. Again, the error bars overlap when comparing before-after, suggesting no change in energy consumption. Only homes with an HPLC result for both before and after are included in each statistic.

Again, although the trend appears to be upward, the change is within the standard error of the mean error bars (i.e., there is no evidence of overall change).

Figure 27: Change in mean HPLC from winter 2023/24 to winter 2024/25 (N = 429 homes, only including homes with sufficient data in winter 2024/25 before / without intervention)

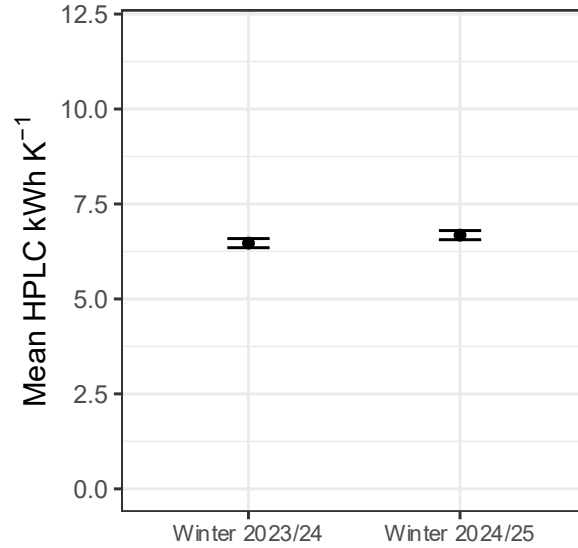


Figure 28: Change in mean HPLC between winter 2023/24 and after intervention winter 2024/25 compared with counterfactual (HfNZ, not SERL) for winter 2024/25

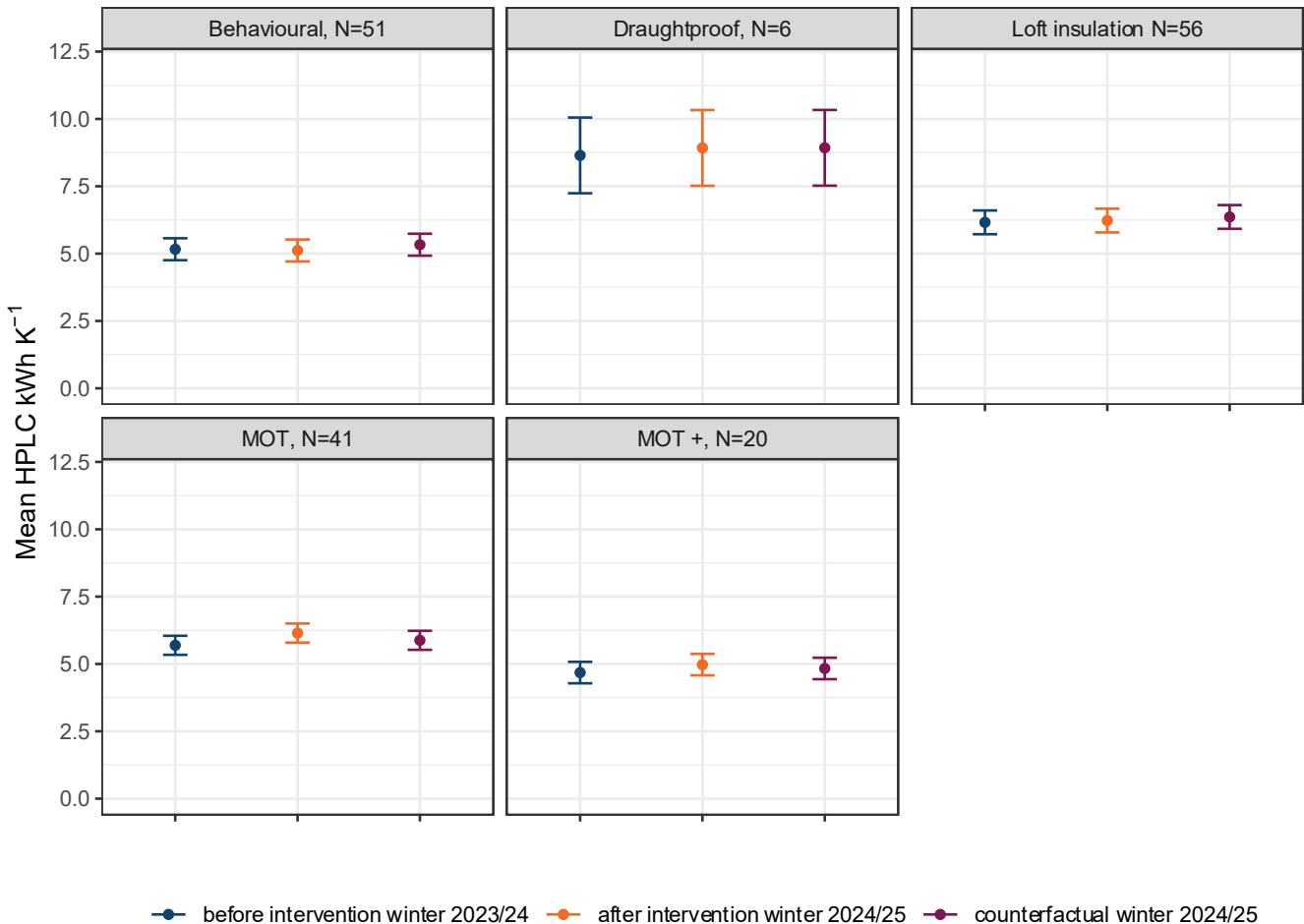
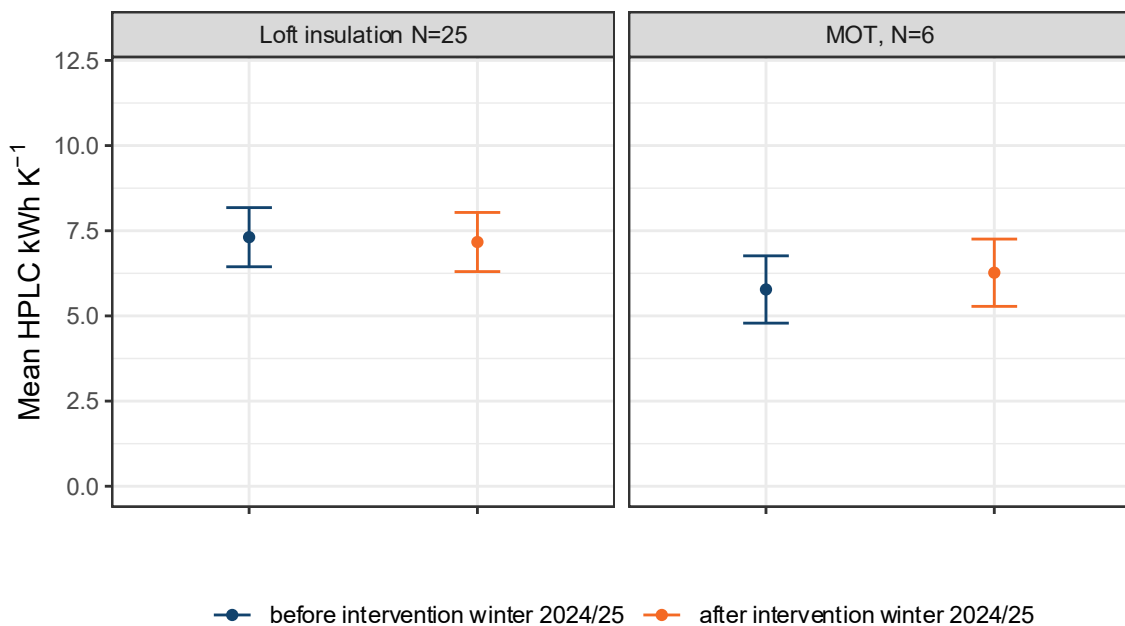


Figure 29: Change in mean HPLC between before intervention winter 2024/25 and after intervention winter 2024/25



It should be noted that due to the small sample sizes, these results are not conclusive evidence that can be generalised to the stock level.

RQ 1.2: What are the energy savings of different packages of measures?

No information is available for energy savings for packages of measures in winter 2024/25. A small number of homes received combinations of loft insulation with other physical measures. Those that received both loft insulation and a heating MOT were classified in a separate “Loft and MOT” group, and this is the only “package of measures” group included in the analysis. This group did not have sufficient after intervention data to be included in the energy saving analysis for winter 2024/25 and so will be reported on in future reports.

3.6.3. Analysis of other effects of measures

For homes that are receiving heating control equipment (i.e., as part of a heating MOT / MOT+), analysis will consider whether a household’s resulting mean internal temperatures differs from that of homes without any measures, or homes that received measures but no improved heating controls.

Since the trial will be lacking comparative internal temperature monitoring data from winter 2023/24, and some installs were completed during winter 2024/25, it will be challenging for the project to analyse ‘comfort taking’. However, analysis will seek to combine data gathered in consumer surveys with data from temperature sensors to investigate whether a correlation between measure installs, perceived changes in heating behaviours, and internal temperatures, can be found.

Finally, data from heat meters fitted in those homes having heating MOT+ will be used to assess the flow temperature set point of boilers following measure install. This analysis will identify evidence of residents (or automatic boiler controls) varying the flow temperature to cope with changing weather conditions. Additionally, data from monitoring equipment will be used to investigate whether homes that had an MOT+ and reduced their boiler flow temperature are heated to a comfortable level in cold weather.

RQ 1.8: Have measures led to comfort taking (increasing either the time or temperature homes are heated following improvements to energy efficiency)?

Core trial householders were asked at the outset of the trial whether they are currently able to maintain comfortable temperatures in their main living space during the day, or bedroom during the night ($n=814$):

- While 64% agreed that they could normally keep comfortably warm in the living room during cold weather last year, under half (49%) could say the same for the bedroom;
- During the warmer months when the temperature was higher at home, respondents were evenly split between feeling too warm in their living rooms (42%), or not (42%). A higher proportion (47%) felt it was too warm in their bedrooms, compared to 40% who did not.

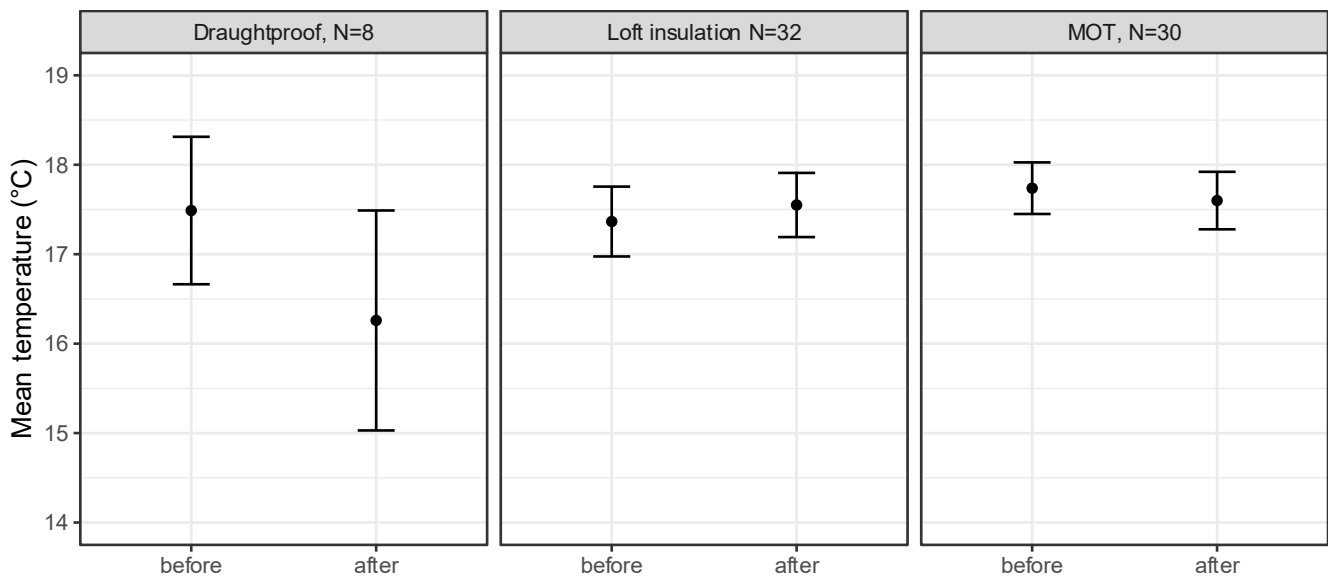
These data on comfort are used by UCL in their analysis in the Winter 25/26 report to be published at a later date and included here for information.

RQ 1.10: Do improved controls lead to higher mean internal temperatures?

