EQUINOX

Initial Insights on the Effectiveness of Commercial Methods

July 2023

Electricity Distribution

nationalgrid

Version Control

Issue	Date
d0.1	07/07/2023
d0.2	12/07/2023
d0.3	18/07/2023
d0.4	26/07/2023
V1.0	28/07/2023

Publication Control

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Contents

1. Executive Summary

EQUINOX (Equitable Novel Flexibility Exchange) is a Network Innovation Competition (NIC) project, funded by Ofgem. Between 2022 and 2025, EQUINOX is developing novel commercial arrangements and supporting technological integrations that unlock flexibility from residential low carbon heating, while meeting the needs of all consumers, including those with vulnerabilities or experiencing fuel poverty.

December 2022 to April 2023 represented the first trial period (henceforth 'trial one') for two novel commercial arrangements. These commercial arrangements saw domestic households who already had heat pumps installed offered financial incentives to turn their heat pump off/down for limited two-hour periods called EQUINOX events (henceforth 'events') occurring on 'event days' across the trial period.

Households in trial one were divided into four trial groups. Each group was assigned a unique combination of two variables, as shown in the table below.

Table 1 – Participant household control grouping variables

		Heat Pump Control Method	
		Aggregator Control	Customer Control
Payment Method	Pay Monthly	Households were paid £25 monthly advances in return for allowing their heat pump to be remotely turned off by their supplier during events, with the option to opt out before or during the events. Opting out did not impact their payment amount.	Households were paid £25 monthly advances to turn their heat pump off during events, with the option to not turn it off at all or to turn it back on at any point. Doing so did not impact their payment amount.
	Pay per Event	Households were paid up to £6 on a per-event basis for allowing their heat pump to be remotely turned off by their supplier during events, with the option to opt out of this remote control before or during the events.	Households were paid up to £6 on a per-event basis to turn their heat pump off during events, with the option to not turn it off at all or turn it back on at any point during each event.

Each group experienced a maximum of 22 events across the trial period, chosen to cover the largest possible range of external temperatures across the winter, during which their household electricity consumption was monitored. For some homes, their heat pump-specific consumption could also be monitored. This enabled evaluation of the demand response provided by each household. The magnitude and consistency of this demand response was compared between trial groups to see which proved most quantitatively effective at delivering demand response to Distribution Network Operators (DNOs) when needed. Participating households' experiences of events were also tracked both quantitatively and qualitatively throughout the trial period via a range of surveys, interviews, and focus groups. The key findings from trial one are summarised below:

- The response to trial one amongst participants was overwhelmingly positive. Households felt in control of their heating, generally remained comfortable, and were satisfied with the simple trial design. Households were motivated to participate for environmental reasons in addition to financial motivations.
- Trial one has shown that households can provide significant turndown when asked to shift their domestic heat pump habits with a day-ahead notice. A total of 386 households provided 10.8MWh turndown across 22 events, with an average turndown of 1.43kWh per household per event. Doing so did not compromise customer safety or comfort.

- Household participation in events was consistently high throughout the trial, with minimal fatigue observed. Households paid after each event participated more consistently than those paid upfront monthly payments. No households pulled out of the trial once they had signed up.
- The most common reason for non-participation in events was no one being home to action the request for heat pump turndown. Not realising that there was an event and the weather being too cold outside were also relatively commonly cited reasons.
- Households with residents identified as having potential vulnerabilities did not appear to face any additional difficulties in navigating the trial. Although these households were not less likely to participate in events, they were slightly more likely to feel discomfort.
- Trial one provided early evidence that households with aggregator controlled heat pumps can provide more predictable flexibility than households whose heat pumps were turned down by customers (customer controlled).
- Temperature of event days, presence of additional Low-Carbon Technologies (LCTs), and Energy Performance Certificate (EPC) rating all seemed to impact turndown rates.
- Trial one provided evidence that a temporary increase in demand (henceforth snapback) is present in households following flexibility events. This was found to be most significant in the aggregator controlled households but smaller snapback effects were also found within those that were manually controlled.
- Ten digital twins of trial one homes were created to simulate the impact of interventions to inform the trial design. The key findings from the simulations around participation, potential for snapback and control type aligned with the trial one outcomes and will also be used to optimise trial design next winter.

Analysis of demand response and customer experience outcomes of trial one is already prompting iterative improvements to the design of EQUINOX, from elements of the customer experience to the terms of the commercial arrangements themselves. These improvements will be integrated, tested, and further iterated via subsequent trials in the 2023/24 and 2024/25 winters, which aim to test progressively closer to future Business as Usual (BaU) practice.

2. Purpose and Guide

2.1. Purpose

The purpose of this report is to provide initial insights on the effectiveness of the commercial methods tested in trial one of the EQUINOX project. This includes analysis and learning from early trial data to understand the impact of commercial methods and control types on flexibility outcomes and an overview of theoretical flexibility simulation modelling based on ‘digital twin’ housing archetypes.

2.2. Guide to this Document

- **Section 3** provides an introduction to EQUINOX, trial one, and the project partners.
- **Section 4** outlines the trial one goals that drove its design. This is split into network flexibility goals and customer experience goals.
- **Section 5** describes in detail how trial one was designed, including the commercial arrangements tested, household eligibility and recruitment strategies, event design, decisions, and operational set-up.
- **Section 6** describes the process actioned to enable evaluation of trial one’s impact. It explains the data collected, the process for calculating individual household and aggregated turn down, and the various methods employed throughout the trial period to collect feedback from households taking part.
- **Section 7** details the results from trial one across three key areas: participation rates throughout the trial, turndown achieved across the trial, and participant feedback about the trial. These results are analysed against key axes such as the commercial arrangement and heat pump control type the households were segmented and classified by considering the demographic breakdown of trial one participants.
- **Section 8** details simulation work undertaken to inform the real-world trial design and complement trial one findings by investigating the impact of particular types of intervention using realistic simulation models (digital twins) of homes.
- **Section 9** details comparative work undertaken to inform our DFES profiles using EQUINOX trial one isolated heat pump data.
- **Section 10** summarises the key learnings from trial one and outlines next steps, with a focus on key points for the second trial scheduled for winter 2023/24.

3. Context

3.1. Introduction to EQUINOX

In 2020, the UK government announced a target to reach 600,000 heat pump installations per year by 2028[1]. Unless new solutions are developed to manage this new load, DNOs are expected to witness a substantial increase in peak demand, triggering significant network reinforcement throughout the later years of the RIIO-ED2 and ED3 investment periods. Currently, limited viable solutions exist for DNOs and other whole system actors to unlock the flexibility from residential low carbon heat at scale in a reliable, cost-effective, and equitable way. To defer costly network reinforcement, and thus prevent additional costs being passed onto the consumer, learning how to unlock flexibility from the various LCTs is key.

EQUINOX is developing at least three novel commercial arrangements that are designed to maximise participation in domestic DNO flexibility services. The range of methods will demonstrate how varying risk/reward frameworks between DNOs, suppliers, and customers can influence the amount, cost, and reliability of flexibility from portfolios for varying customer segments including those who have vulnerabilities or are experiencing fuel poverty.

EQUINOX is a first of a kind project that will answer key questions on how DNOs can help decarbonise heat in the most cost-efficient manner for customers. The project will pave the way for how DNOs will leverage flexibility from heat, to manage the increasing network demand while maintaining network reliability, consumer choice, and comfort within homes. In the future, it's expected that the DNO would in its capacity as the Distribution System Operator (DSO) be responsible for this service. (Henceforth, the term 'DNO' refers to the DNO and its capacity as the DSO).

3.2. Introduction to Trial One

December 2022 to April 2023 represented the first trial period for two novel commercial arrangements developed between May and November 2022. These commercial arrangements saw domestic households who already have heat pumps installed offered financial incentives to turn their heat pump off for limited two-hour periods occurring on 'event days' across the trial period.

For this first trial, requests for demand flexibility via events were simulated across National Grid Electricity Distribution's (henceforth 'National Grid') whole license area. In the future, it is expected that National Grid would request demand response from households in specifically constrained parts of the networks, called Constraint Managed Zones (CMZs) via energy suppliers and flexibility providers during times of high network stress. During each future trial, we will test arrangements that are closer to our future BaU approach.

Households who signed up to trial one were divided into four trial groups. Each group was assigned a unique combination of two variables: the method for turning off their heat pump, and the method by which they were paid for doing so. Each group experienced a maximum of 22 events across the trial period, during which their household electricity consumption was monitored. For some homes, their heat pump-specific consumption could also be monitored. This enabled evaluation of the demand response provided by each household.

The magnitude and consistency of this demand response was compared between trial groups to see which proved most quantitatively effective at delivering demand response to National Grid when needed. In addition to the heat pump control method and financial incentives, trial one evaluated the impact of external temperature, the presence of individuals with vulnerabilities within the household, and the presence of other LCTs on the demand response provided.

Participating households' experiences of events were tracked both quantitatively and qualitatively throughout the trial period through surveys, interviews, and focus groups. This allowed customer satisfaction to be monitored and feedback on trial design to be captured. Participation in certain feedback methods was financially incentivised in order to maximise the number of responses and facilitate a more nuanced discussion of their experiences among participants.

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[1] HM Government, 2020

Analysis of demand response and customer experience outcomes of trial one is already prompting iterative improvements to the design of EQUINOX, from elements of the customer experience to the terms of the commercial arrangements themselves. These improvements will be integrated, tested, and further iterated in subsequent trials in the 2023/24 and 2024/25 winters.

Since trial one was the first time that domestic heat pump flexibility was trialled at commercial scale in the UK, payments received by participants were higher by design than those expected for a BaU flexibility product. This was carried out to account for the fact that participants were providing data that enables analysis of their first of a kind insights. Ultimately, trial one has laid the groundwork for future trials to finetune the commercial arrangements and deliver a DNO flexibility product which unlocks cost-effective and widely accessible flexibility from residential low carbon heating.

EQUINOX trial one has explored a broad group of factors to deliver initial learnings for networks and other stakeholders. We have demonstrated that heat pump demand turn-down can be achieved in a two-hour event window during the evening peak period without unduly affecting customer comfort and with a high level of customer satisfaction.

3.3. Introduction to Project Partners

EQUINOX features multiple project partners and collaborators, as detailed in ***Table 2***.