117 homes had improved heating controls installed. For the majority of homes with intervention, internal temperature measurements started at approximately the same time as the intervention, so it was not possible to compare temperatures in the home before and after the modification. Figure 30 shows the results of analysis for those homes where there was at least 10 complete days of temperature data both before and after the intervention. For all the intervention groups, there was little change in mean temperature from before to after intervention, suggesting that, on average, the households did not choose to keep their home any warmer than they had before. For homes that had draughtproofing, the mean drops by just over 1°C, but the error bars overlap and so (statistically speaking), it is not possible to be sure that a difference is observed.

The homes with MOT or MOT+ interventions showed no significant change in mean internal temperature. These initial results indicate that improved controls may not lead to higher mean internal temperatures, but further data and analysis is required to further test this.

Figure 30: Mean change in mean internal temperature before and after intervention, in winter 2024/25 in living rooms



RQ 2.1: What impact can simple, low-cost measures have on the cost and suitability of homes to install low carbon heating such as heat pumps?

For homes that received MOT (75 homes) or MOT + (29 homes), the flow temperature recorded by the heat meter was investigated to establish whether the residents with replacement radiators (MOT+) were running their radiators at a lower temperature than those who only had the MOT intervention. For a heat pump to run more efficiently, lower flow temperatures than those normal for a gas boiler are required and the MOT+ intervention (i.e., increasing surface area of emitters so they can be run at lower temperatures) were the first step in improving suitability for heat pumps.

A mean flow temperature of 62.1°C for 49 homes with MOT+ was 6.3°C lower than that for 68 homes with MOT only (68.4°C) suggesting that the lower flow temperatures set during MOT+ had persisted in many homes. In both groups there are maximum flow temperatures of over 80°C, suggesting that some households reverted to an increased flow temperature after the MOT+.

Due to small samples sizes it is not possible to draw wider conclusions at stock-level on energy savings from the results on low cost, low disruption measures.

3.6.4. Analysis of overheating in homes

Granular data collected by the temperature monitoring devices was used to understand whether, and to what extent, homes within the trial are prone to overheating. Overheating could be exacerbated by retrofit measures that reduce the natural ventilation rates of homes.

The impact of overheating differs depending on the time of day and part of the home that is being occupied at any given time. Therefore, the internal temperature data was split into two datasets - bedrooms and living rooms (i.e., rooms that are not bedrooms are likely to be

occupied during 7am-10pm). For the two types of rooms, and for each month from June to September, the percentage of time at which the room temperature exceeded 24°C, 26°C or 28°C, either during the night (10pm to 7am) or during the day (7am to 10pm) was calculated. Various temperatures were chosen to reflect that relevant standards (e.g., CIBSE TM59 and SAP) that define overheating do not use the same overheating setpoint.

Contextual data about the mean and maximum external temperatures, as well as hours of sunshine, per month, was analysed alongside the internal temperature data.

RQ 4.1: What is the current level of overheating according to recognised definitions in sample homes?

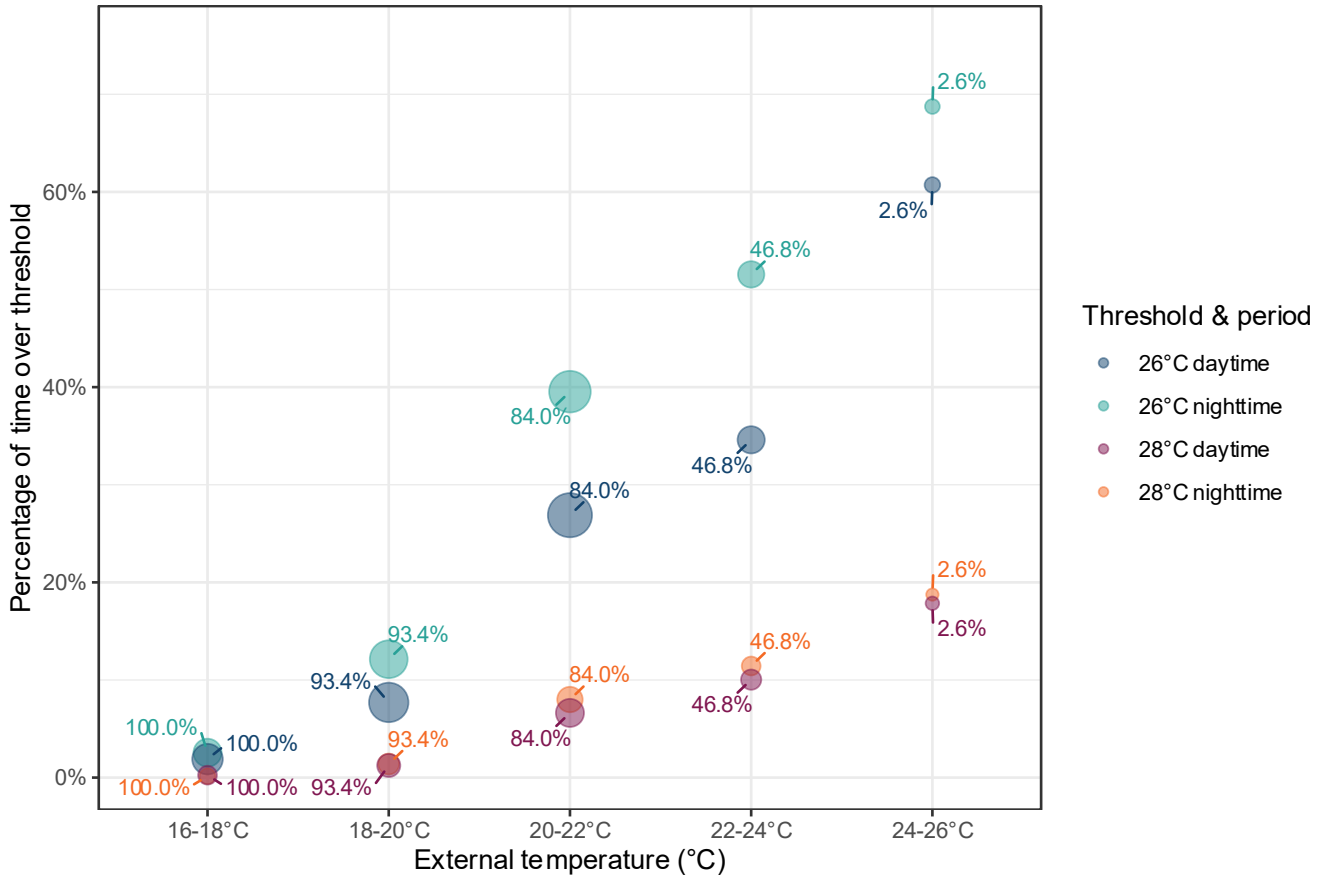
A preliminary analysis of time above threshold temperature was carried out for Summer 2024. This analysis will be expanded and linked to survey answers in future reports. As can be seen from Table 5, external temperatures in summer 2024 were moderate.

Table 5: Mean external temperatures in summer 2024

Month	Mean daily temperature (°C)	Mean maximum hourly temperature in day (°C)
June	14.3	18.3
July	16.2	20.2
August	16.8	21.0
September	13.5	17.1

Overheating (defined as percentage of time over a threshold temperature) in bedrooms was analysed for times between 10pm and 7am, with overheating during the day analysed in all other rooms from 7am to 10pm. The proportion of these hours during which the measure temperature was over a threshold was calculated for the period 1st June 2024 to 30th September 2024. Figure 31 shows plots of the day and night overheating results for two thresholds: 28°C and 26°C (only rooms with at least one hour of overheating in the period are shown.. Point size is proportional to the number of home-days when overheating occurs. Daytime overheating in living rooms and nighttime overheating in bedrooms shown separately.). The percentage of time overheating was very low. Daily mean external temperature rarely rose above 24°C so, although the percentage of homes experiencing overheating in higher temperature bands increased, the number of homes where this was the case was very small.

Figure 31: Proportion of time a room was over threshold temperature in summer 2024 plotted against mean daily external temperature. Percentage next to bubbles is percentage of homes falling within the external temperature band at any point in Summer 2024. Point size is proportional to the number of home-days when overheating occurs.



Short surveys have been administered to householders shortly after extreme weather events such as a heat wave or cold weather. These are deliberately short surveys with just a few questions to understand how householders cope during extreme weather.

The first survey was administered just after a heat wave in the summer of 2024. More than 500 householders were invited to participate, and more than 300 responses were collected. Charts shown here cover questions about ability to maintain a comfortable temperature (Figure 32), and success in reducing temperature (Figure 33).

Figure 32: Householders' ability to maintain a comfortable temperature during the heatwave in 2024

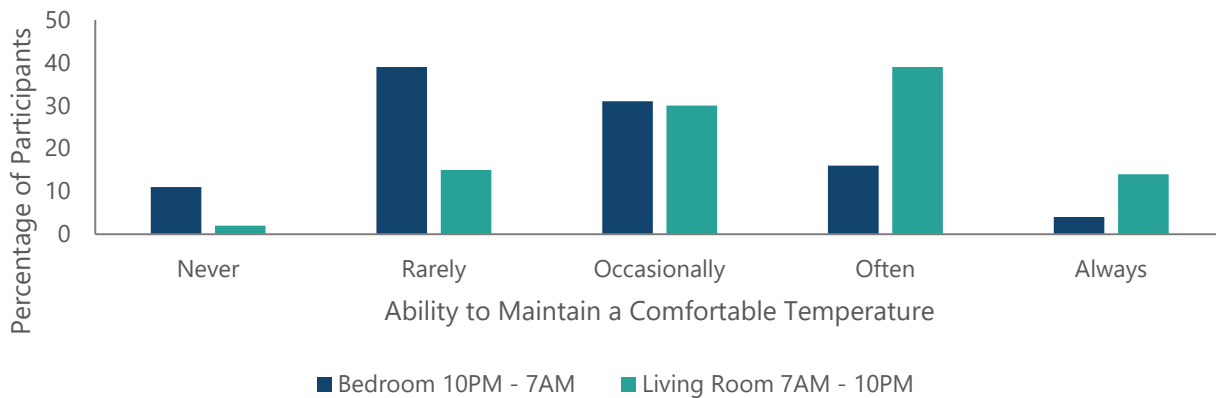
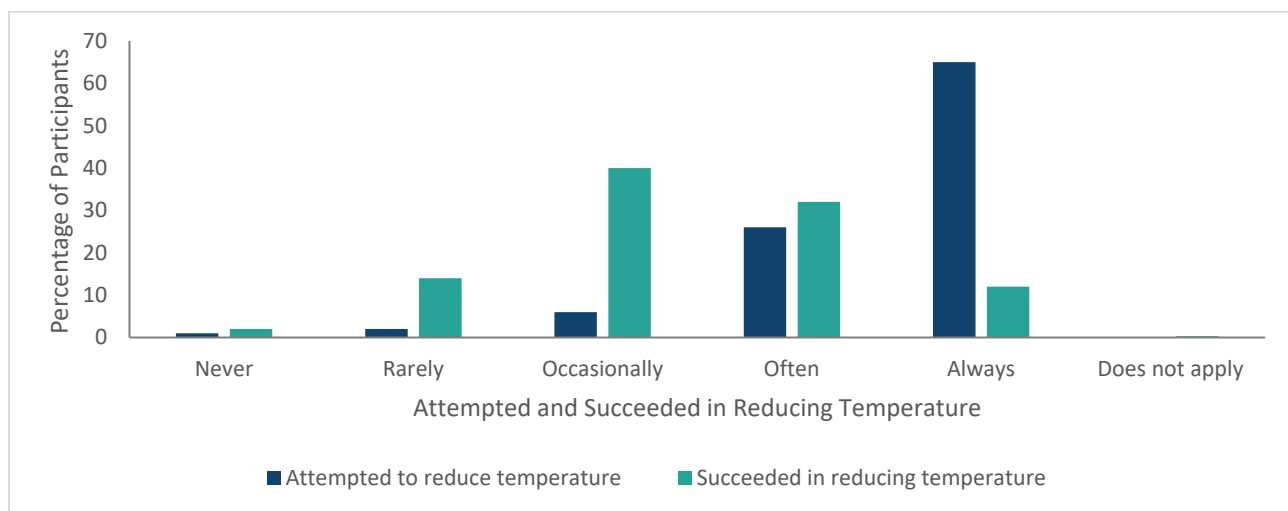


Figure 33: Householders' success in reducing temperature



Householders reported that heat affected people of all ages in their households. Analysis of the data collected after the heat wave found the following:

- most householders struggled to keep their homes at a comfortable temperature, especially in their bedrooms overnight;
- despite actively taking measures to lower the temperatures (e.g., opening windows, using fans), most were unsuccessful;

In future reports, these surveys of perceived temperature will be compared with actual temperature data.