Table 2 - List of EQUINOX partners and collaborators

Company	Name	Project Function	Role
nationalgrid	National Grid Electricity Distribution	DNO	Project lead. We are responsible for running the technical integration, trial design, and project management and knowledge workstreams. We want the EQUINOX product to align with our existing and future DSO flexibility services and products.
Guidehouse Outwit Complexity	Guidehouse	Consultancy	Partner. Responsible for leading the commercial arrangement design and customer engagement workstreams. Supporting on trial design, project management, knowledge dissemination.
octopusenergy	Octopus Energy	Energy supplier and flexibility aggregator	Partner. Responsible for planning and administering the trial with their customers with heat pumps in the National Grid license areas and undertaking data processing. Octopus Energy will also be assisting with commercial arrangement and trial design.
sero	Sero	Energy services provider and flexibility aggregator	Partner. Responsible for planning and administering the trial with their customers with heat pumps in the National Grid license areas and undertaking data analysis. Sero will also be assisting with commercial arrangement and trial design.
SCOTTISHPOWER	Scottish Power Energy Retail (SPERL)	Energy supplier and flexibility aggregator	Collaborator. A supplier brought on board to ensure interoperability of commercial arrangements and technical integrations. SPERL will recruit customers for trials two and three.

passiv	Passiv UK	Smart energy technology company providing digital twin simulations and modelling	Partner. Responsible for simulating the flexibility impacts for different intervention strategies and household archetypes.
West Midlands Combined Authority	West Midlands Combined Authority (WMCA)	Local Government	Partner. Responsible for coordinating a social housing heat pump installation programme which can contribute customers to trials two and three.
Llywodraeth Cymru Welsh Government	Welsh Government	Government	Partner. Responsible for running a social housing heat pump installation programme which can contribute customers to trials two and three.
NEA	National Energy Action (NEA)	Charity	Collaborator. Responsible for running customer focus groups to understand the perceptions of the trials. NEA will ensure that the needs of customers with vulnerabilities are accounted for in the trial design.
SP ENERGY NETWORKS	Scottish Power Energy Networks (SPEN)	DNO	Partner. A DNO brought on board to ensure that the design is interoperable for other DNOs. SPEN's license areas will join trial three.
ESO	National Grid Electricity System Operator	Electricity System Operator (ESO)	Collaborator. Responsible for sharing learnings between EQUINOX and other ESO flexibility trials, notably the Demand Flexibility Service and Crowdflex.

4. Trial One Goals

Trial one represents the first of three planned winter trials. With limited existing knowledge in the area of commercial-scale domestic heat pump flexibility provision, a broad scope was adopted to capture data in several areas across the EQUINOX project goals. Further trials will facilitate a deeper understanding in areas that are not fully served in trial one.

The goals for trial one were grouped into two segments: network flexibility and customer experience. Each goal aims to answer questions from the Final Submission Pro forma (FSP).

Network flexibility goals are met by capturing the changes in heat pump electricity demand that are achieved through trial events. The potential impact of this flexibility was explored for two payment methods and control types, and the effects of other customer archetype data on heat pump flexibility.

Customer experience goals focus on the EQUINOX aim to make heat pump flexibility services widely available for different customer groups, including households that are experiencing fuel poverty or have residents with vulnerabilities. These goals were addressed through quantitative and qualitative measurements of customer experience, perceptions, and attitudes. While the work in EQUINOX deliverable one (*Customer Perceptions on Unlocking Flexibility from Heat)* focused on a representative sample of the UK population as a whole and not necessarily heat pump owners, the customer experience goals in trial one focus exclusively on participants in the heat pump flexibility trial.

4.1. Network Flexibility Goals

The network flexibility research goals for trial one are detailed in ***Table 3*** below.

Table 3 – Network flexibility research goals

FSP Question	Goal
• How much flexibility can be unlocked from residential low carbon heating?	Uncover the amount of aggregated flexibility that can be procured from domestic heat pumps without compromising customer comfort or safety.
• At what cost and reliability to the DNO can the flexibility be unlocked from residential low carbon heating? • What is the impact of different building characteristics, technologies, processes, and control strategies on this flexibility? • What is the behavioural response from residential customers under each of the proposed methods?	Assess the predictability of the aggregated flexibility.
• What is the impact of different control strategies on this flexibility? What is the behavioural response from residential customers under each of the proposed methods? • How does the presence of smart thermostats and thermal storage enhance the value of flexibility?	Assess whether and how the amount and predictability of aggregated flexibility differs between heat pump control methods.
• What is the impact of different commercial arrangements on this flexibility? What is the behavioural response from residential customers under each of the proposed methods?	Assess whether and how the amount and predictability of aggregated flexibility differs between commercial arrangements.
• At what cost and reliability can flexibility be unlocked from residential low carbon heating? • How can DNOs, energy suppliers, and the ESO align their objectives to participate in DNO flexibility markets? • How does procuring domestic flexibility across a local, aggregated portfolio of homes enhance the value of flexibility?	Assess whether flexibility from domestic heat pumps is a viable option for the DNO.
• Additional to FSP	Stress and test the systems and processes that make the procurement of aggregated flexibility possible

4.3. Customer Experience Goals

The customer experience research goals for trial one are detailed in ***Table 4*** below.

Table 4 – Customer experience research goals

FSP Question	Goal
• How do DNOs ensure that customers who have vulnerabilities or are experiencing fuel poverty have an equal opportunity to participate in flexibility services?	Assess whether this aggregated flexibility can be procured in an equitable way that does not unduly bias against underrepresented households.
• At what comfort, convenience, and control levels for the customer can the flexibility be unlocked from residential low carbon heating? • How can DNOs and energy suppliers facilitate markets for flexibility to minimise customer bills?	Promote domestic heat pump flexibility as a valuable product for the network and for customers.
• What is the behavioural response from residential customers under each of the proposed methods?	Understand the main reasons for participants choosing not to/ being unable to participate in flexibility events.

5. Trial One Design

5.1. Commercial Arrangements Overview

EQUINOX is developing novel commercial arrangements and supporting technological integrations that unlock flexibility from residential heat pumps. Two payment methods were devised and tested in trial one. These were paired with two methods of turning down households' heat pumps.

These methods and their combination are described below.

5.2 Heat Pump Control Method

To explore how different heat pump control methods impact the demand response capability from residential heat pumps, participants in the first winter trial were asked to provide heat pump flexibility (demand response) for up to two hours during flexibility events via one of the two following methods.

- **Aggregator Control:** where the default for participating households was to allow for their heat pump to be turned off directly and remotely by their energy supplier for the event period. Households still had the option to opt-out on a per-event basis. Households under aggregator control could opt out in advance of an event, or at any point during the two-hour event window by informing their supplier.
- **Customer Control:** where participating households were required to opt into each flexibility event by turning their heat pump off for the event period. Households under customer control could choose not to opt into any event or, if they had chosen to opt in, could stop participating at any point during the two-hour event window by turning their heat pump back on. There are two types of customer control[2].
  - **Manual customer control:** where households participated by either manually turning off their heat pump or by lowering their thermostat set point to a much lower temperature for the two-hour event window.
  - **Remote customer control:** where households participated by either turning off their heat pump or by lowering their thermostat set point to a much lower temperature set point using an app.

5.3 Demand Response Payment Method

EQUINOX also aims to understand how different payment methods incentivise the amount of demand response provided. Participating households under both of the heat pump control methods were therefore split under the following two payment methodologies, each delivered as credit on the customers' electricity bills:

- **Pay Monthly:** where a fixed £25 monthly payment was credited to the energy bill of participating households which covered the events occurring for the month ahead. In other words, pay monthly payment method aimed to incentivise flexibility by paying participants in advance. The payment amount was fixed, so participating households under the pay monthly type were paid the same regardless of their level of participation in events. Pay monthly participants could earn a maximum of £100 (four monthly payments across trial one).
- **Pay per Event:** where a per event payment was credited to the participating household after the event. In other words, pay per event monthly payment aimed to incentivise flexibility by rewarding participants for each event they participated in. For the first 13 events, households received £6 as long as their heat pump was off for at least 30 minutes of the two-hour period. For the latter nine events, the payment was stratified based on the household's level of participation in that event. If the household opted out prior to or within the first thirty minutes of an event (if aggregator control) or did not opt in by turning off their heat pump at all or keeping it off for less than a thirty-minute spell across the event (if customer control), they received no payment for that event. If they did not

[2] The two types of customer control were not pre-defined by the project team but emerged as a result of within-trial feedback on customers' home heating set-ups. We captured data on the two types of customer control to enable additional data segmentation.

opt out (aggregator control) or successfully opted in (customer control) and participated for one hour, they were paid £4. Those who participated for an hour and a half were paid £5, and those who participated in the full two hours received £6.

5.4 Trial One Experimental Groups

Combining the two control methods with the two payment methods, households taking part in trial one were split into four experimental groups, as summarised in ***Table 5***.

Table 5 - Trial one experimental groups

		Heat Pump Control Method	
		Aggregator Control	Customer Control
Payment Method	Pay Monthly	Households were paid £25 monthly advances in return for allowing their heat pump to be remotely turned off by their supplier during events, with the option to opt out before or during the events. Opting out did not impact their payment amount.	Households were paid £25 monthly advances to turn their heat pump off during events, with the option to not turn it off at all or to turn it back on at any point. Doing so did not impact their payment amount.
	Pay per Event	Households were paid up to £6 on a per-event basis for allowing their heat pump to be remotely turned off by their supplier during events, with the option to opt out of this remote control before or during the events.	Households were paid up to £6 on a per-event basis to turn their heat pump off during events, with the option to not turn it off at all or turn it back on at any point during each event.

5.5 Eligibility and Recruitment

5.5.1 Eligibility

To be eligible to take part in trial one, households needed to fulfil six criteria:

1. Be located within the National Grid DNO license areas, which covers the South West, South Wales, the East Midlands, and the West Midlands
2. Have an electricity smart meter operating in smart mode and have agreed to half-hourly readings data being shared with the project.
3. Be customers of one of the EQUINOX trial one partners: Octopus Energy or Sero.
4. Already have a heat pump installed and operating.
5. Agree to participate in events and share their experience and consumption data for analysis in this trial.
6. Not be participating in any other demand flexibility trials or services running throughout winter 2022/23.

Regarding criteria one, households could be recruited from anywhere across National Grid's distribution network, not limited to live CMZs. CMZs are areas of the network prone to being constrained where DNOs forecast and purchase their flexibility requirements in order to manage these constraints. Since trial one was the first test of technical feasibility and participant appetite for providing residential heating flexibility, the level and flexibility impact of participation remained unknown when the trial was being designed. Further, we recognised the low likelihood of a significant proportion of eligible households signing up to take part being clustered in the National Grid's CMZs, given that the rate of heat pump ownership is comparatively low (see ***Section 5.5.2***) and therefore the number of households meeting all six eligibility criteria above is relatively small.

It was therefore deemed that events should not be called in live CMZs in times of network stress. Instead, the timing of events was set manually by the project team as described in ***Section 5.6.2***. Events were simulated at these chosen times as described in ***Section 5.6.4.1***. For these simulations, the exact location of participating flexibility assets (heat pumps in participating households) did not need to correlate with the National Grid CMZ locations.

Regarding criteria two, whilst inclusion of those without smart meters was considered, it was concluded that the additional effort required to evaluate the impact of flexibility events on such households' electricity consumption was too great to warrant their inclusion. This was because:

- These households would have had to provide meter readings prior to and after each flexibility event. However, these readings would not have been guaranteed. Residents could have forgotten to take them or have been out of the property and unable to take them. As such, accurately validating these households' electricity consumption for heating during flexibility events would have been challenging.
- If not asked to provide manual meter readings, households would have had to consent to having extra metering equipment installed in their properties to measure the electricity consumption of their heat pumps. As consent would not be guaranteed and because EQUINOX aims to minimise the need for participating households to have any additional equipment installed as part of the trial process, this approach was also deemed unsatisfactory.
- Furthermore, as an innovation project which will be proposing BaU arrangements at the end of its lifespan in 2025, a balance had to be struck between maximising inclusion today and tailoring the trial design towards the reality in 2025. Current government policy aims for every household to have a smart meter installed by the end of 2025, hence all future heat pump flexibility will in theory be provided by residents with smart meters. It was therefore deemed less important to include households with heat pumps but no smart meter in trial one.