3.6.5. Analysis of indoor air quality

Indoor Air Quality (IAQ) is a descriptor of the air within buildings and can be assessed through surveys or empirical measurements of pollutants. IAQ forms part of Indoor Environmental Quality (IEQ), which encompasses thermal conditions, lighting, noise, and visual elements. These components often interact and can be in conflict. For instance, ventilation needs for air quality may clash with noise concerns about opening windows, or the desire to minimise required heating to maintain thermal comfort.

Previous IAQ data has largely been gathered using passive sampling techniques which limits analysis of pollutants to averages over long periods, typically weeks and months. However, Lascar EL WEM+ monitors monitor pollutants at 1 minute resolution. That means that the data gathered in this study has the potential to present a much more detailed picture of IAQ than has previously been available, with potential to study pollutant exposure related to different occupants, at different times of day, and across different seasons.

A statistical analysis of IAQ data will be carried out to investigate levels of pollutants. Maximum values each day during expected occupancy hours of the living areas will be calculated. The percentage of homes exceeding selected thresholds will be calculated, along with the proportion of the time for which thresholds are exceeded. The threshold for each pollutant will be selected based on recognised standards for:

- particulate matter (PM10, PM2.5, PM1.0);
- volatile organic compounds (VOCs);
- carbon dioxide (CO₂);
- relative humidity (RH).

The analysis conducted for HfNZ will provide a baseline of IAQ within monitored homes and some contextual data will be analysed alongside it (e.g., presence of internal sources of pollution and rural/urban location of homes). However, the current monitoring design will be limited in its ability to establish more complex occupancy patterns or ventilation behaviour; as highlighted in the IAQ literature review carried out for HfNZ, more complex research requires additional internal monitoring (i.e., multiple rooms) as well as monitoring of external air quality.

RQ 4.4: What is the current level of air quality inside homes?

The median values from 69 living rooms in core trial households from April 2025 are shown in Table 6. They provide an overview of various metrics of air quality. Several factors affect air quality – primarily proximity to sources of pollution inside and outside the home that data has not been collected for, yet - that make interpreting these data and commenting on whether they are in line with expectations, or not, a difficult task.

Table 6: Statistical summary of available pollutant data in April 2025 for 69 sensors in core trial household living rooms

Pollutant	Limit ⁴⁵	Mean	Standard Deviation	Median	Interquartile Range	Outlier filter
Carbon Dioxide (ppm)	N/A	655	129	576	423	300 <value <3000 ppm

⁴⁵ WHO Air Quality Guidelines (2021)

Humidity (%RH)	N/A	50.3	6.8	50.2	12.9	10% < value < 100%
Particulates (PM1.0) (ug/m3)	N/A	5.30	5.3	1	5	0 < value < 500
Particulates (PM2.5) (ug/m3)	15µg/m ³ (24hr mean) 5µg/m ³ (annual mean)	6.86	5.8	2	6	0 < value < 800
Particulates (PM10) (ug/m3)	45µg/m ³ (24hr mean) 15µg/m ³ (annual mean)	7.64	6.8	2	6	0 < value < 800
VOCs	N/A	94.8	15.3	73.4	113.2	value < 2000

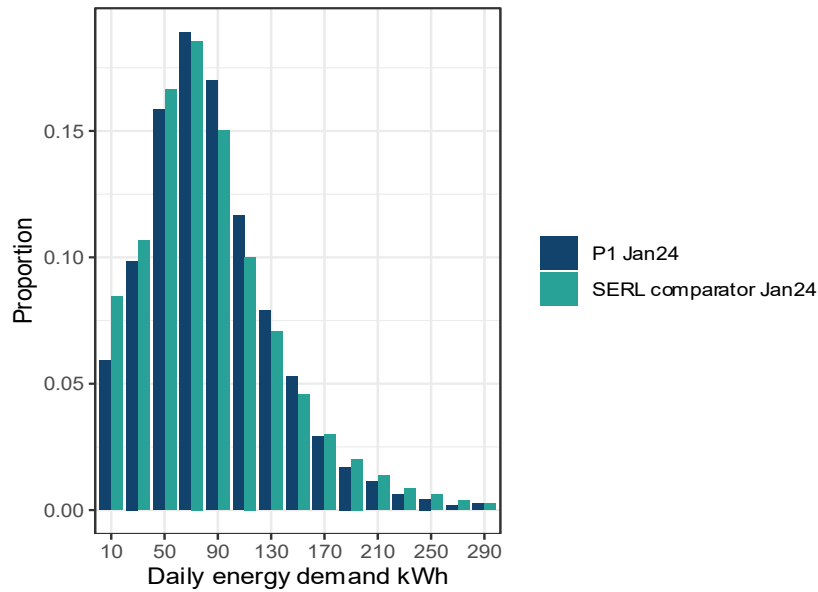
3.7. Trial profile

A number of research questions assess the profile of the homes in the trial, in respect to their energy use and awareness of Net Zero. A research question pertaining to the representativeness of the sample, in terms of occupancy, construction type, EPC rating and heating system details, was covered in 2.2.5.

RQ 3.1: What is the current distribution of energy consumption in homes within the monitored sample?

Figure 34 shows distribution of daily demand for January 2024, the month with highest heating energy demand in winter 2024/25. The distribution for the core trial households is very similar to the SERL comparator group.

Figure 34: Distribution of daily energy consumption for January 2024 in core group (N=850), compared to SERL observatory comparator group (N= 1,400), counts less than 10 suppressed



RQ 3.2: How does the energy consumption of the trial homes compare with a representative sample of homes?

Figure 35 and Figure 36 show mean daily demand each month during winter 2023/34 and winter 2024/25 for the core trial households and SERL comparator group. The means are very similar in the first winter while usage in the core trial households is slightly higher than the SERL comparator group in the second winter. There is no known reason why this should be the case.

Figure 35: Mean monthly energy demand for core homes and SERL comparator group, November 2023 to March 2024

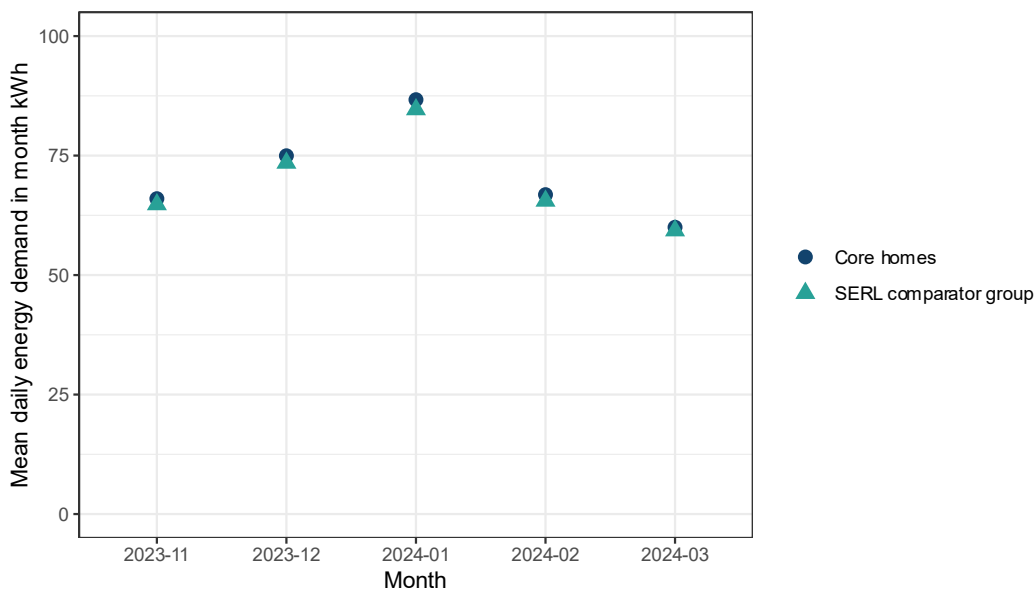
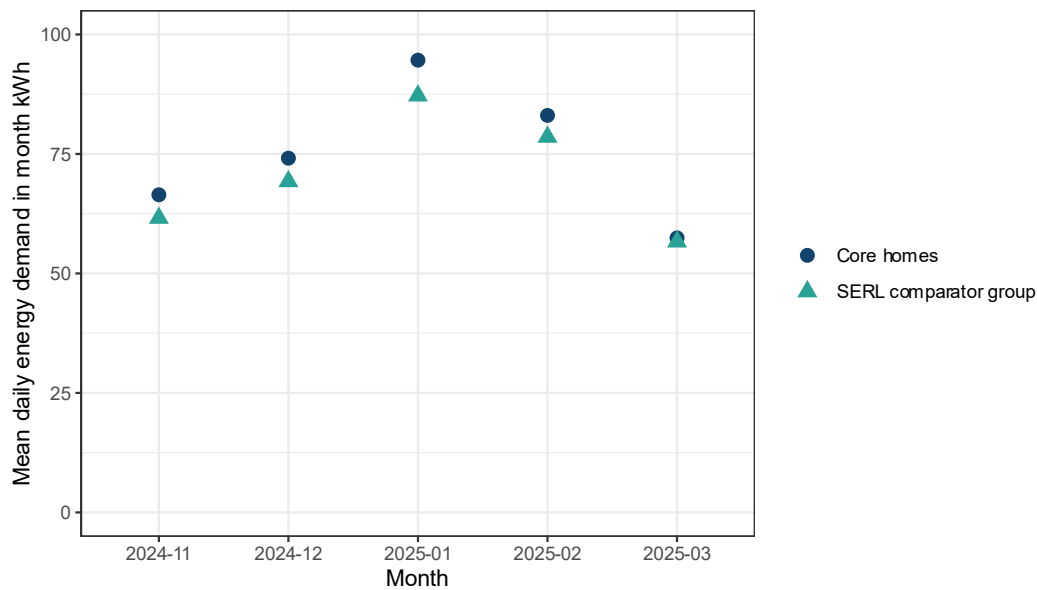


Figure 36: Mean monthly energy demand for core homes and SERL comparator group, November 2024 to March 2025



RQ 3.4: How do the trial participants compare to the wider population? Including:

- **Interest and awareness of climate change and Net Zero policies**
- **Age, gender, income level, education level, language**

Representativeness of sample (core trial)

Householders enrolled in the core trial were compared with the wider population using the Census 2021 datasets⁴⁶ (last updated on 15th January 2024).

- The survey sample consists of 68% males ($n=449$) and 32% females ($n=214$), which, compared to the wider population, is over-representative of males.
- The distribution of ages within the sample is aligned with the wider population, with slightly less representation of those aged 65 and over.
- Of the householders in this trial, 21% reported having a health condition or a disability, compared with 31% across England and Wales.

Although gathered using a different mechanism, the median household income in the sample is between £50,001-£75,000, compared to around £50,000 in England and Wales⁴⁷.

Awareness of climate change and Net Zero policies (core trial)

At the outset of the project, households in the core trial answered questions seeking to understand their awareness of Net Zero:

⁴⁶ Trial participants have been selected from across the UK, compared to Census data which has mainly been collected from England and Wales.

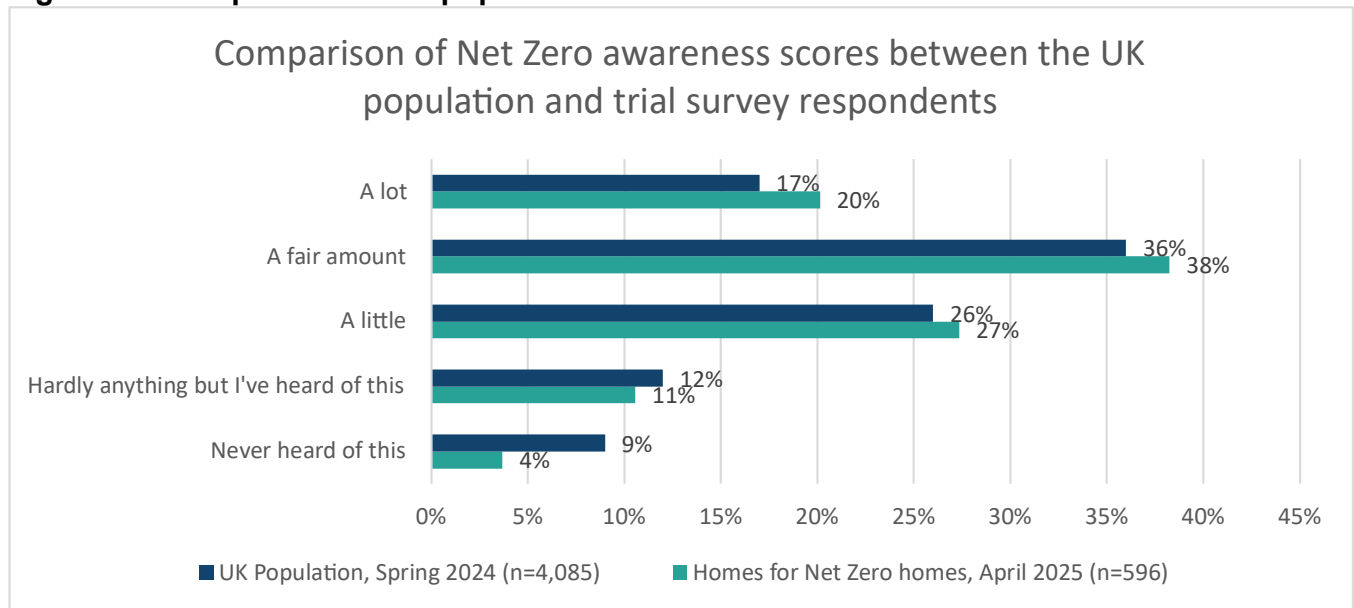
⁴⁷ Gross salary before tax calculated based on the median disposable income in the UK being £34,500 in [2023](#).

- Almost 3 in 4 respondents (71%) agreed or strongly agreed that they could “confidently explain to someone who was unfamiliar what is meant by the phrase ‘Net Zero’...”.
- 67% of respondents agreed or strongly agreed that they were aware of different ways they could adapt their property, or behaviours, for their home to be Net Zero compatible.
- 23% of respondents agreed or strongly agreed that they have a clear plan on what they will do to prepare their home for Net Zero.

Based on these answers, an overall awareness score was derived using the modal value. A majority (63%) of respondents displayed high levels of Net Zero awareness according to answers to these questions.

This survey was followed up in April 2025, and questions from the DESNZ Public Attitudes Tracker: Net Zero and climate change⁴⁸ were used to re-assess interest and awareness. Figure 37 provides a comparison of responses from the UK population ($n=4,085$) with responses from core trial householders ($n=596$). Core trial householders are more likely to report that they have ‘a lot’ or ‘a fair amount’ of awareness of Net Zero, and less likely to report that they have ‘never heard of’ or ‘heard hardly anything’ about Net Zero, when compared to the UK population.

Figure 37: Comparison of UK population and core trial householders' awareness of Net Zero



Awareness amongst those that received a roadmap

Of the 596 responses to the survey questions about Net Zero awareness, 86 were from those who had received a roadmap. Overall, there was a shift in Net Zero awareness scores from ‘Lower’ to ‘Higher’ across the whole cohort from when they entered the trial to when they completed the second trial survey in April (proportion classified as higher at the start = 57%, proportion classified as higher in April = 66%; $Z=-2.2$, $p<0.05$, $n=596$), suggesting that since joining the trial, the trial cohort’s awareness of Net Zero has increased.

⁴⁸ <https://www.gov.uk/government/statistics/desnzs-public-attitudes-tracker-spring-2024/desnzs-public-attitudes-tracker-net-zero-and-climate-change-spring-2024-uk#awareness-of-net-zero>

Due to a difference in the way Net Zero awareness was evaluated for those with electric vs gas heating⁴⁹, it isn't possible to directly compare the change in Net Zero awareness between the two cohorts, and sample sizes are too small. However, we did see a 19% increase in Net Zero awareness from 'Lower' to 'Higher' of those in gas heated homes who received a roadmap (from 54% to 73%, $n=56$), in comparison to a 10% increase in Net Zero awareness scores (from 57% to 67%, $n=510$) amongst those in gas heated homes who did not, suggesting the roadmap may have an impact, though a larger sample would be required to verify this.

RQ 6.5: What are the costs of (a) installing, maintaining and (b) operating heat battery systems?

Installation and maintenance costs

Noting the participant and home archetypes outlined within Section 2.2.1, Table 7 provides a summary of installation and maintenance costs for the three heat battery systems.

Table 7: Installation and maintenance costs for three heat battery types and ASHP counterfactual

	tepeo ZEB	Eskimo Clive	Sunamp Thermino xPlus/ePlus	ASHP Counterfactual
Cost basis	Unit costs are retail prices. Installation costs are based on actual installations but not necessarily those on the trial. All costs include VAT.	All costs are estimates for when product is available on retail. Noting that prototyping costs are higher. All cost estimates include VAT.	Unit costs are retail prices. Installation costs are both Sunamp and 3 rd party contractor estimated costs. All costs and estimates include VAT.	MCS Data dashboard – 2024 average for capital costs. Estimated maintenance cost based on anecdotal evidence.
Unit Cost x No. of units (kWh size)	£6,000 x 1 (40 kWh)	~£300 x 4 ~ £1,200 total (10 kWh total)	£2,590 x 2 = £5,180 total (24 kWh total)	-

⁴⁹ **Limitation:** the methods used to quantify awareness of Net Zero for gas and electrically heated homes were different. Whilst those in electrically heated homes use the Net Zero awareness question from the [DESNZ Public attitudes tracker](#), this question was not asked in the original baseline survey for gas heated homes. Therefore, the score for Net Zero awareness for gas home was calculated using a combination of 3 questions that participants answered in the baseline survey. The questions included their confidence in being able to explain Net Zero to others, their awareness of ways to adapt their homes, and having a clear plan on how to make their home Net Zero compatible. Although both gas and electric homes in the April survey answered the same Net Zero awareness question from the public attitudes tracker, the initial use of different measurement approaches introduces a non-equivalence of measures. This limits the comparability of the change in Net Zero awareness scores over time between gas and electrically heated homes, especially considering the larger observed increase among gas-heated homes.

Installation Cost	£2,200 - £7,500 (avg. £4,500)	~£1,000	~£3,770 - £7,270	-
Total upfront cost (unit and installation)	£8,200 - £13,500	~£2,200 plus cost of ASHP	~£8,950 - £12,450	£12,736 zero-rated for VAT.
Additional Requirements (excluded from installation costs)	Includes all central heating system components for the installation details provided. Excludes separate domestic hot water provision which would be required. Note that other systems may require additional home upgrades which are excluded here.	Includes heat batteries and related components only. Excludes domestic hot water thermal storage and heat pump system which would both be required.	Includes all system components for the system in the trial. Hot water provision is intrinsic within the system. Note that other systems may require additional home upgrades.	These costs should include all primary heating and hot water system components however, some contractors may exclude new radiators from costs.
Maintenance Cost	£149/year annual health check or £10/month care plan.	~£100/year plus heat pump maintenance	~£100/year	~£250/year

Operating costs

The data that tepeo shared with the project included a time series of electricity consumption and tariff information for each consumer. From this the electricity cost in each time period was calculated.

Simply aggregating the cost per time period over a whole month would underestimate the operating costs if there was missing data in that month. Therefore, the aggregated cost was multiplied by a correction factor, based on how much the monthly electricity consumption is underestimated due to missing time slices. The key assumption for that calculation is that regardless of whether electricity consumption is high or low in a time slice, the likelihood of that time slice being missing is not impacted.

Figure 38 shows the distribution of costs for the ZEB's electricity consumption by season. This cost only covers the electricity used for heating, and not for other equipment such as pumps or fans. It is based upon the participant's actual tariff.

ZEB's which have a full year of cost data are represented in the category "annual." Noting that all electricity consumed by the ZEB is assumed to be metered grid electricity, and incurs a cost based on the supplier's electricity rate. This leads to errors in the cost calculation when the ZEB consumes electricity generated by solar PV. However, the estimate of the ZEB's total

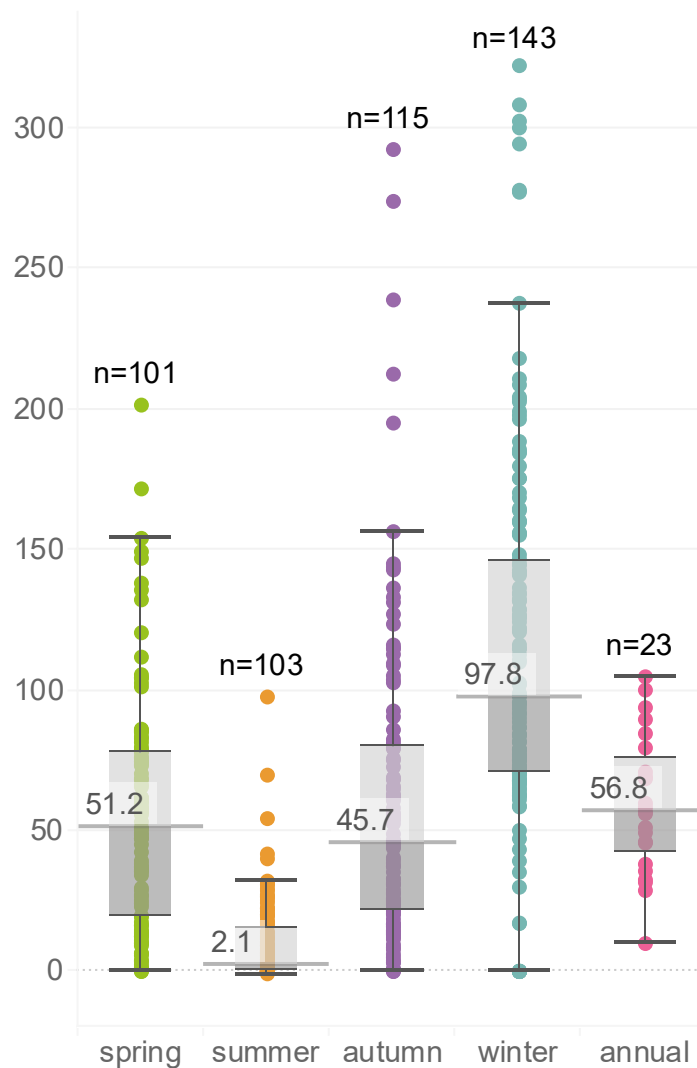
energy consumption is not affected by that assumption. The median annual costs are £682, averaging to around £57 per month. While the median costs in summer are very low (£2 per month), there are stark outliers (e.g., the calculation indicates one participant paid £98 in June 2024). These high costs are likely caused by suboptimal operation of the ZEB, likely by less cost-sensitive participants (or those with solar PV).

The seasonal values demonstrate a very high range in operating costs (particularly in Winter). This is likely due to home archetype, monthly weather variation, and some participants being more cost-sensitive than others.

Ten ZEBs are excluded from the cost calculation. These households participated in the Neat Heat trial⁵⁰ with OVO Energy and UK Power Networks. For these homes, the tariff information does not reflect the actual price paid by the consumer, but instead it was used as a charging signal during the trial. In some time periods, the electricity consumption logged by the ZEB is reported as having a small negative value, which is likely caused by historical calibrations for electricity consumption. These values were regarded as zero electricity consumption.

⁵⁰ <https://www.tepeo.com/neatheat/>

Figure 38: Operating costs for tepeo ZEB by season (£/month)



Costs savings

In addition to calculating the operating cost, cost savings have been calculated against direct acting space electric resistance heating (DASH), gas boilers, and Air Source Heat Pumps (ASHPs). These are provided as annual figures. The calculation subtracts the ZEB’s actual operating cost from the calculated operating cost of providing “equivalent heat output.” To calculate the operation cost of the counterfactuals, Ofgem’s price cap at the time of operation for Single-Rate Metering Arrangement and a direct debit payment method was used.

In some homes the ZEB is used to provide hot water, while others use an alternative heat source for hot water such as an immersion heater. To make these costs comparable, 6.25 kWh are added to the daily heat demand of those consumers that use alternative hot water sources. This number is based on a typical annual value of 2,281 kWh.⁵¹

⁵¹ Domestic hot water use in the UK – DESNZ March 2024, accessed via: <https://www.gov.uk/government/publications/domestic-hot-water-use-in-the-uk>

To estimate the electricity consumption of DASH, we assumed it would have an efficiency of exactly 100%.

To estimate the electricity consumption of an ASHP, we assumed it would have an SPF of 2.89 as per the values found by the DESNZ Electrification of Heat Demonstration Project⁵². The efficiency boundary we assume is H₃, explained on p.51 in the same report. This boundary includes immersion heaters and all the heat pump's heat output but does not include auxiliary equipment like circulation pumps (equivalent to the heating system components included in the ZEB's electricity consumption measurements).

To estimate the gas consumption of a boiler, we have assumed it would have an efficiency of 84% which is an average between different boiler types in the Government's condensing boiler monitoring trial⁵³ to represent the stock average.