Regarding the final criteria, households that signed up were informed that EQUINOX was the only demand flexibility trial they could sign up for that winter. This meant they were ineligible for other initiatives such as *Saving Sessions*, Octopus Energy's product for the NGESO Demand Flexibility Service (DFS). There were two reasons for this decision:

- Since trial one was a proof of concept for commercial-scale UK demand flexibility from residential heating, the data gathered needed to be of reasonable quality. If households were on multiple flexibility schemes at the same time, this could have introduced biases, such as prioritising one scheme over the other, which would have made it more difficult to isolate the demand flexibility impact from EQUINOX.
- The administrative burden associated with ensuring that households on multiple schemes were not subjected to overlapping or same-day flexibility events from more than one scheme was deemed prohibitively onerous.

Nevertheless, suppliers and networks desire a BaU future where they can offer customers the ability to participate in multiple flexibility schemes. As such, EQUINOX trials two and three intend to consider the impact of 'stacking' domestic flexibility services to allow customers to be on another scheme as well as EQUINOX.

5.5.2 Recruitment Strategies

Approximately 250,000 heat pumps have been installed in UK residential properties as of February 2023[3]. However, only approximately 40,000 of these fall within the National Grid license area, limiting the potential pool of customers for the first trial.

The heat pump installation programmes in social housing in the West Midlands, via the West Midlands Combined Authority's Net Zero Neighbourhoods programme, and Wales, via the Welsh Government's Optimised Retrofit programme, need to progress further but are expected to provide suitable properties for the second and third trial phases.

[3] Nesta, February 2023

Heat pumps have been regarded as a novel, 'alternative' heating technology in Great Britain, where gas central heating is used by over 70% of households. Although there are Government and industry efforts to bring down the cost of heat pump purchase and installation, the technology is only now coming in line with the cost of a gas boiler[4]. It was expected that participants in trial one would have installed their heat pumps as early adopters of the technology, at greater expense than traditional alternatives, or as participants in previous efforts to subsidise heat pump installation. It is therefore hypothesised that these customers would be more engaged with their home heating technology than average consumers.

An early success of trial one was far greater interest in trial one than had been anticipated, dwarfing original recruitment by six-times, and providing the opportunity to explore more variables in the provision of heat pump flexibility than had been initially planned for. Although trial one was able to be adapted to make use of this windfall, future trials will include prioritisation factors for selecting participants in the event of over-subscription.

5.5.3 Octopus Energy Recruitment

Octopus Energy used a two-step sign up process, whereby customers living in the National Grid license areas were:

- Invited to submit information about their home heating in a 'registration of interest' step.
- Those with heat pumps were then offered to fully onboard to the trial with terms and conditions specific to their control group: aggregator control or customer control.

This approach was used to identify and engage with customers whose heat pumps were eligible for aggregator control through Octopus Energy. The heat pump feature was new at the time of recruitment and the number of customers in this group was expected to be relatively low.

Invitations to the 'registration of interest' step were sent to approximately 750 customers in the National Grid license areas who had self-reported as having heat pumps. A further 40 invitations were sent to customers living in the National Grid license areas who responded to a press release and indicated interest in the project. Of the approximately 790 customers sent invitations, 470 customers completed the 'registration of interest' form. Six customers were offered aggregator control through Octopus Energy, of whom three completed set up. Including these three customers, a total of 368 customers were fully onboarded to the Octopus Energy cohort for trial one by the 1st of December 2022 deadline.

Customer recruitment for trial one did not include a commitment to participate in further trials and the public interest sign-up sheet remains live on the Octopus Energy website[5], allowing customers to indicate if they would like to be contacted when recruitment begins for trial two. Trial one was aiming to recruit 50 customers into the Octopus Energy cohort and public interest in the project far exceeded expectations.

At the recruitment stage, Octopus Energy could only engage in direct control with specific Daikin heat pump installations. Households with this installation formed a minority of this pool of potential recruits. Therefore, most Octopus Energy recruits were placed into one of the two customer control trial groups (see ***Table 6*** below).

5.5.4 Sero Recruitment

Sero opted to recruit customers from the Aspen Grove housing development which they administer. This is because houses in this development could be most easily enabled for aggregator control. This development provided a pool of 50 potential households, all with ground source heat pumps, who were contacted via email to gauge interest. From January there were an additional five to ten residents moving in per month.

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[4] National Grid, June 2023
[5] https://octopus.energy/blog/equinox-flexibility-trial/

Recruitment included leaflet drops, email campaigns and face to face discussions involving Sero team members on site talking with residents. Ten households signed up during Sero's initial recruitment campaign, all recruited through face-to-face conversations with residents.

The EQUINOX trial then became part of Sero's onboarding process for residents newly moving into homes between December to February. An email in early January calling for further participants brought the total to 18 households by the end of trial one a larger cohort complementing the small group of Octopus Energy aggregator control homes.

5.5.5 Segmentation of Trial One Participants

Whilst the split between pay monthly and pay per event participant numbers was roughly 50/50 for trial one, with both Octopus Energy and Sero randomly allocating their participating households to each payment group. ***Table 6*** demonstrates that the split between participant numbers in the aggregator and customer control groups in trial one skewed towards the latter due to the smaller number of aggregator control homes. Three participating Octopus Energy households had onboarded heat pump installations which Octopus Energy could control remotely. Whilst Sero were able to remotely control all of their participating homes, their participant pool was smaller. Therefore, across the 386 participating households, 21 fit within the aggregator control group. While the aggregator control group is small, trial one acted as a successful proof of concept of remotely controlled heat pumps providing distribution grid flexibility. Recruitment expectations were exceeded in trial one, and an expected increase in aggregator control numbers for trials two and three will allow direct comparisons of flexibility impact between aggregator control and customer control methods.

Table 6 – Trial one participating households in each experimental group, broken down by supplier

		Heat Pump Control Method			
		Aggregator Control		Customer Control	
Supplier	Payment	Number	Supplier %	Number	Supplier %
Octopus Energy (368)	Pay Monthly	2	0.50	191	51.9
	Pay Per Event	1	0.30	174	47.3
Sero (18)	Pay Monthly	9	50.0	-	-
	Pay Per Event	9	50.0	-	-
Total (386)	Pay Monthly	11	2.80	191	49.5
	Pay Per Event	10	2.60	174	45.1

5.6 Event Design

5.6.1 Event Schedule

Trial one ran as follows: December 2022 acted as a pilot trial period in which participants experienced three events on December 13th, 16th, and 19th to learn how they worked and what was expected of them. These events also enabled:

- Validation of technical logistics, including successful sending and receipt of National Grid signals to Octopus Energy and Sero requesting flexibility, and supplier notifications of events to participants. See ***Section 5.6.4*** for more details.
- Initial testing of the methodology used to baseline household consumption and calculate the kWh of demand turn down that they provided during event periods. The methodology, described in more detail in ***Section 6.3***, was tweaked following this early analysis, and further altered throughout the trial as more data became available for use.

- After each event, participants were asked to complete a short (four questions maximum) post-event survey asking them to confirm participation, define their comfort levels during the event, and flag any issues they experienced. Only minimal issues relating to heat pump operation were reported. These were unrelated to the trial set up or participation and were dealt with via the relevant supplier customer service team. Had any issues directly related to the trial set up been reported, the trial design could have been tweaked for the main trial period.

The main trial period ran from January to March 2023, in which participants experienced an average of two to three events per week. During this time, participant data was collected as defined in ***Section 6.1*** and ***Section 6.2***.

Given that the maximum number of households participating in any given trial one event was 386, and that participants were already segmented by payment method and heat pump control method, as well as aggregator control for the latter being a small group for trial one, it was considered impractical to add any further experimental variables. Therefore, for trial one:

- All events occurred at **the same time of day (5-7pm),** chosen to coincide with National Grid's typical evening peak period.
- Participants were always notified **the day before the event,** so they had time to plan and decide whether to opt in/out.
- Events only occurred on **weekdays**.

5.6.2 Choosing and Tracking Event Days

In addition to payment type and control method, temperature was a key variable explored during trial one. Therefore, event days were chosen on a weekly basis by considering the external temperature forecast for the following week.

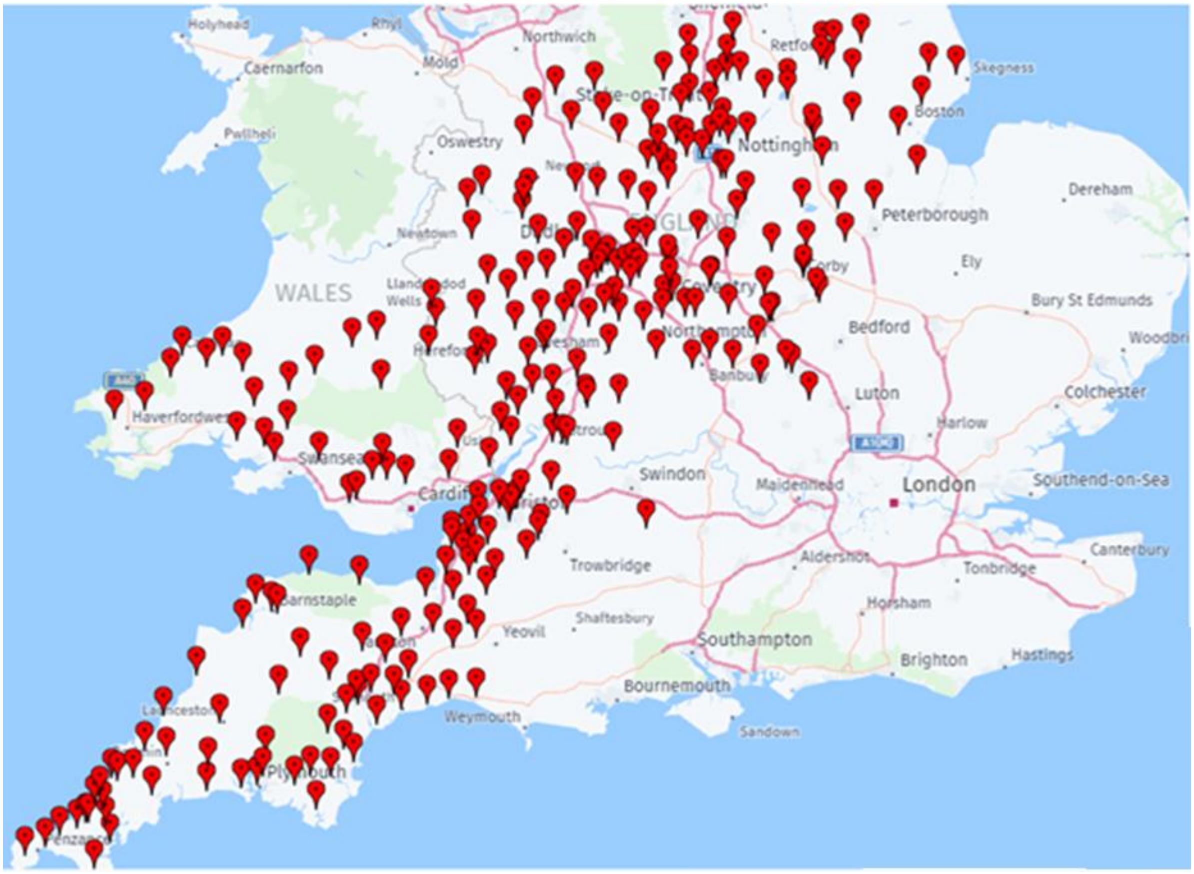
The choice of event days for the following week was driven by the following three requirements.