For all counterfactuals, we have considered two separate ways to define the "equivalent heat output":

- In the "heat generation" basis, the counterfactual heating technology is required to provide heat output corresponding to all the electrical energy that enters the ZEB. (i.e. this basis assumes that all the energy that enters the ZEB remains within the thermal envelope of the home and contributes to thermal comfort.)
- In the "heat delivery" basis, it is assumed that the heating technology is only required to provide the heat that the ZEB outputs and enters the heat distribution system (radiator circuit). The ZEB's heat output is measured as the flowrate times the temperature difference of outgoing and return water.

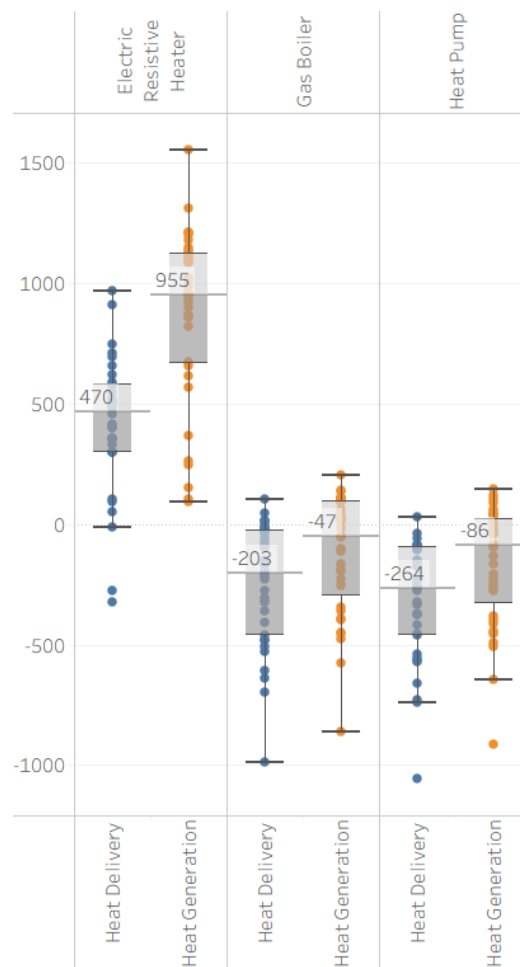
Neither of these is perfect and the true counterfactual energy consumption for the trial participants is likely to be between the two, nearer to the "Electricity in" method for this cohort.

The results are provided in Figure 39. Note that a negative 'savings' value indicates that the ZEB costs more to operate than the counterfactual.

⁵² Electrification of Heat Demonstration Project - Insights from Heat Pump Performance Data, Energy Systems Catapult, accessed via: <https://es.catapult.org.uk/report/electrification-of-heat-summary-reports-and-datasets/>

⁵³ Final Report: In-situ monitoring of efficiencies of condensing boilers and use of secondary heating, Energy Savings Trust, accessed via: https://assets.publishing.service.gov.uk/media/5a75149be5274a3cb28697f7/In-situ_monitoring_of_condensing_boilers_final_report.pdf

Figure 39: Annual cost savings by heating technology (£/annum)



When compared annually using the current tariffs, the ZEB almost always provides cost savings when compared with DASH. In the median, the ZEB is more costly to run than heat pumps or gas boilers, but only slightly so in the heat delivery accounting method. In that case, the ZEB is cheaper than a gas boiler in 39% of the months and the cost difference disappears for consumers on EV tariffs. Further analysis on running costs and the impact of different tariffs is explored in the Summer 2025 report⁵⁴

The fact that the “Heat delivery” method produced lower savings evidences the importance of ZEB install location. Whilst in most cases, savings are still seen (vs. DASH), if the heat is lost to atmosphere, there will be negative impacts on bills (Note: ZEB heat output is under-represented and tepeo estimates efficiency would increase by 3% if corrected).

RQ 6.1: What is the occupant’s lived experience with heat batteries? Do they provide required comfort when needed? Are they easy to operate and control?

The same questionnaire sent to heat battery participants upon conclusion of recruitment was used to ascertain lived experiences with heat batteries, made possible by recruiting

⁵⁴ Add reference to Summer 2025 report

households who already had the technology installed before joining the trial. As noted previously, 43 of the 50 participants with a tepeo heat battery completed the survey.

Disruption

The majority of respondents (80%) found that there was no disruption or only slight when installing their ZEB.

- Of those who cited some disruption, the most common issues were:
 - The time taken to install the ZEB (17%).
 - Negative impacts on comfort levels during installation (17%).
- Half of the respondents provided written descriptions of the disruption, these included:
 - Having several people in the home for prolonged periods.
 - Changes to ancillary equipment like pipework.
 - Needing to redecorate.
 - Minor disruption like moving furniture or avoiding areas of the home.

Satisfaction

Overall, homeowners are satisfied with their home heating, with the majority praising the new ZEB system. The top benefits selected by users were:

- Environmentally friendly
- Low maintenance
- Long lifespan

Most participants reported that their ZEB was easy to use, and nearly all participants agreed that the ZEB met their overall expectations, highlighting the technology's positive impact on modern home heating.

Comfort

After installing a ZEB, 91% of homeowners now enjoy comfortable warmth throughout their homes, with 93% experiencing on-demand comfort when needed. A closer look shows that 91% feel cosy in their living rooms and 71% in their bedrooms. More participants felt always or mostly warm (91% after, 87% before) after ZEB installation. However, some homeowners have reported a decrease in their ability to stay warm. Fewer people now feel “always warm,” (40% before, 21% after) and fewer can consistently achieve comfort in both bedrooms and living rooms. Half the respondents highlighted three key issues with their ZEB:

- Does not provide enough heat

-
- Occupies too much space
 - Take too long to charge

Some users noted that on cold days the battery requires frequent recharging or boosting, often during peak hours, so resulting in higher costs. Some found it challenging to find a tariff that aligns with their energy consumption. Homeowners in larger properties, particularly four and five-bedroom houses, found the system struggled to keep their homes adequately warm. Also, participants perceived that the lack of integration of the tepeo product with solar panels limits the ability to realise increased cost savings.

RQ 6.2: How effective are heat batteries at storing and discharging required levels of heat⁵⁵?

To evaluate how effective heat batteries are, in-use, we analysed the following four things:

- Duration of substantial charge events
- Duration of substantial discharge events
- Use of the boost function
- Heat battery heat loss

Substantial charge events were defined as an event where the heat battery charged by 20kWh or more (half of its maximum capacity) within 8 hours. Substantial discharge events were defined as an event where the heat battery discharged 10kWh or more (one quarter of its capacity) within 8 hours. This is because, it is rare for heat batteries to fully charge or discharge within one cycle.

Use of the boost function may be indicative of the heat battery not providing enough energy for the heat requirements of the home. There may be many reasons for this. To analyse use of the boost function, we relied on consumer survey data.

One of the most important features of effective heat battery operation are its ability to store heat. This is why we considered heat loss from the heat batteries. Heat loss is non-linear, so we used the monitored energy data to estimate the instantaneous heat loss from the heat battery relative to the amount of energy stored. We then used all of these heat loss values to produce a simulation of the ZEB heat loss, beginning at full charge down to full discharge, assuming that no energy is discharged into the heating system. This simulation was used to estimate the amount of energy which would be left in the ZEB at given time intervals.

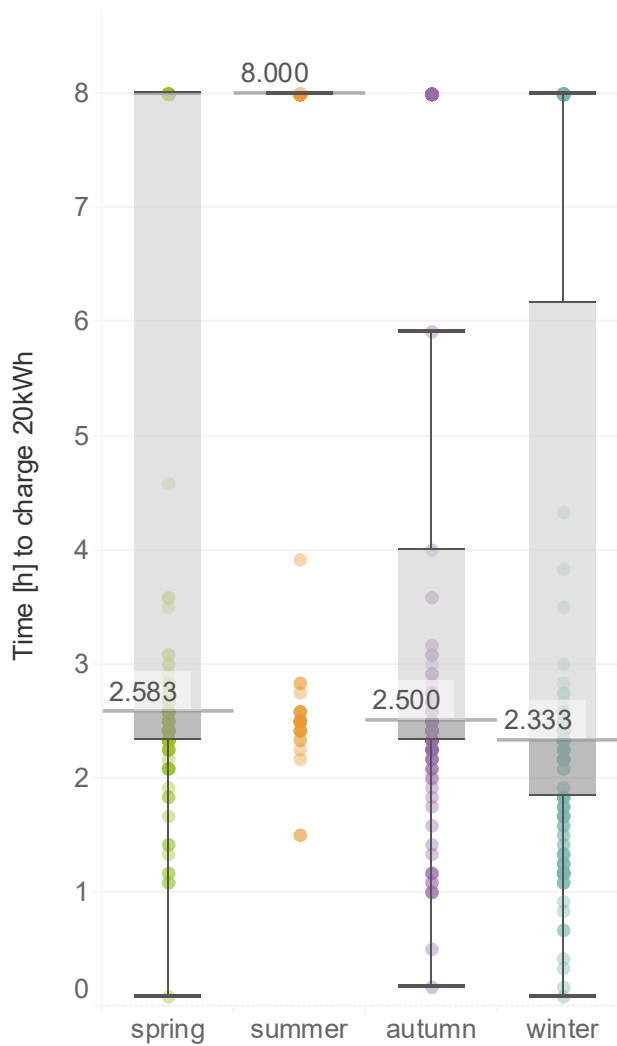
Duration of substantial charge events

The ZEB can store 40 kWh of heat. However, in homes, they rarely charge or discharge the full store within one cycle. Figure 40 shows a point for the shortest time it took to charge each ZEB by 20 kWh within each month these points are bucketed per season. If a ZEB did not charge by 20 kWh within 8 hours, the charge time is labelled as 8 hours.

⁵⁵ Only data for the tepeo ZEB is included in the analysis, due to the very small (each is n=1) sample sized for the other two types of heat battery included in the trial.

The time to charge 40 kWh reported by tepeo is 4.5 hrs, the time to charge 20kWh is therefore around 2.25 hrs. This is achieved if the ZEB constantly charges at the maximum possible electricity input of 9 kW. The median of the shortest time taken to charge 20kWh in winter was between 2.25 and 2.5hrs which is as expected and confirms the manufacturer’s claims of a 9-kW charging power are accurate.

Figure 40: Duration of substantial charge events



This indicates that the ZEB can fully charge well within an ordinary (Economy-7) Time-of-use-tariff off-peak timeframe and offers some flexibility for other tariffs with shorter or less rigid off-peak periods.

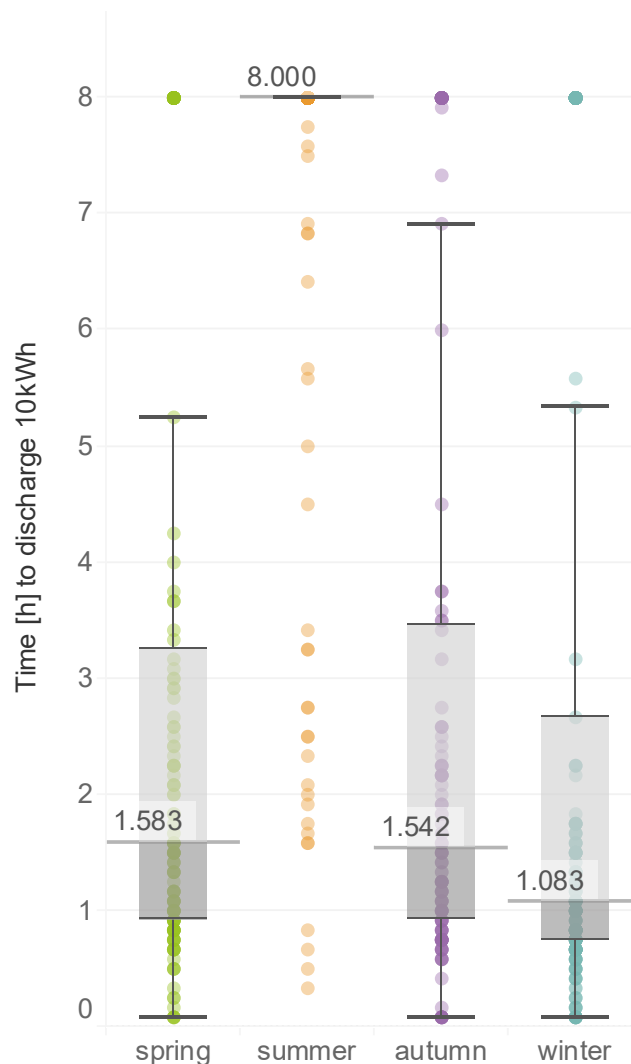
Duration of substantial discharge events

Discharging tends to happen in shorter events than charging. This is why the graph (Figure 41) shows shortest time to discharge 10 kWh. If a 10kWh discharge did not occur within 8 hours, the discharge time is labelled as 8 hours.

The maximum possible rate of discharge quoted by tepeo is 15 kW which would allow 10 kWh to be discharged in 45 minutes. The analysis shows that the ZEB can discharge 15 kW for a sustained period when it is needed, confirming the manufacturers claims.

However, for trial homes across most of the year, the 15-kW discharge is not necessary. This is reflected by the median winter discharge time being around 1 hour 5 mins. This is reflective of flexibility in the rate at which the ZEB discharges heat.

Figure 41: Duration of substantial discharge events



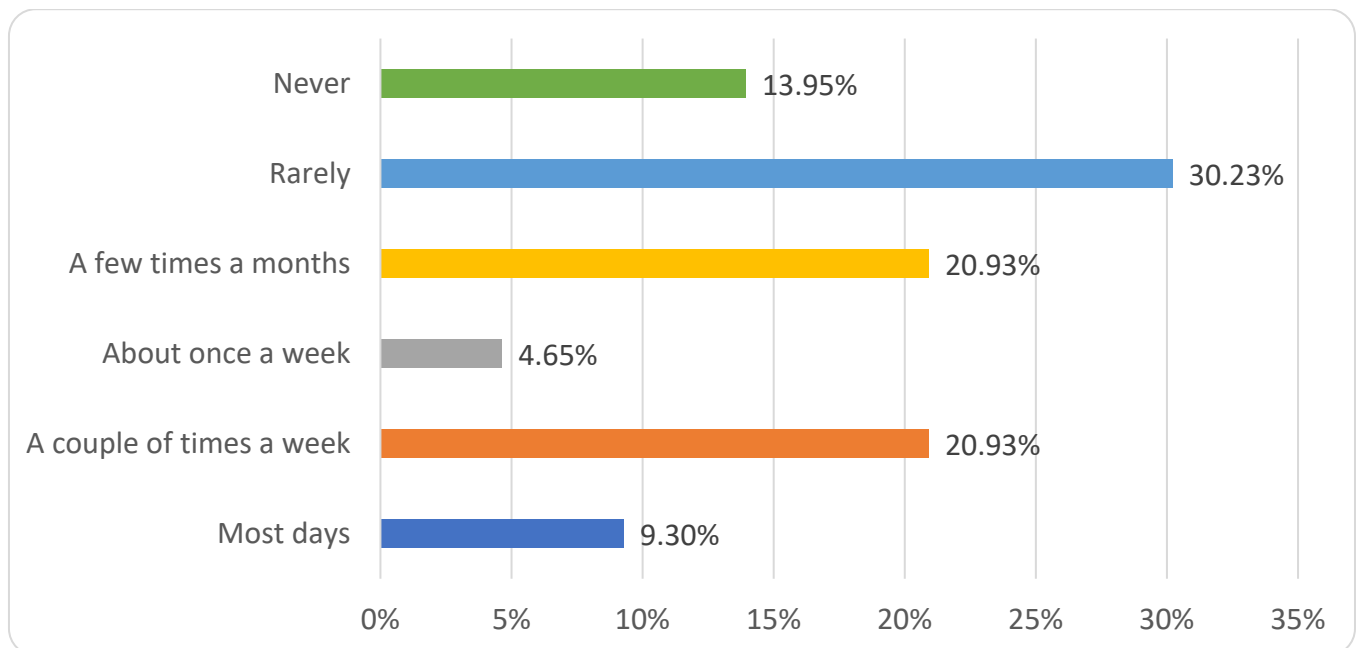
Boost function

The tepeo ZEB offers a boost charging feature designed to provide additional heat into the heat battery when a customer desires. While many homeowners rarely rely on this function, one in three reported finding themselves using it at least a couple of times a week during the winter months, highlighting boost charging as an important feature for some participants to control the heat battery as they wish (see Figure 42).

This is potentially indicative of undercharging or full utilisation of the available charge during the day. It may also be indicative of participants taking advantage of cheaper within-day tariff periods. Excessive use of the boost function may add to cost for the consumer if it is used in peak periods. tepeo analysis suggests that the 'boost' function is used most frequently by

those who use custom charging, and across the whole cohort of participants, it has accounted for 2% of total charge (kWh) during the trial period to date.

Figure 42: Frequency of use of boost function



Heat battery heat loss

The effectiveness of heat batteries at storing heat can also be measured by how much heat they lose to their environment. As the ZEB heat storage is mostly sensible, the heat loss varies based on:

- the period of time between charging and discharging the stored energy,
- the frequency that the ZEB is 'overcharged' (charged overnight with more energy than is needed the following day), and
- the extent of that overcharging.

The risk of high heat loss is amplified in properties where a custom charging strategy is chosen and the weather is milder, as the ZEBs are more likely to overcharge. 'Undercharging' (charging less heat than is needed the following day) is also a concern and is reflected by the 'boost' statistics above.

Heat loss varies based on heat battery temperature and the ZEB core has a large useful temperature range (80°C - 800°C), thus the rate of heat loss will vary significantly. The Catapult has used the operational trial data to model the heat loss of the ZEB at different core temperatures. It has then used these models to estimate how much stored heat the ZEB will retain, if unused for a prolonged period.

The simulation estimates that a fully charged ZEB will retain:

- 65% of its useful heat after 24hrs
- 45% of its useful heat after 48hrs

-
- 33% of its useful heat after 72hrs

By way of comparison, the standard for High Heat Retention Storage Heaters is to retain 45% of their useful heat after 16hrs.

3.7.1.RQ 6.3: How efficient are heat battery systems in-use?

For heat battery systems, we have considered the efficiency as the ratio of energy input to useful energy output; the energy input is the electricity consumed by the heat generator, however the due to the heat losses from the heat battery into a property's thermal envelope, there are two potential definitions for 'useful energy output':

- The amount of heat entering the property's thermal envelope
- The amount of controlled heat entering the heat distribution system

This leads to two potential definitions of 'efficiency':

- **Heat generation efficiency:** heat entering the property's thermal envelope divided by the electricity consumed
- **Heat delivery efficiency:** heat entering the heat distribution system divided by the electricity consumed

Heat generation efficiency represents purely the efficiency of the heating element, provided that the heat battery is located inside the property's thermal envelope. Heat delivery efficiency is the efficiency of the heat battery as a storage device. Note that the Standard Assessment Procedure (SAP) for the energy rating of dwellings uses the equivalent of the heat generation efficiency if the product is installed within the thermal envelope.

This project has not measured heat generation efficiency. However, as the ZEB uses electric resistance heaters, the value is assumed to be 100% under all circumstances.

The annual median heat delivery efficiency is 70%; the median seasonal heat delivery efficiency is 76% in winter, 64% in spring, 63% autumn and 43% in summer (see Figure 43). The summer value has little bearing on overall efficiency due to the low relative energy consumption and low sample size in summer months. The variance is lowest in winter and highest in summer as heating is less consistently used across the cohort in the summer. Due to a known heat meter issue, the ZEB heat output is underreported and tepeo estimates average efficiency would increase by 3% if corrected.

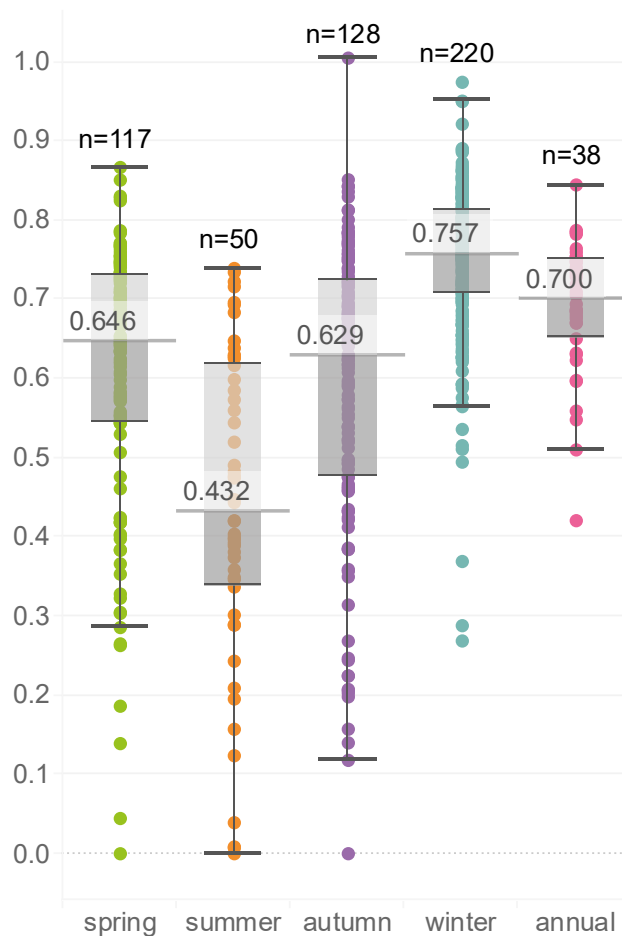
Understanding the variance in efficiency

The conversion from electricity to heat is essentially 100% efficient because there are no physical intricacies influencing the heat delivery efficiencies as is the case for heat pumps or gas boilers. Instead, heat losses are caused by both time delays between charging and discharging as well as the ZEB charging more heat than that which is required within the next day. The more heat that is required the less likely this is to happen, explaining why the efficiencies are lowest in summer (i.e., sometimes efficiency is zero when the ZEB is charged, but heat dissipates until it is fully discharged) and highest in winter.

tepeo has informed the project team that in ‘custom’ charging mode, users typically set a higher target state of charge than smart charging would decide, tolerating higher running costs for greater control.

In winter, the effects of suboptimal charging profiles are less pronounced, as a high proportion of the heat charge is typically utilised within a day. However, in summer a fully charged ZEB may remain unused for several days, resulting in greater heat loss and an increased variability in heat delivery efficiency.

Figure 43: Heat delivered efficiency by season for tepeo ZEB⁵⁶



RQ 6.6: What additional systems are required when using heat batteries e.g. secondary heating?

To fully understand the performance of heat batteries, an assessment of additional systems (e.g., secondary heating) required by householders was included. The aforementioned survey that 43 of 50 participants completed was used to assess additional system needs.

Nearly two-thirds of respondents (63%) used additional devices, most commonly in the living room. Half of those who had used additional devices had used a wood burning stove, and

⁵⁶ The annual category uses one point per ZEB per year. Seasonal categories include one point per ZEB per month (within the season), n is the number of points in each category.

nearly half of the homeowners (47%) used additional heating about the same as before. This suggests that for some, the use of additional heating is a preference, or a system led issue not introduced by the ZEB, however one-in-four found themselves reaching for heating devices more often since installing the ZEB. In some cases, participants told us this was to avoid using the ZEB's boost function. One-in-four noticed they needed their heating devices less frequently.

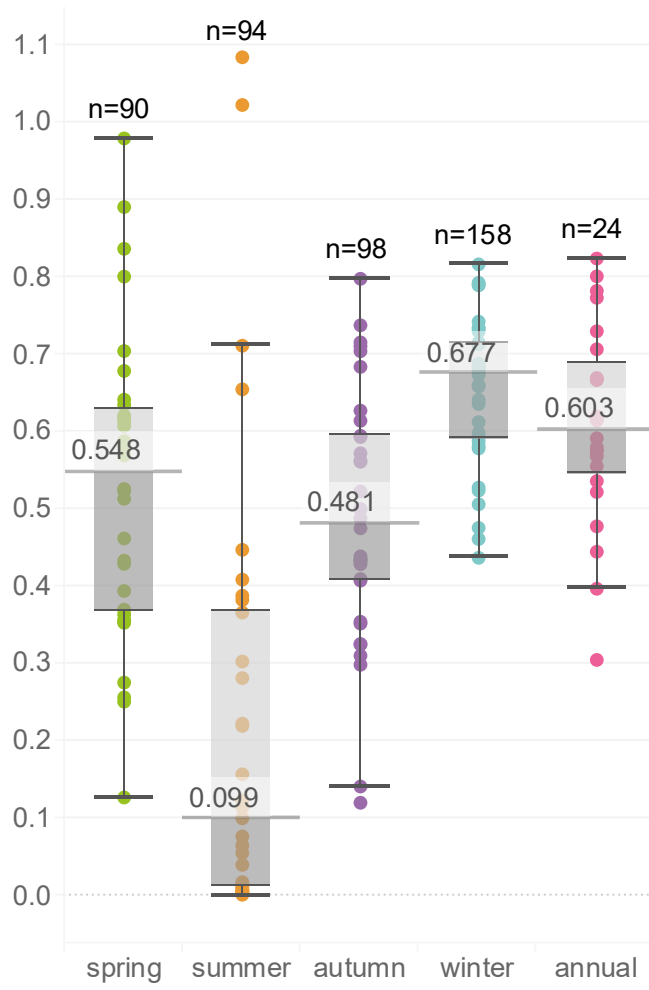
RQ 6.7: What proportion of a household's total electricity demand do heat batteries account for?