- To better understand the impact of temperature on demand response, a range of temperatures needed to be captured across the 22 events in trial one. In particular, the coldest days of the year needed to be adequately captured. Therefore, **the coldest forecast days were prioritised when choosing event days for each following week**. However, this requirement is limited somewhat by the second requirement.
- To favour an accurate baseline of household heat pump usage before considering the impact of demand response, **the number of coldest days which were non-event days had to proportionately equal the number which were event days**. For every very cold day (<0°C) chosen to be an event day, another similar day should *not* be an event day. This is because household heat pump kWh consumption is likely to depend on temperature even before demand response is considered. ***Section 5.6.3*** provides more details.
- To understand how participating households responded to a range of requests, **the days of the week on which events were scheduled were varied from week to week**, whilst accounting for the first two requirements above. This included two instances of event days being scheduled consecutively, to see whether participation levels would drop for the second day.

With these three principles in mind, weekly meetings were held on Wednesdays where we selected two to three event days for the following week using the week ahead weather forecast.

The forecast was collected from the Meteo Group, who we use for day-to-day operations (for instance to appropriately plan for upcoming adverse weather). The data was collected in the form of hourly external temperature forecasts. Hourly 'feels like' temperature and wind speed data were also collected for extra data context.

Figure 1 – Map which shows trial one participant locations



Although external temperature is an important variable in heat pump flexibility provision, a single, central temperature point was deemed sufficient for use in selecting event days. ***Figure 1*** shows that participating households were spread across the National Grid license areas and were likely to experience a range of temperatures on any particular day. In order to simplify trial one processes, we accepted the assumption that patterns of temperature variation across time would be consistent across participating households. Bristol weather station was chosen as the central temperature point, and weather stations in Plymouth and Birmingham were monitored to serve as an alert for any large changes in the scale of variation between these locations. The validity and use of this assumption will be revisited in the design of trial two.

Hourly temperatures for the weekdays of the following week were extracted for these three weather stations and stored on a tracking spreadsheet. The average temperature at the Bristol station between 4pm and 8pm (i.e., from one hour before the start of a potential event on that day to one hour after the final end of the event) was calculated.

The spreadsheet also contained the actual average temperature measured between 4pm and 8pm every weekday during the trial period so far. This enabled three actions:

- Comparison of forecast temperatures with actuals. There could be occasional notable disparities between the two, particularly if an event day was chosen to occur later in the week. A Friday event day would occur nine days after it was chosen on the preceding Wednesday.
- The ability to track the spread of temperatures that were observed between 4pm and 8pm on event days that had already occurred, and thus gauge which temperature range (mild, cold, very cold) required more event days to provide a sufficient amount of experimental data.
- The ability to track the spread of temperatures that had been observed between 4pm and 8pm on non-event days that had already occurred, and thus gauge whether the event and non-event day temperatures matched, or whether a certain temperature value needed to be prioritised for a non-event day to improve the baselining analysis.

During each Wednesday meeting, we:

- Used the tracking spreadsheet to gauge which temperature range(s) required more event days and look for temperatures within this range in the following week's Monday to Friday forecast.
- Used the average 4pm to 8pm forecast temperatures to choose two to three event days which met this criterion.
- Ensured that the non-event days chosen maintained a proportional balance between event days and non-event days at similar temperatures.
- Made any adjustments to the chosen days as needed.

Sero and Octopus Energy were then informed of the two to three days chosen to be event days the following week. This gave them plenty of time to prepare the necessary operational elements such as 24-hour messages to participating households informing them of an upcoming event.

Following events, Sero and Octopus Energy provided us with an initial estimate of how many of their recruited participants provided flexibility for that event (rather than opting out) via a separate shared spreadsheet.

5.6.3 Selected Event Days

There were 22 events across trial one. The first three were held in mid-December (the pilot period) to enable the suppliers to confirm that the end-to-end event process worked for both them and their customers, and that data was being collected as intended.

The full trial period in early 2023 saw nine events in January, seven in February, and three in March. Due to participants being informed of events day ahead, a day was typically left between events, barring two exceptions on the 30th and 31st January, and the 20th and 21st February. These consecutive day events were chosen to see how trial participants would respond.

Figure 2 – Time series of trial one events comparing forecast and observed temperatures used for event scheduling

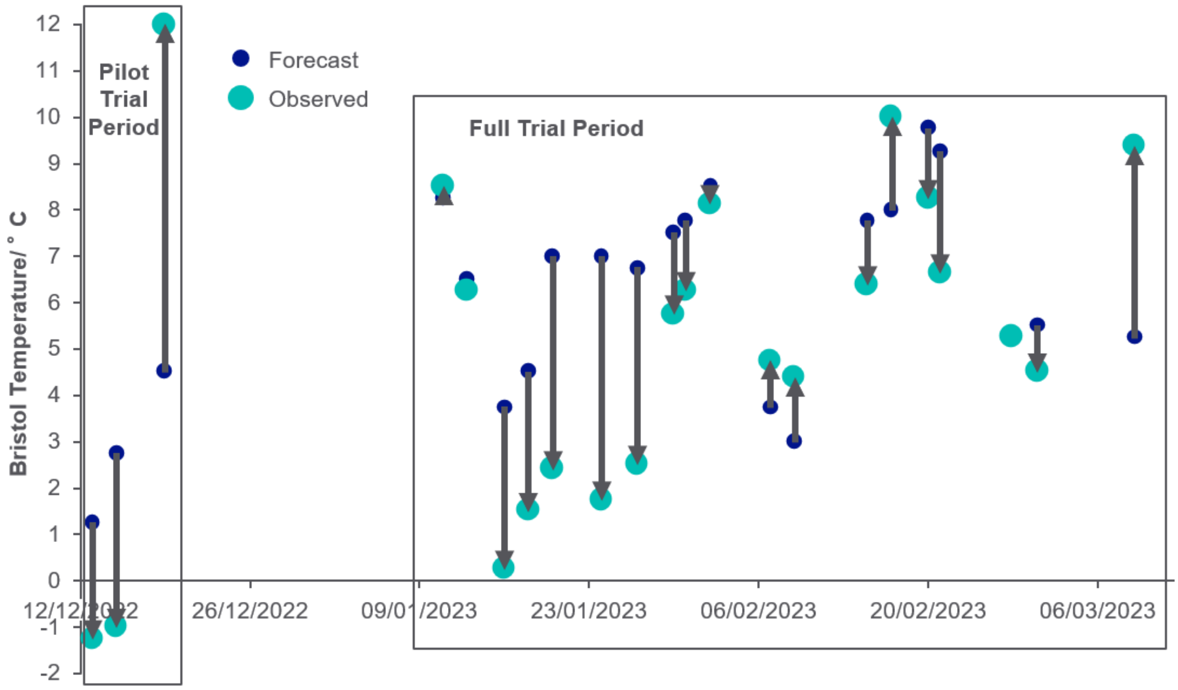
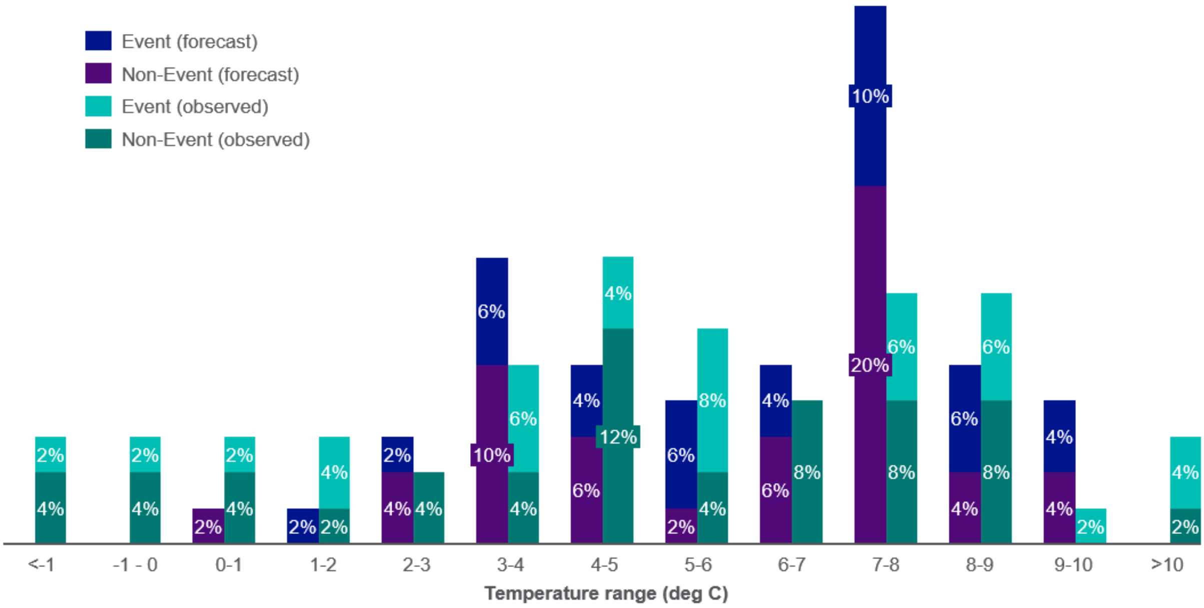


Figure 2 shows a time series marking out the average forecast temperature between 4-8pm in the central Bristol location and the average recorded temperature between 4-8pm in the same location for all 22 event days chosen across the pilot and full trial periods.

Winter 2022/23 had no sub-zero 4-8pm periods forecast in Bristol but experienced a two week "cold snap" in December with sub-zero temperatures followed by a dramatic temperature rise (reported to be +12°C in some locations). This coincided with events in the pilot trial period and caused difficulties with some initial data analysis. In the full trial period, the observed temperature was consistently cooler than forecasted week ahead, as shown on ***Figure 2****.*

Figure 3 – Proportional breakdown of the 4-8pm Bristol temperature ranges across event and non-event days throughout the trial period, for both forecast and observed temperatures



These weather forecasting variations did not prevent trial one events from covering a wide temperature range. ***Figure 3*** compares the proportional breakdown of event and non-event days based on forecast and observed temperatures. Whilst over 80% of the 51 days considered for events during the trial period had forecast 4-8pm Bristol temperatures bunched around 3-9°C, and no days were forecast to have temperatures below 0°C or above 10°C, observed temperatures straddled a wider range. In trial two, it is hoped that more events can cover sub-zero temperature ranges to enable better understanding of the heat pump turndown achievable in very cold temperatures.

As will be discussed later, the temperatures on each event day varied hugely between trial one participant households based on their geographical location, sometimes over almost the entire range covered in ***Figure 3***.

5.6.4 Event Operational Considerations

5.6.4.1 Event Signal Dispatch

The Flexible Power platform was used to schedule and dispatch the flexibility events for EQUINOX in trial one. To interface with Flexible Power, a provider requires an Application Programming Interface (API) which receives the dispatch signals sent by Flexible Power. The API would allow the provider to submit metering data post event. Although this was not a requirement for trial one, the intention is for it to be a requirement for trial two.

The API for Octopus Energy was already implemented prior to the commencement of EQUINOX, whereas the API for Sero was implemented during the course of the project. For trial one, Sero's API was simply set up to receive dispatch signals by Flexible Power, rather than to also submit metering data post event. The creation of this API followed the standard process outlined in the Flexible Power Guide to API Setup & User Acceptance Testing (UAT) Testing[6].

Following the completion of the APIs, a new CMZ was set up in Flexible Power solely for EQUINOX (hereafter 'EQUINOX zone'). This ensured that the project did not impact with BaU flexibility

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[6] The Flexible Power Guide to API UAT testing can be found here.

procurement. Both providers were allocated to the dispatch group in the CMZ which was set up to follow the Sustain flexibility product.

After selection of event days for each upcoming week (see ***Section 5.6.2***), the DSO team declared availability in the EQUINOX zone on the Flexible Power portal by end of day every Wednesday. The availability was automatically scheduled, creating the events for the week ahead.

Flexible Power then sent a start signal to each provider in the EQUINOX dispatch group via an API 15 minutes before an event was due to start. This triggered Octopus Energy and Sero to aggregate the start signal to their participants via their chosen method, as described in ***Sections 5.6.4.2*** and ***5.6.4.3***.

At the end of an event, Flexible Power sent a stop signal to each provider in the EQUINOX dispatch group via an API. Similarly, this triggered Octopus Energy and Sero to aggregate the stop signal to their participants via their chosen method, also described in ***Sections 5.6.4.2*** and ***5.6.4.3***.

5.6.4.2 Octopus Energy Set Up

Octopus Energy had 368 customers involved in trial one. Six customers were eligible for aggregator control of their heat pump for the trial, of which three chose to engage with the product and were enrolled in the trial as aggregator control customers. All three of these customers were allocated to the pay monthly group.

Including the three eligible customers who declined to participate in aggregator control for the trial, 365 customers were onboarded as customer control participants, where each household was responsible for enacting the events. Of note, two households in this group may have agreed to participate in third party aggregator controlled events, if they were facilitated by their existing home management supplier.

Customer control participants were randomly assigned to either pay monthly or pay per event groups. Customers were not given the option to select a preference for which group they would like to be in, and each group was communicated with separately with regards to payment mechanisms. This allocation was done on a semi-rolling basis (three occasions) as recruitment was left open as long as possible for trial one. Across all participants, there were 193 customers in the pay monthly group, with the remaining 175 in the M2 pay per event group.

All outbound customer contact was conducted by email. Almost all inbound customer contact was made via email, with some phone calls and some contact on Twitter. Customer contact relating to the project was managed by specified Energy Specialists who were familiar with the project context and trial mechanics.

Customers were notified day ahead of each upcoming event. These emails were sent in three groups: the aggregator control, the customer control pay monthly, and the customer control pay per event group.

The ‘event invite’ email included the event day, event time, instructions for participating in the event, instructions for opting out part way through the event and a reminder that reporting to Octopus Energy via the post-event survey (see ***Section 6.4***) would be important for data collection.

Aggregator and customer control customers were provided with an opt-out and opt-in link, respectively. Pay per event customers were provided with the incentive structure for the event. This changed after 14 events, as detailed in ***Section 5.3***.

All participants were sent the same reminder email around three hours before the event start at 5pm. All participants were sent the post-event email at approximately 7pm, when the event ended. This included a thank you message, a reminder to complete the survey and a link to the post-event survey.

Participants were paid in bill credit depending on their payment group. The pay monthly group were paid £25 in bill credit around the 10th of each month. The pay per event group were credited for their participation around three days after each event.

5.6.4.3 Sero Set Up

Throughout the trial, participating households were informed of each upcoming event via text and email, both 24 hours and 2 hours before the start of the event at 5pm. Residents could call, email or text to opt out of individual events, before or during any event.

All participating Sero households were in aggregator control trial groups and were randomly split between the pay monthly and pay per event payment types. Sero therefore composed a system to send commands to these homes to turn their heat pumps off and on. The system used an API to send signals via Hypertext Transfer Protocol (HTTP) and then Message Queuing Telemetry Transport (MQTT) to an Internet of Things (IoT) device. Within this device, logic translated that signal into an on/off command to the heat pump via the smart home energy management box installed in the property, the Building Energy Engine (BEE).

To capture failures over the network, Sero set up log-based metrics on the cloud side which alerted them if an error had been detected, such as an off command being sent when the BEE was offline, or the off command being sent but the device not having a heat pump. In case of issues with the on command, there was a fallback mechanism in place on the BEE which turned the heat pump back on at 7:15pm if it did not receive an on command after the event ended at 7pm.

5.6.4.4 National Grid Contact Centre Involvement

If a participant had an issue with their heat pump, either during or outside of event windows, they were told to contact the project partner with whom they normally engage regarding their energy supply (Octopus Energy or Sero). However, given that EQUINOX's participants were located within the National Grid license areas, it remained a possibility that a member of a participating household could contact their contact centre instead. Pre-empting this possibility, National Grid Contact Centre staff were advised to respond to such calls via a two-step process:

- Confirm whether the caller was part of EQUINOX. National Grid's project team used a project 'tag' to alert contact centre staff if they were contacted by a customer who was participating in EQUINOX.
- If the calling household was indeed part of EQUINOX, the handler was to direct them towards the appropriate resource at Octopus Energy or Sero for the issue to be solved.

6. Trial One Impact Evaluation Plan

6.1 Octopus Energy Data

Octopus Energy used smart meter electricity consumption (henceforth 'consumption') data to evaluate the impact of heat pump flexibility on household consumption for trial one. This data was collected and held as part of Octopus Energy's role as electricity supplier for these customers and was available at half-hourly granularity. For the purposes of EQUINOX, site metering in this way had the advantages of familiarity, accuracy, and ease of availability through established systems. There was no requirement for installation of additional hardware. Half-hourly smart meter data is currently the required standard for settlement of flexibility services with National Grid.

The main disadvantage of this approach is that the data represents household consumption in whole and is not disaggregated to show heat pump flexibility in isolation. This created difficulties in identifying changes in consumption caused by trial events, particularly where customers had irregular use patterns of other high consumption appliances (e.g. electric oven) during the event. Being able to measure consumption of the heat pump in isolation (asset metering) would have been preferable but was not widely available. Installation of asset meters was not pursued for several reasons, including costs, logistics, metering accuracy, and compatibility of metering with the diversity of heat pumps in participating homes. For trial one, a premium was placed on breadth of customers eligible to participate and on overall size of the trial cohort. It is expected that further customers will become eligible for the aggregator control group in trial two, which by its nature will also confer asset metering capabilities.

6.2 Sero Data

Monitoring data was obtained during trial one from energy meters (Schneider and Eastron), temperature sensors (Thermokon), and the heat pump system (Mastertherm) installed in participating Sero households. It was collected by the BEE and sent to the Sero centralised database.

The collected data included the following:

- Heat pump energy consumption (5-minute resolution)
- Whole house energy import (and export if the energy meter allowed it) (5-minute resolution)
- Status of the heat pump compressor (on or off) (one-minute resolution)
- Global status of the heat pump (on or off) (one-minute resolution)
- Temperature in the two monitored zones by the thermostat system (one-minute resolution)
- External temperature, as used in the thermostat system (one-minute resolution)

These more advanced sensors allowed for heat pump consumption to be monitored separately, enabling comparison of heat pump demand and whole house energy demand during and after events. This is an additional layer of detail that was unavailable for the Octopus Energy households.

6.3 Demand Response Impact Calculation Methodology

To calculate demand response, both Octopus Energy and Sero used historical customer consumption data (half-hourly granularity) to predict a customer "baseline" that represented the counterfactual on an event day i.e., what consumption would have been expected from each household if the event had not occurred. Demand response impact was then calculated by deducting the observed consumption (during an event) from the expected consumption (the baseline prediction).

The baselining method used for trial one was an adjusted version of the domestic flexibility baseline calculation that was accepted by National Grid ESO for settlement in their winter 2022/23 DFS. The base calculation uses the P376 method for using the ten previous non-event weekdays (excluding holiday days, up to a maximum of 60 days back from the event day) to calculate a projected baseline consumption for each half hour of the event day[7]. The ten eligible days were averaged (weighted equally) by settlement period to produce an unadjusted daily baseline profile.

As in DFS, an in-day adjustment was included to indirectly account for weather effects. In the DFS baseline calculation, the four hours previous to an event are used to determine the in-day adjustment. The observed consumption for the first three of those four hours (event minus four hours to event minus one hour, the 'in-day reference window') is compared to the corresponding baseline values and the difference is averaged and then added to the baseline projections for the event period. The last of those four hours (event minus one hour to event start) is excluded from the in-day adjustment calculation (a 1 hour 'exclusion window').

For EQUINOX trial one, this method was tested with a three-hour exclusion window (event minus six hours to event minus three hour as the in-day reference window, and event minus three hours to event start as the exclusion window). This change from the DFS method was suggested as a way to exclude anticipated customer preheating behaviour from the in-day adjustment period.

Interim analysis performed after the first three trial one events indicated that the absolute mean error of the baselining method (a measure of difference between baseline and observed consumption) was improved by reverting to the same one-hour exclusion window that was used in DFS. Further adjustments were made to adjust the length of the in-day reference window, finding that a one-hour window (rather than a two or three hour window) further reduced the mean absolute error of the baseline. This method was adopted by both suppliers for analysis of trial one data.

To recap, both suppliers adopted the following baselining method for trial one analysis. P376 baseline, which is the mean consumption of the previous ten similar non-event days, per half hourly period with added in-day adjustment. The difference between baseline and observed consumption at event minus two hours to event minus one hour.

Both Octopus Energy and Sero applied the same baselining approach to whole household consumption, with Sero also applying it to the isolated heat pump consumption. Sero also considered another baselining approach called Linear Regression, which performed on par with the adjusted P376 approach.

While there were no concerns around the metering accuracy of observed consumption (settlement standard meters are used), it must be noted that Octopus Energy could not disaggregate heat pump flexibility from household consumption using this methodology. Rather than attempt to do so, it has been assumed that the average demand response observed from the trial one cohort over 22 events can be attributed to the effect of trial participation and therefore be derived from heat pump flexibility. This is an assumption that can be mitigated through consideration of other variables such as customer use of a home battery or of a time of use tariff, and by potentially analysing demand response excluding these customers. Nonetheless, this approach is in line with current business practice and flexibility procurement, where we receive site metering data (not asset metering) to confirm EV flexibility provisions for the DNOs' Dynamic flexibility products. Comparisons to Sero's findings and to findings in later trials with substantial rates of asset metering could be used to reassess findings from trial one.

Use of a predicted customer baseline imparts a measurable uncertainty to the demand response calculation.

6.4 Customer Experience

A multi-pronged approach to capture participant insights was utilised throughout trial one. The aim being to balance the desire to collect information to enable continuous improvement and meet research objectives without overburdening households taking part. The main forms of evaluation were a post-event survey, end of trial survey, focus groups, and interviews.