On an annual basis, the ZEBs consumed 60% of the overall metered grid electricity consumption. The median ZEB consumption was more than 50% of the metered home electricity in spring (55%) and winter (68%). It consumed almost 50% in autumn (48%) and only around 10% in summer. By comparison:

- a typical UK 3-bedroom household's energy use is around 80% gas and 20% electricity.
- around 77% of the gas consumption is used for heating whilst the remainder is used for hot water (which is often not provided by the ZEB) and cooking.

Using these benchmark figures, the analysis undertaken would model the ZEB's electricity use to be around 61% of the home's total annual electricity demand. Note that 15 of the participants indicated their hot water is provided by the ZEB. So, the true value expected is slightly higher. Note also that this does not account for self-consumption of renewable energy and some of the participants have indicated that they have solar PV (hence values above 1). Figure 44 provides a summary by season.

Figure 44: Proportion of household electricity use consumed by the tepeo ZEB



4. Conclusion

This interim report has described progress in the HfNZ project, the two trials in the project, and the many activities that are already taking place or due to commence soon.

The amount of activity and timescales for delivery are the biggest challenges facing the project, as the project requires the recruitment of ~1,200 homes, installation of over 3000 items of monitoring equipment, upgrading the performance of around 350 homes, behavioural measures with around 150 householders, and collection and analysis of a plethora of data.

Recruitment has been challenging due to the strict eligibility criteria used to select homes, and low level of incentive offered to attract households to a research trial. The eligibility criteria have been used to ensure the types of homes and/or heating systems that are of interest to DESNZ are recruited to the projects, whilst also allowing for practical considerations such as geographical location. Whilst some households are keen and willing to participate in research with a view to developing evidence bases and informing government policy, others typically expect more compensation for their time and efforts or join only in the hope of having measures installed.

Some installations of measures have proved difficult due to some householders already having taken action to improve their home, or the complex nature of the permissions required before an installation can be agreed (i.e., RAAHP). Other installations, for example the heating MOT+ measure have proved both popular with householders and easy to identify homes suitable for the measure. Behavioural measures have commenced, with baseline surveys and surveys on coping in extreme weather conducted, as well as a piloting of tailored roadmaps.

Initial analyses of data against some of the project's research questions has begun to provide an insight already; however, these should be treated as 'initial', and most (all but one) will be superseded by future analyses.

In the remainder of the project's timescales, primary activities include finalising recruitment alongside installation of further measures for the AEH trial, and continued monitoring and analyses for both trials.

Appendices

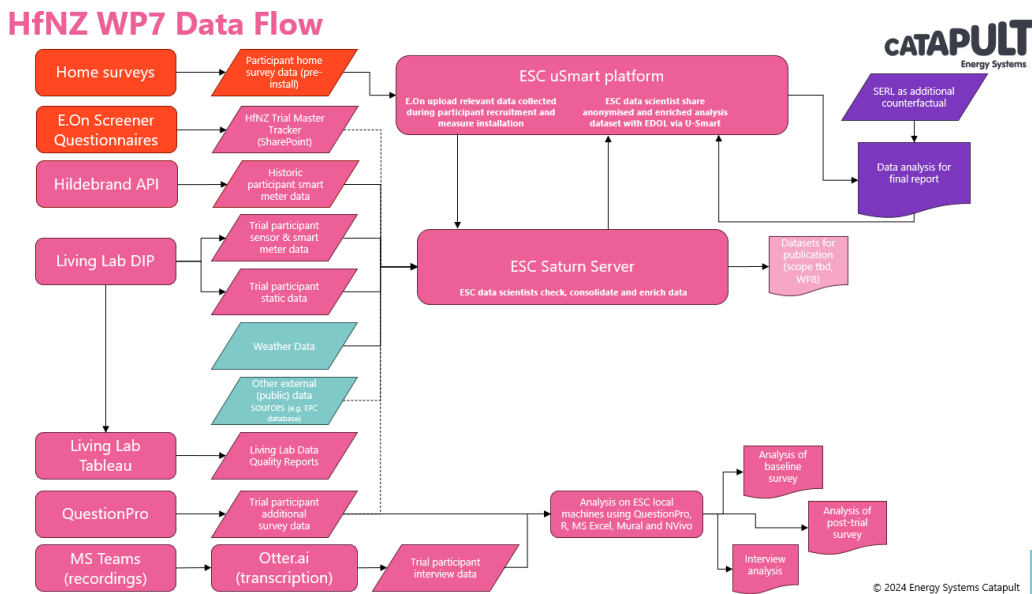
Appendix 1: List of research questions

Trial	Research Question ID	Research Question
Core	1.1	What are the energy savings of individual measures?
Core	1.2	What are the energy savings of different packages of measures?
Core	1.3	Are initial energy savings maintained over time?
Core	1.4	What is the cost of delivering individual measures?
Core	1.5	What is the relative cost of delivering individual measures vs packages of measures?
Core	1.6	How long will it take for measures to pay back?
Core	1.7	What additional benefits do measures provide?
Core	1.8	Have measures led to comfort taking (increasing either the time or temperature homes are heated following improvements to energy efficiency)?
Core	1.9	Have measures led to improvements in occupant comfort?
Core	1.10	Do improved controls lead to higher mean internal temperatures?
Core	1.11	How disruptive did consumers find the installation of the measures? Would this impact them choosing these measures if they were paying for them?
Core	2.1	What impact can simple, low-cost measures have on the cost and suitability of homes to install low carbon heating such as heat pumps?
Core	2.2	Which measures, of those offered, are more or less attractive to consumers?
Core	2.3	Are there other measures, not offered, that consumers are interested in installing?
Core	2.4	What are the measures that most homes can take to put them on the path to a Net Zero compatible home?
Core	2.5	Which of these measures are most effective and should be prioritised?
Core	2.6	What is the opportunity for incremental improvement compared to whole house retrofit?
Core	3.1	What is the current distribution of energy consumption in homes within the monitored sample?
Core	3.2	How does the energy consumption of the trial homes compare with a representative sample of homes?
Core	3.3	How does the sample of trial homes compare to the wider population of England and Wales in terms of: - Occupancy - Tenure - Level of energy efficiency - Heating systems - Construction
Core	3.4	How do the trial participants compare to the wider population? Including: - Interest and awareness of climate change and Net Zero policies - Age, gender, income level, education level, language
Core	4.1	What is the current level of overheating according to recognised definitions in sample homes?
Core	4.2	What is the perceived level of overheating in sample homes?
Core	4.3	What measures are occupants taking to manage overheating?

IAQ	4.4	What is the current level of air quality inside homes?
IAQ	4.5	What factors influence indoor air quality (IAQ) in homes in the trial? Including but not limited to; behavioural, location e.g. proximity to external sources of pollution, internal sources e.g. wood burning stoves, cooking, ventilation, occupancy.
AEH	5.1	What are the costs associated with designing, installing, operating and maintaining RAAHP systems in homes? What additional technologies are needed to provide comfort and DHW requirements?
AEH	5.2	How are systems sized for heating and what cooling capacity does this provide?
AEH	5.3	How efficient are RAAHPs in providing space heating to homes when they are the sole space heating device and when in combination with other technologies?
AEH	5.4	How efficient are RAAHPs when providing cooling and is the capacity sufficient for occupant comfort?
AEH	5.5	What is the electricity demand profile for different system designs?
AEH	5.6	What factors led to consumers choosing to install a RAAHP system? How much of a factor was the ability to provide space cooling?
AEH	5.7	What is the occupant's lived experience with RAAHPs? o What are the comfort levels in cold weather? o Are they easy to control and use? o What are comfort levels in hot weather? o How is indoor air quality affected and how does this compare with homes that do not have space cooling? o Are there any issues with noise from the internal or external units?
Heat battery	6.1	What is the occupant's lived experience with heat batteries? 1. Do they provide required comfort when needed? 2. Are they easy to operate and control?
Heat battery	6.2	How effective are heat batteries at storing and discharging required levels of heat?
Heat battery	6.3	What proportion of heat demand is met by secondary heating in homes with heat batteries?
Heat battery	6.4	How efficient are heat battery systems in-use?
Heat battery	6.5	What are the costs of (a) installing, maintaining and (b) operating heat battery systems?
Heat battery	6.6	What additional systems are required when using heat batteries, e.g. domestic hot water (DHW) provision, secondary heating?
Heat battery	6.7	What proportion of a household's total electricity demand do heat batteries account for?

Appendix 2: Data flow

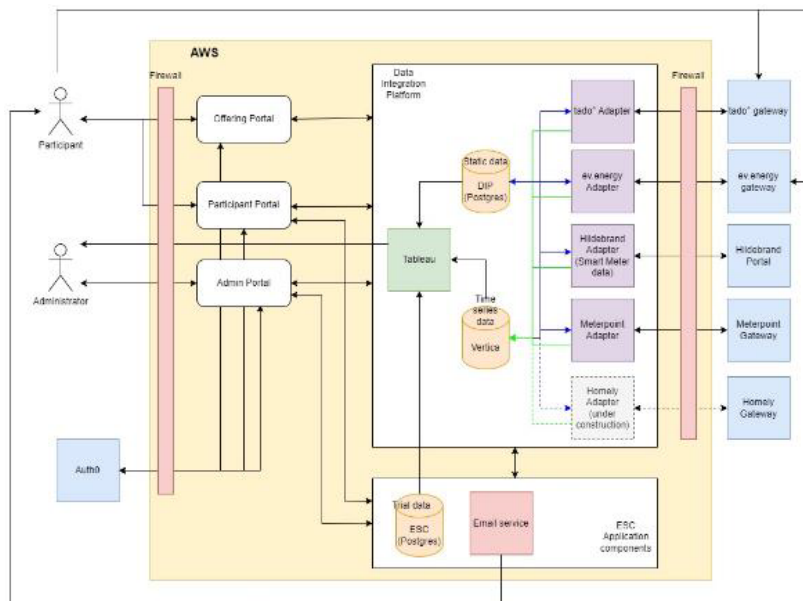
Figure 45: HfNZ data flow



Appendix 3: Living Lab and Tableau architectures

The following Figures depict the architecture of the Living Lab components, and the Tableau data sources and architecture.

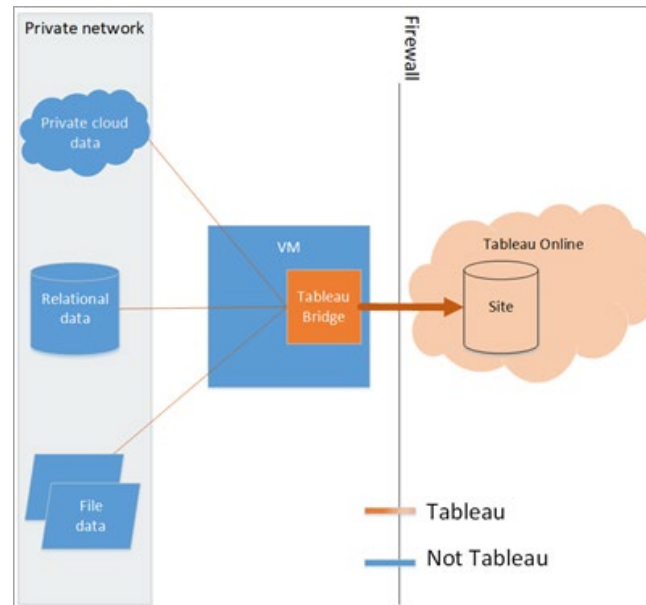
Figure 46: High level architecture of the Living Lab



Given the number of disparate data sources, creating a stable working HfNZ data source has been problematic with issues arising because of, for example, changes being made to spreadsheet structures, and new software releases by a third-party supplier disrupting data in a production table. These have been tracked on an individual basis as they have arisen, and

strict change controls have been put in place as lessons have been learnt. To give an indication of the level of complexity, refreshing Tableau data takes over an hour and so extracts are taken only three times a day (to maintain a balance between technical constraints and operational requirements over the number and status of sign-ups).

Figure 47: Tableau bridge architecture



Appendix 4: Recruitment Challenges

The first householders joined the core trial in March and April 2024; most of these who joined at this time were already in the Catapult's Living Lab. Recruitment was then through the routes managed by E.ON and described in section 2.2.2. Progress was initially slow. E.ON's initial screening to check households qualified required both an online form to be completed and a phone call between the householder and E.ON (to go through and check eligibility criteria) before inviting those who are eligible to join the trial. After several weeks of this approach to recruitment being live, the number of households who had joined the trial was fewer than 100. At this point the approach was adapted, with the initial screener phone call being replaced with an online form for applicants to complete in their own time before being checked by E.ON. Occasionally this still required a phone call, but this was only if an application was not clear or if a householder had provided information that contradicted information from another source (i.e., the Energy Performance Certificate (EPC) said the home had cavity walls, a phone call and / or street view was used to determine wall type).

Progress significantly improved and at the end of July 2024 the number of households who were in the recruitment and onboarding pipeline were considered sufficient to close all recruitment campaigns. However, by the middle of September, some of the conversions rates between recruitment stages were not as high as previously seen, and so a shortfall in the

number of households recruited was identified. Recruitment activities and campaigns were re-opened towards the end of September.

The full process of recruitment and onboarding householders required many sequential tasks to be completed, with requirements placed on the householder, or the Catapult, or E.ON. At each stage, not all households in the process always progressed to the next stage; sometimes they lost interest and stopped replying to requests, sometimes they could not progress due to technical difficulties (i.e., smart meters could not be linked).

The following lists these requirements sequentially:

- **Step 1:** Householder registers an interest in the trial with E.ON; as noted, this was initially via an online form and a phone call but was subsequently replaced with an online form only. E.ON checks applications and other sources (i.e., EPC) and invites eligible households to join the trial.
- **Step 2:** Before the householder joins the trial, they must first join the Catapult's Living Lab. Householder is sent an email inviting them to join the Catapult's Living Lab, a process that requires filling out a short survey.
- **Step 3:** Upon joining the Living Lab, householders were then allowed to ask to join the trial via the Living Lab's 'trials and offers' portal. During recruitment, it was found that this two-stage process (i.e., joining the Living Lab then asking to join the trial) was confusing, and so an automated process of enrolling householders onto the trial once they had joined the Living Lab was developed.
- **Step 4:** Upon joining the trial, householders were asked to link their smart meters to their Living Lab account. Whilst for many this was a straightforward task, for some it required support from the Catapult's Operations team, and/or the Catapult's smart meter data provider (Hildebrand).
- **Step 5:** Once a householder had successfully connected their smart meters, they were sent temperature and humidity monitoring equipment.
- **Step 6:** Upon receipt of monitoring equipment, householders created accounts and setup and connected the equipment.
- **Step 7:** Householders were then paid the first incentive payment.

A small number of households completed all the recruitment and onboarding steps and then subsequently asked to leave the trial. These households were not replaced and therefore account for the difference to the target of 1,000 joining the trial. Likewise, a small number of households completed all the steps up to and including Step 5, but then never setup their monitoring kit and did not return it, despite numerous requests. Because the number of monitoring kits purchased for the trial was 1,000, these households also cannot be replaced. They remain in the trial as they are providing data from their smart meters and have not asked to leave.

Many householders made it through some or all of steps 1 to 4 but left the trial before setting up their smart meters. These were *always* replaced and not considered to be enrolled

householders as they had not connected their smart meters and been sent monitoring equipment. The figures below highlight this attrition in recruitment:

- 4,676 completed an application for the trial but were found to be ineligible;
- 2,299 completed their application and were found to be eligible, but then never went on to create a Living Lab account;
- 614 created a Living Lab account and were accepted into the trial but never connected their smart meters to their Living Lab account and so were later removed (after several prompts asking them to connect).

Table 8: Methods utilised for recruitment of households into AEH trial

Method	Organisation	Type of Lead	Recruitment approach	Reach	Applications made	Homes provided	Tados issued
Recruitment methods as per original proposal.	Roots research	Recruitment agency	34 other recruitment companies 100,000 panel members 48,000 social media campaign	148,034	4,481	235	73
	Further Afield	Recruitment agency	15 other recruiters (thousands of leads)		295	102	67
Additional recruitment methods undertaken.	Catapult via Linked-in/Bluesky/X Post (February)	Social media		Impressions: 15,210 Clicks: 807 Engagements: 268		14	
	Paid for social media - Facebook	Social media		Impressions: 5,803,655 Reach 668,000 Clicks: 14,800	37	28	13
	Loco Homes	Retrofit organisation	Membership of around 300 homes - three blocks of flats, newsletter reaching approx. 700, plus blanket leafletting of known suitable buildings			4	
	Federation for Private Residents Association (FPRA) first engagement	Industry Body	e-shot issued to members	460 members (includes resident management companies, a few MPS)			
	FPRA Newsletter	Industry Body	Newsletter issued	460 members (includes resident management companies, a few MPS)	7	0	
	Carbon Coop	Retrofit organisation	Newsletter circulation of 1,000	600 members		18	
	Green Rose (Lancashire)	Retrofit organisation	Circulating on social media and messaging Cosy Homes households. Newsletter circulated March 12th. Follow up targeted e mail issued 3/4/25	Targeted email sent to 146 residents ("whose properties were suitable for the trial") this led to 54 opens	9	1	
	Changeworks	Retrofit organisation	Post issued 18/03 on Changeworks social media - LinkedIn, Instagram (990) and Facebook	10,500 followers across social media platforms	9	1	

Table 9: Further methods utilised for recruitment of households into AEH trial

Organisation	Type of Lead
Centre of Alternative Technology	Educational organisation
SCARF	Energy advice service
Heat Pump Federation	Industry Body
TopCo "United Living Group"	Property services
Staff LinkedIn	Social media
Community Energy Plus	Community Energy Org
Energy Capital	Energy transition investor
Flat living	Property service
News on the Block	Magazine and newsletter
Furbnow	Retrofit organisation
Zero Carbon Oxford	Retrofit organisation
Glebe Housing Association	Housing association
Home Energy Scotland	Energy advice service
Energy Saving Trust	Energy advice service
EON	Energy company
Centre for Net Zero (Octopus)	Energy company
Habodel	Housing association
Heat Pump association	Industry Body
Six local authorities	Local authorities
SE London Community Energy	Retrofit organisation
Repowering London	Retrofit organisation
Assorted Facebook groups	Social media
Other HP providers	Technology partner

Appendix 5: Known and potential biases (AEH – heat battery trial)

During recruitment and setting up of the heat battery trial, several biases, both known and potential, were identified:

- All homes have been deemed suitable for installation of the analysed product prior to the trial taking place and the trial set no targets related to property archetype. Therefore, the results are not reflective of the potential performance of all heat battery products across the whole UK housing stock.
- The results reflect the performance of the specific products analysed during the timeframe of this project. The products control strategy relies on Tepeo software which is regularly updated. The performance can therefore be upgraded over time through firmware updates which may be pushed to existing hardware.
- Since recruitment was led by the OEMs, there is a possibility that the installations involved are more representative of favourable conditions.
- The consumer surveys were undertaken post-installation and use of the heat batteries, therefore any comparisons between heat batteries and previous heating systems are based on participants' memory of the previous system.
- The relative efficiency and energy balance of heat battery systems will vary based on the installed location. For example, if the heat battery is installed within the main thermal envelope of the property, then any heat loss from the heat battery may be considered useful heat as it is "lost" to the environment which the system is trying to heat. Conversely, if the heat battery is installed outside or within unoccupied/unheated spaces (such as a garage) then the heat lost from the heat battery can be considered true heat loss. In this trial, all tepeo installations were within the main thermal envelope of the property.
- The tepeo heat battery (ZEB) heat meters provide data which is slightly inaccurate. The impact of this is different for each installation, however, during the analysis conducted for this report, they are estimated to underrepresent the heat output by a factor of 3% to 4% on average.

Appendix 6: Recruitment survey (AEH – heat battery trial)

Upon recruitment to the heat battery trial, participants were asked several questions. Of the 50 participants with a tepeo heat battery, 43 responded. 1 of the 43 participants indicated that they had worked with the company as a client or partner, the remaining 42 had no association with tepeo prior to installation. A summary of the findings is provided:

House type and size

Houses are larger than average and more than 90% of the participants with ZEBs are in detached (51%), semi-detached or end-terrace (40%) properties. Mid-terrace properties make up the remaining 9% and there were zero flats recruited. Ninety-one percent of the properties recruited had three or more bedrooms.

Old heating system

ZEBs were used primarily to replace traditional gas and oil boilers. Sixty-three percent of ZEBs replaced gas boilers whereas 28% replaced oil boilers. The remaining 9% replaced other heating systems and were mostly used to replace gas (63%) or oil (28%) boilers.

Reasons for installing ZEB

Forty percent of the participants installed ZEBs for environmental reasons. Twenty percent did so to reduce energy bills. When considering alternatives to having a ZEB, air or ground source heat pumps were most often considered, these were considered by 54% of participants.

Additional home upgrades

When installing the ZEB:

- 22% made no additional home upgrades,
- 21% installed a new hot water tank,
- 18% added extra insulation,
- 13% upgraded radiators.

Appendix 7: Quantitative Analysis – Method

A note on statistical data control

Participants in the trial were assured that no data would be published that would allow their homes to be identified. Procedures for Statistical Data Control followed by the UCL SERG group (and based on ONS guidelines⁵⁷) were followed. The data analysis was carried out in the UCL Data Safe Haven secure environment. Analysis results were checked to ensure they were not disclosive before being exported from this secure environment.

No results for individual homes are included in this report. Aggregated values and statistics for groups of a minimum of 5 homes are presented.

Energy analysis

Comparator homes from the SERL Observatory were chosen to include all those homes in the Observatory built before 1930, in England and Wales and with gas central heating.

Daily energy data is the sum of 48 half hourly readings. If any of the half hourly readings for either gas or electricity was missing, this day was not included in the energy analysis.

⁵⁷ ONS SDC guidelines

Smart meter data was available for both gas and electricity usage. The results presented in this report for the (gas heated) core group are calculated based on gas data only. UCL work has shown that the HPLC parameter from the PTG method calculated using the sum of gas and electricity demand is very similar to that calculated for gas only. Analysis based on gas alone removed any influence of non-metered electricity use in the small number of core sample homes with PV generation.

Background on the PTG method used to assess the changes in energy demand after intervention is given in Chambers and Oreszczyn (2019)⁵⁸. This is the gradient of the plot of demand power P against external temperature T_{ext} as given in the equation:

$$P = HPLC(T_b - T_{ext}) + P_b \quad (\text{for } T_{ext} < T_b)$$

Where T_b is the balance temperature, the external temperature below which heating is used and P_b is the baseload power for non-heating uses (e.g. water heating and cooking). A Python scikit-learn linear regression model fit for optimisation of the model parameters was used to derive the relevant model parameters for each home.

The chosen model was run twice for each dataset. Based on the results of the first run days when $T_{ext} < T_b$ and $P < P_b$ were identified. The data for these days, classified as ‘unoccupied’ since there was no heating on a day with mean temperature below the balance point, was then removed before the second model run. Homes for which the R^2 was less than 0.1 in the first run were removed before the second run since there was very low confidence in model fit.

Temperature analysis

The readings from the tado temperature sensors are not at set intervals, since temperatures are recorded each time there is a change. This variable time series data was converted to temperatures at set intervals of 10 minutes (based on the last recorded value, unless the time gas was sufficient to suggest a loss in communications, in which case N/A was recorded).

The “unoccupied” days identified from the energy analysis were excluded from winter comfort analysis. When analysing temperatures experienced by the household, the readings from a small number of sensors placed in rooms not considered to be representative of the locations in which most time is spent were identified. Sensors tagged bathroom, corridor, garage, toilet, utility and conservatory were excluded from the analysis.

‘Comfort taking’ analysis.

The mean daily temperature for each room was calculated for all homes with temperature data in Winter 2, with the calculation for split between ‘before’ and ‘after’ for those homes with interventions.

⁵⁸ Chambers, J.D. and Oreszczyn, T. (2019) ‘Deconstruct: A scalable method of as-built heat power loss coefficient inference for UK dwellings using smart meter data’, *Energy and Buildings*, 183, pp. 443–453. Available at: <https://doi.org/10.1016/j.enbuild.2018.11.016>.

For homes with MOT or MOT +, the heat meter allows analysis of boiler flow temperature. The 95th percentile of this each day was used as an indication of the radiator temperature when the heating was running.

If you need a version of this document in a more accessible format, please email alt.formats@energysecurity.gov.uk. Please tell us what format you need. It will help us if you say what assistive technology you use.