The post-event survey was a short, two to five question (depending on responses from customers) survey sent by suppliers to households after each event. The survey was sent out after an event had concluded and gathered information about whether households participated in the event and if they

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[7] BSC P376 'Utilising a Baselining Methodology to set Physical Notification', 2023 https://www.elexon.co.uk/mod-proposal/p376/

experienced any temperature discomfort during the event. The response rate to this post-event survey was on average 91% percent throughout all 22 events of trial one.

In addition to the post-event survey, we conducted a longer survey (henceforth 'trial one survey') to capture participant experience and satisfaction, which was conducted towards the end of trial one. It had a very high uptake at 96% percent.

Finally, we conducted qualitative research through focus groups and interviews to understand how, if at all, participating in the trial impacted the daily lives of trial one participants and to get deeper insights on their experience with the processes of the trial. These took place following the completion of trial one. Nine one-to-one interviews and three focus groups were completed to gain additional insights of participant views, especially on nuanced questions related to motivations for participation, satisfaction, impact on comfort, and barriers to participation. The focus groups and interviewees were segmented based on control type, payment type, and participants with potential vulnerabilities to understand how those aspects impacted perceptions and experience in more depth.

7. Trial One Results

7.1 Introduction

The trial one results are split into three categories.

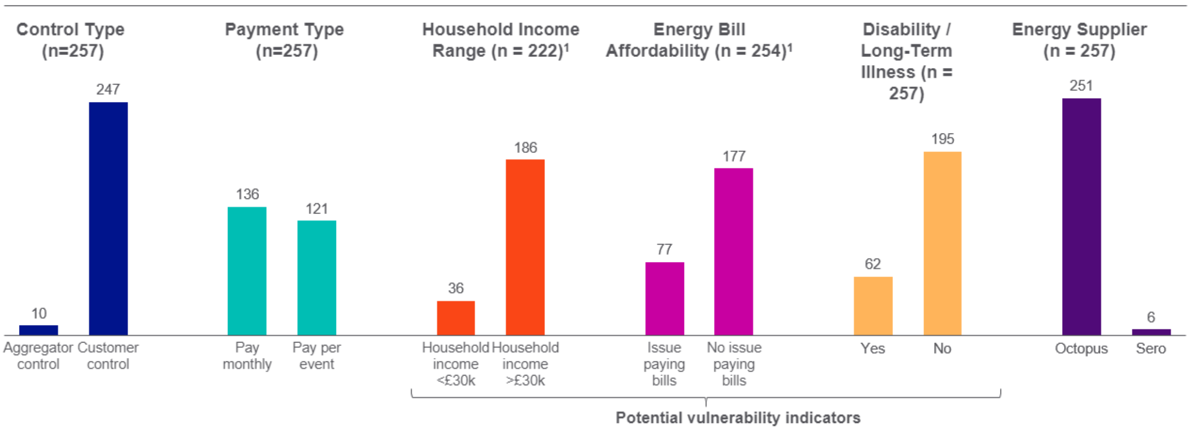
- Participation Rates: The proportion of recruited households who participated in each EQUINOX event. For customer control households, participation was largely self-reported through the post-event surveys, with energy usage data being used occasionally to validate participation for customers who did not fill out the surveys. For aggregator control households, energy usage data was used to validate participation.
- Turndown: The kWh turndown achieved per household per event. This has been considered from a per participating household and a per recruited household perspective (the latter includes the figures from recruited households who chose not to participate in specific events). The average kW turndown achieved per customer has also been calculated to estimate impact on household demand.
- Participant Feedback: Collating feedback on various elements of trial logistics, participation motivation, and satisfaction from the post-event surveys, trial one survey, interviews, and focus groups.

7.2 Participant Demographics

It is important for the trial one survey results to be grounded in an understanding of the demographics of the households who took part. In trial one, there were 386 customers participants, with 368 of these being Octopus Energy customers and 10 being from Sero. This rose to 18 Sero customers by the time of the final events.

The customers who consented to their contact details being shared with Guidehouse and NEA, who were completing customer research for the trial, were invited to take part in the trial one survey, interviews, and focus groups. ***Figure 4*** below provides insights on the characteristics of the 257 trial participants who took part in the trial one survey helping us to get an understanding of the trial one participants.

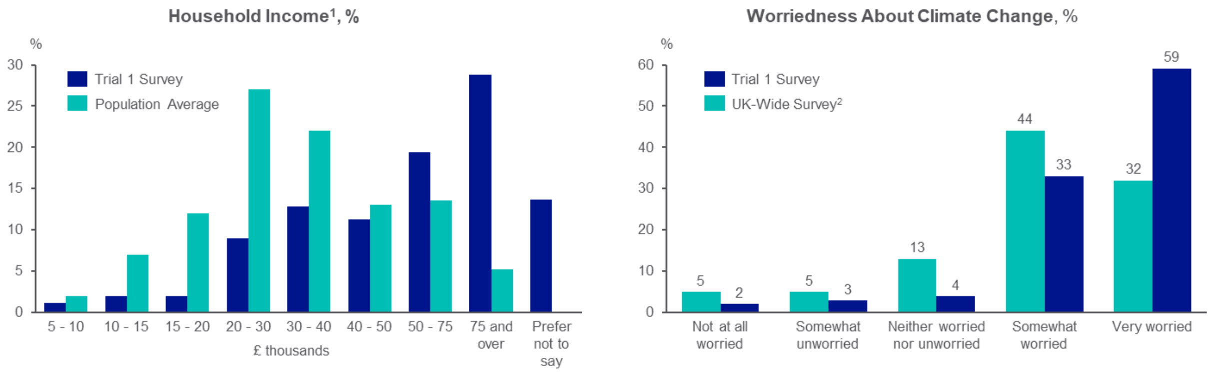
Figure 4 – Number of survey respondents segmented by different variables



Segmentation was performed along the lines of control and payment type, household income range, energy bill affordability, disability and long-term illness, and household energy supplier. The number of respondents across each variable generally allowed comparative conclusions to be drawn. However, it should be noted that direct comparison between the aggregator and customer control households is somewhat limited. This is due to the small number of aggregator control households who participated in the trial (10) relative to the number of customer control households who participated (247). Furthermore, there were differences in internal processes (namely the different event notification delivery channels) and customer profiles between the two trial one energy suppliers. These posed additional limitations when it came to drawing direct comparisons between the two customer groups during trial one.

In general, trial one households had higher annual income than the UK population average[8] as depicted in ***Figure 5***. They also reported that they were able to pay their energy bills with little to no behaviour change required despite the energy crisis.

Figure 5 – Comparison of the household income and worriedness about climate change for EQUINOX trial participants and the UK population average



Trial one participants were also more environmentally aware and anxious about climate change[9] than the UK population average, with an overarching majority of 92% reporting they were ‘Very worried’ or ‘Somewhat worried’ about the impact of climate change compared to 76% from the UK-wide survey EQUINOX undertook in August 2022[10]. Likewise, 17% of trial participants (as identified by the trial one survey) noted that they are currently, or were previously, employed in a role related to the energy industry or the environment. This is significantly larger than the approximate 2% of the UK population who work in energy industry[11], and the 2.2% of new UK jobs in 2022 which were classed as ‘green’[12].

As one of the research questions for EQUINOX was to understand the ability of different types of customers to benefit from flexibility offerings, we utilised three indicators from the survey data to identify customers with vulnerabilities. These indicators were participants that had a household income under £30,000 annually, had reported problems paying their energy bills consistently, or had an occupant with a disability or long-term health condition. These three indicators were used to assess if the trial had any disproportionate impact on comfort or satisfaction for customers with potential vulnerabilities. A third of households who completed the trial one survey (85/257) met one or of the criteria for vulnerability[13]. It is acknowledged that these are imperfect indicators due to the complexity of vulnerabilities, and that the trial may have missed other characteristics that make a household vulnerable. We will build on this research in later trials by the use of targeted recruitment to capture a wider demographic of vulnerability indicator.

7.3 Participation Rates

If a household turned off or down their heat pump for at least 30 minutes of the event period, they were deemed to have participated in the event. An average of 82% participants took part in each event by providing heat pump demand response. Event four saw the highest participation at 92%.

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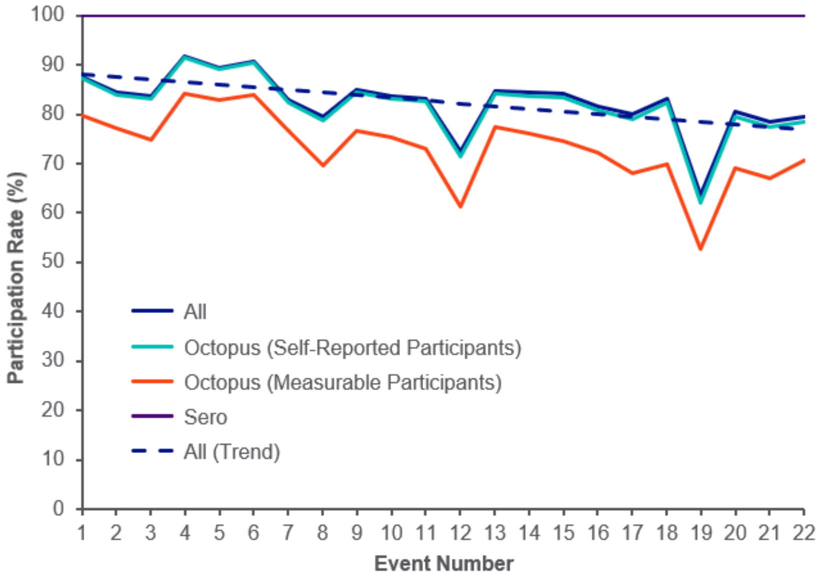
[8] UK-wide figures taken from Office for National Statistics, Census 2021
[9] UK-wide figures taken from Customer Perceptions on Unlocking Flexibility from Heat, 2022
[10] Customer Perceptions on Unlocking Flexibility from Heat, 2022
[11] Based upon the 743,000 people who are directly or indirectly employed in the energy sector (Energy UK, 2022) compared with a UK labour market of 33 million people (House of Commons, 2023)
[12] PWC, 2023
[13] Note that not all households completed the survey or these questions and many did not consent to their supplier sharing their details with Guidehouse to receive the survey which is why these figures do not align with total participating households.

Figure 6 – Event-by-event participation rates, overall and by supplier[14].



As ***Figure 6*** demonstrates, overall participation rates in events remained relatively high throughout the trial period. However, average participation did fall from 88% from event one to 77% by event 22, suggesting trial fatigue amongst a gradually increasing proportion of participating households. There was no correlation between temperature and participation level.

Most events had two or more days between them. For the two events held the day after the previous one, the two lowest participation rates occurred. These were events 12 and 19, which has participation rates of 72% and 64%, respectively. Both represented the second of two consecutive event days. The causes of these dips in participation were not investigated but do not necessarily represent trial fatigue as there were anecdotal reports of customers being unaware that they had been notified of a second event immediately following the first event. A re-examination of operational process for consecutive events is planned for trial two.

Sero's cohort of homes participated for the full two hours in all 22 events. Since they were all aggregator controlled, their participation was directly recorded by Sero.

Octopus Energy's household participation rate (almost all customer control control type) was variable but consistently high. Excluding events 12 and 19, the average Octopus Energy household participation as collected in the post-event surveys ('self-reported participants' in ***Figure 6***) was 83%, with 77% being the lowest participation rate. Across all 22 events, Octopus Energy household's participation averaged 82%.

When segmenting the self-reported participation data from the trial one survey using the three vulnerability indicators mentioned above, households who reported having one or more of these characteristics were no less likely to participate in EQUINOX events than households without these characteristics.

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[14] For Octopus Energy, participation was measured two ways. Self-reported participation was gathered through a typeform survey administered after each event. Measurable participation rejects trial participants with sub-zero baselined (predicted) consumption during that event, and those whose smart meter did not provide a full set of half-hourly meter readings for that event (both of which impact the ability to properly calculate an estimate for that household's turndown). The 'All' series uses the self-reported Octopus Energy participation figures, since the measurable figures are unlikely to capture all those who turned their heat pump off/down during the event.

Figure 7 – Breakdown of responses to the trial one survey question asking participants whether they have chosen not to participate in at least one EQUINOX event

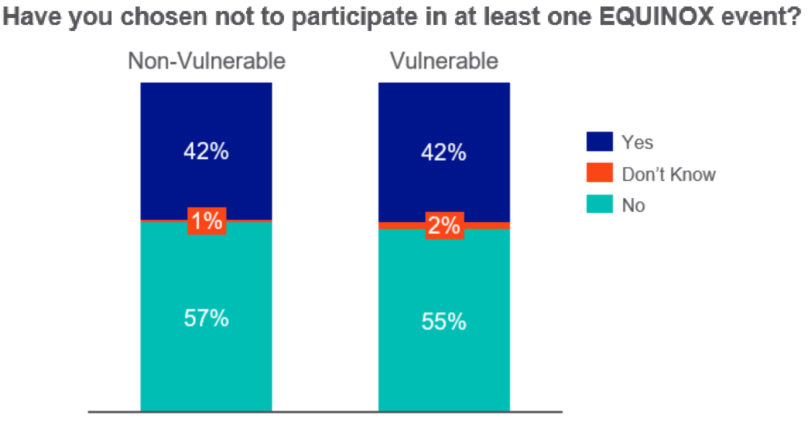
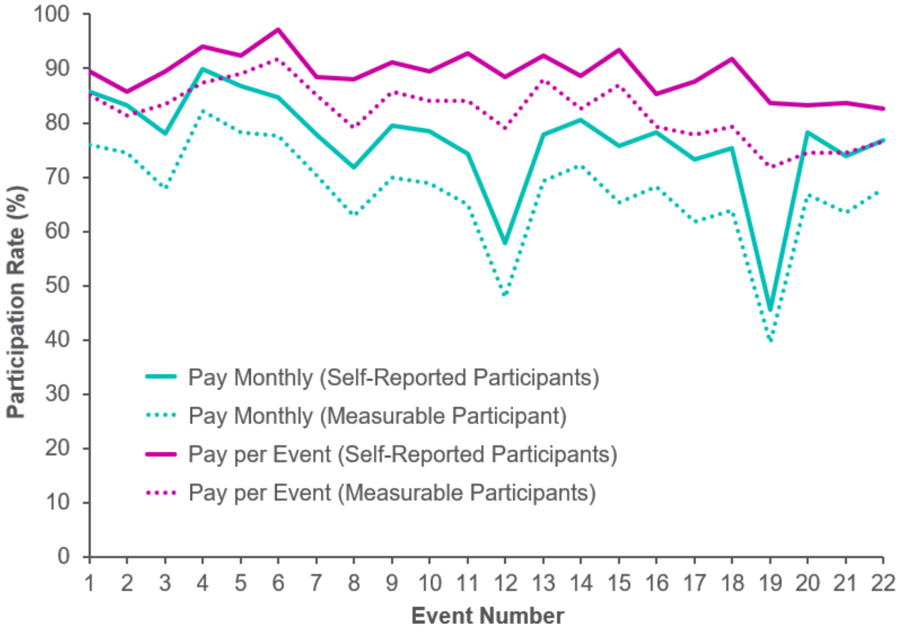


Figure 7 that households who reported having one or more vulnerability criteria had about the same likelihood to report participating in all or choosing not to participate in at least one EQUINOX event as participants without these characteristics.

7.3.1 Participation by Payment Type

Segmenting both self-reported and measurable participation rates between pay monthly and pay per event households reveals consistently higher participation by households being paid for their participation after each event. ***Figure 8*** shows that the pay per event participation rate exceeded that of the pay monthly group for all 22 events, often by more than 10%.

Figure 8 – Event-by-event participation rates by payment type

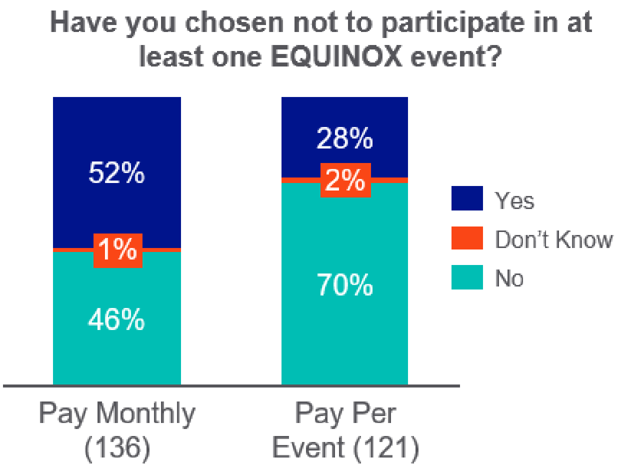


The pay per event and pay monthly average participation rates (using self-reported figures, including the Sero and Octopus Energy aggregator controlled homes) were 77% and 89%, respectively. For event 5, a high of 97% of pay per event households participated. Pay per event participation never fell below 80%.

Recall in that overall participation dipped for consecutive day events 12 and 19. ***Figure 8*** clearly shows that pay per event households were more likely than pay monthly households to participate in both events.

Whilst only one quarter of pay per event households chose not to participate in an event, over half of pay monthly households did so as shown in ***Figure 9***.

Figure 9 – Breakdown of responses by household payment type to trial one survey question asking whether households had chosen not to participate in at least one event



Of the 121 pay per event households who responded to the trial one survey, 70% participated in all 22 events compared to 46% of pay monthly customers. Combined, these findings suggest that pay per event households were more committed throughout the trial, perhaps driven by the constant incentives of a £6 payment for participating. The fixed payments for the pay monthly group may have disincentivised certain households from participating in as many events, even though a pay per event household participating in 17/22 events would have earned no more than a pay monthly household earned across the trial.

7.3.2 Participation by Control Type

Aggregator controlled households had a 100% participation rate across all events. Whilst the sample size was small (18 Sero households and 3 Octopus Energy households), this was markedly higher than the customer control group.

Figure 10 shows the event-by-event participation rates segmented by control type. Aggregator controlled households participated in all 22 events. Despite the small sample size this finding provides early evidence that aggregator controlled heat pumps can provide the most reliable participation rates. This correlates with the findings of aggregator control studies in France and the USA[15].

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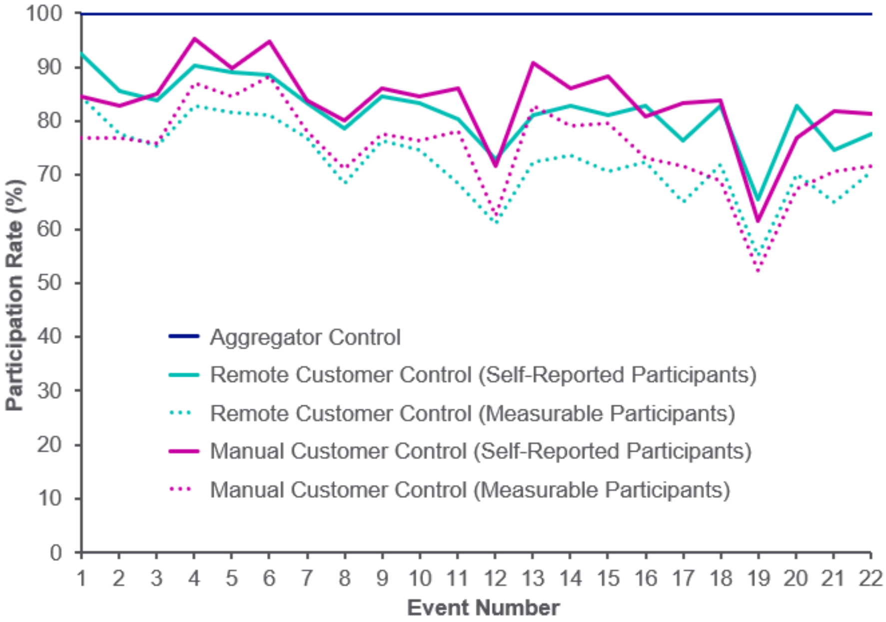
[15] See the Equinox Horizon Scan for more details

Figure 10 – Event-by-event participation rates by control type



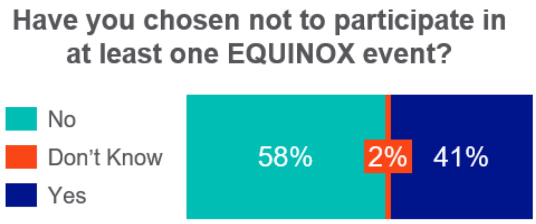
As previously stated, two types of customer control were observed within the Octopus Energy households: those who could control their heat pump remotely via an app, and those who had to manually turn off their heat pump or turn down their thermostats. ***Figure 10*** shows that the participation rates between these manual and remote customer control subgroups were largely consistent throughout the trial, averaging 84% and 82%, respectively. This suggests that being able to control the heat pump remotely did not make a household more likely to participate than a household that had to physically interact with their heat pump. This is unexpected given that customers reported the most likely reason for non-participation was not being home to control the heat pump as discussed in ***Section 7.3.3*** below.

Trial two will have a larger pool of aggregator controlled households, enabling more robust validation of whether aggregator control participation is indeed higher than customer control participation, as suggested by trial one findings.

7.3.3 Reasons for Partial or Non-Participation

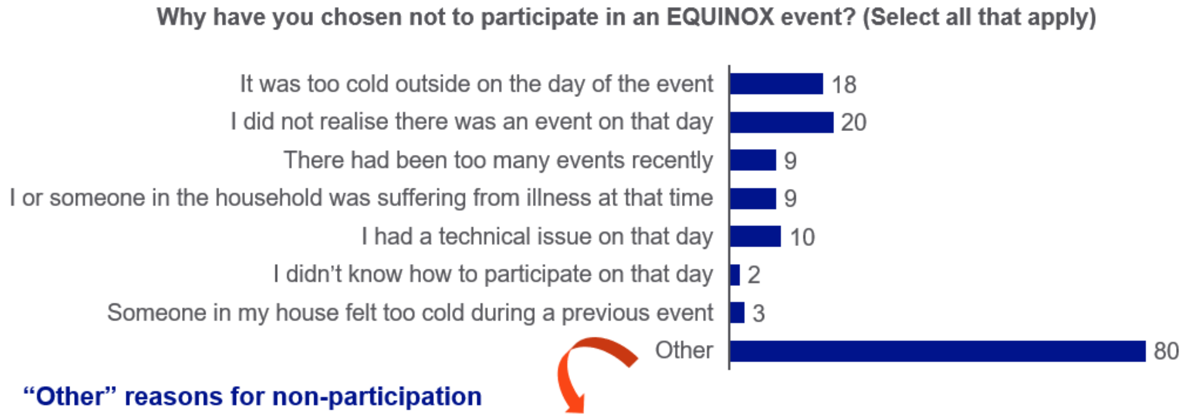
The trial one survey asked customer control participants whether they had chosen not to participate in one or more events across the trial. As shown in ***Figure 11***, almost 60% of them reportedly participated in all 22 events.

Figure 11 – Breakdown of responses to the trial one survey question asking whether participants had chosen not to participate in at least one event



When reasons for non-participation were investigated in a follow-up question, as shown in ***Figure 12***, the most common reason was that there was no one home to action the request for demand response. Not realising that there was an EQUINOX event and it being too cold outside were also commonly cited reasons for non-participation.

Figure 12 – Breakdown of responses to trial one survey question asking those who indicated that they had chosen not to participate in an event and their reason(s) for doing so

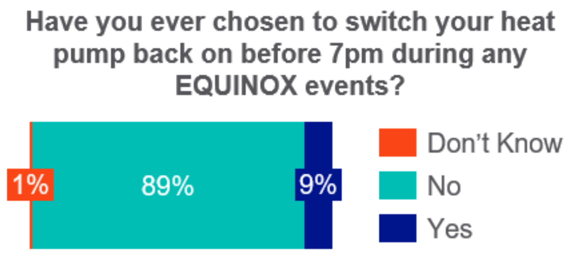


"Other" reasons for non-participation

Not at home	Not convenient	Visitors	Other	Tech set up	Forgot
60	3	6	7	4	2

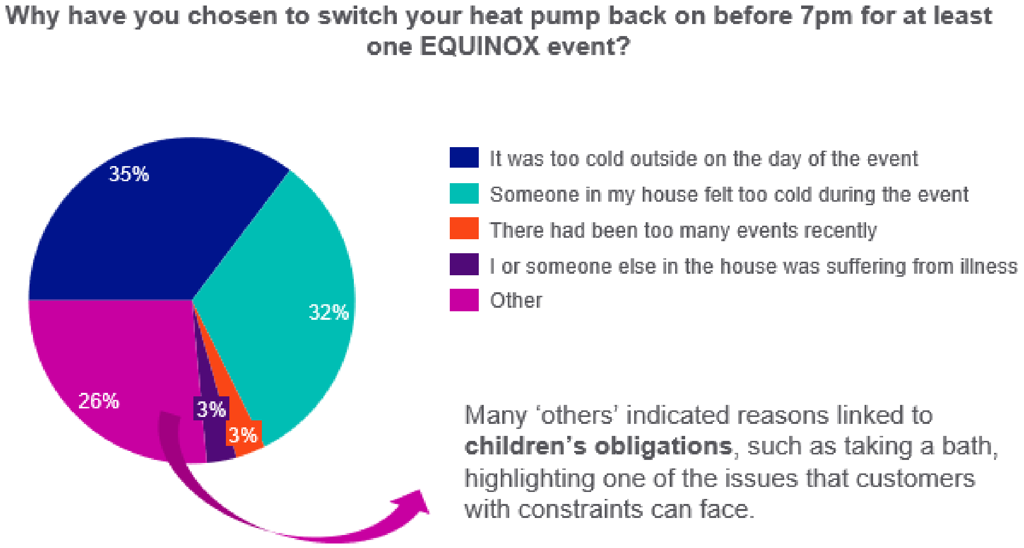
Considering that a household providing demand response for at least 30 minutes was deemed to have participated in an event, it was also sought to understand how many customer control participants kept their heat pump off for the full two-hour event window. The trial one survey asked participants whether they had ever switched their heat pump back on prior to the end of the event. ***Figure 13*** shows the results breakdown. Approximately 90% of participants reported providing heat pump demand response for the full two hours.

Figure 13 – Breakdown of responses to trial one survey question asking whether participants ever chose to participate in an event, but not for the full two-hour window



For those customers who reported non-participation for a full two-hour event period, the most common reasons were related to feeling too cold, as shown in ***Figure 14***. Several participants also mentioned obligations relating to looking after children, like cooking dinner or running a bath, in which their heat pump needed to be switched back on.

Figure 14 – Breakdown of responses to trial one survey question asking those who indicated they had chosen not to provide heat pump demand response for the full event window their reasons for not doing so



7.4 Turndown

Across all 22 events, the average measurable event participant provided 1.47 kWh of turndown per event[16]. This corresponds to 0.75kW per half hour settlement period[17]. Note that this is turndown measured at the smart meter level, so does not solely account for heat pump turndown. Nevertheless, the turndown is above 0.8 kWh for all events and there is a discernible relationship between the turndown figures and the external temperature as shown in ***Figure 19***. This suggests that the heat pump demand response is a significant part of the turndown.

Figure 15 – Event-by-event average household turndown for all participating households and all recruited households

[16] Measurable participants do not include trial participants with sub-zero baselined (predicted) consumption during that event, and those whose smart meter did not provide a full set of half-hourly meter readings for that event (both of which invalidate estimates for that household's turndown).
[17] kW has been derived from half hourly smart meter data so represents an average kW figure for each half hour period.

Turndown peaked above 3kWh for the first two events as shown in ***Figure 15***. These two events were the coldest of the trial, but may have experienced a change in customer behaviour related to the novelty of the trial.

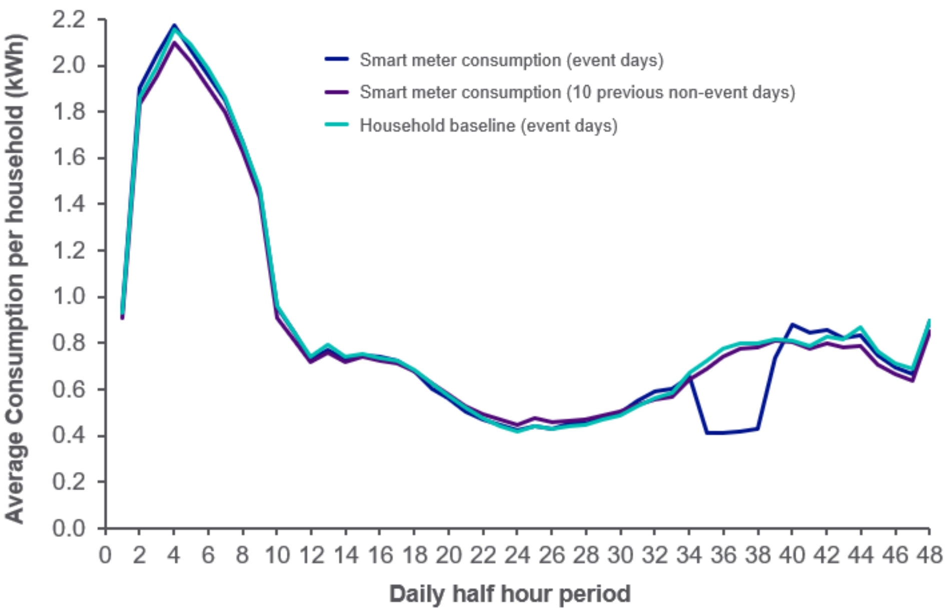
Figure 15 also demonstrates that accounting for trial households who did not participate in each event does not significantly reduce the average household per event turndown, which goes down by only 0.04 kWh to 1.43 kWh. This could be explained by two factors:

- Event participation rates were generally strong as outlined in ***Section 7.3***. The non-participation figures only exceeded 100 households once across the trial and were always strongly outnumbered by the participation figures.
- Non-participants had observed turn down across almost every event that they did not provide heat pump demand response for. This spill-over effect is discussed further in the following section.

7.4.1 Octopus Energy Participants

All Octopus Energy turndown data relates exclusively to the smart meter consumption. As shown in ***Figure 16***, participating households collectively delivered clearly visible turndown in household consumption throughout trial one. On average, there was approximately 1.5 kWh of turndown per actively participating household. This corresponds to an average 420kWh of turndown per event across an average of 270 customers.

Figure 16 – Half-hourly smart meter and baselined consumption profile for the average Octopus Energy trial household across the trial period (kWh)



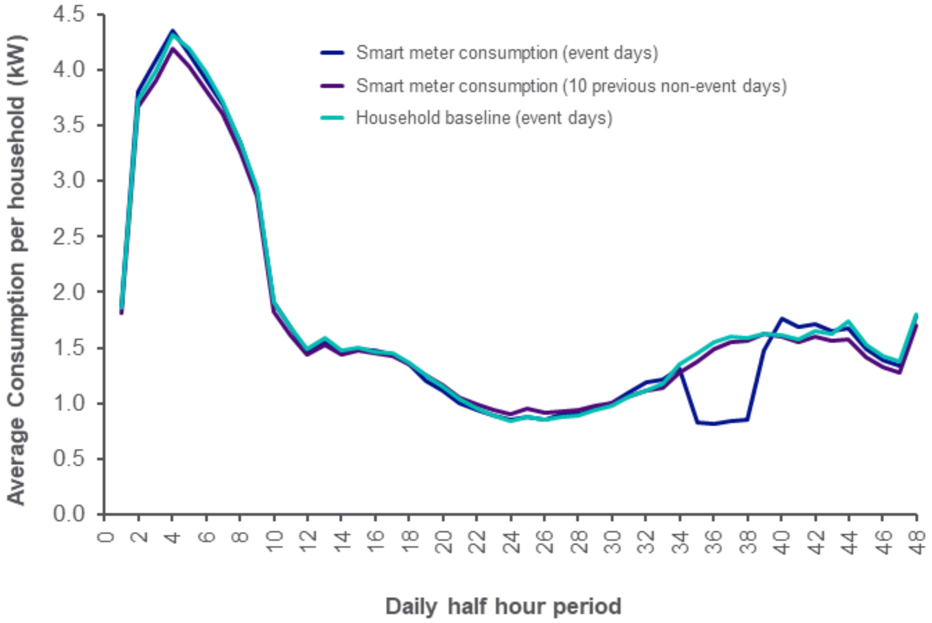
As ***Figure 16*** above illustrates, gradually increasing consumption between 5-7pm on non-event days was replaced with a sharp drop at 5pm and flatlining consumption to 7pm. The figure also shows that the baseline for the event days closely followed the average household consumption on recent prior non-event days, providing confidence in the turndown calculations.

Note that the large overnight spikes across event and non-event days are attributed to time of use tariffs that provide a price incentive for customers to shift large consumption loads to the overnight period (such as electric vehicle charging).

Figure 17 provides a view on kW turndown as derived from half hourly smart meter data. This represents an average kW figure for each half hour period, and it therefore should be noted that this will not demonstrate peak real power demand. On average, there was an approximate 0.75 kW reduction per participating household, which without diversity would correspond to a reduction of

210kW for the two-hour period per event across an average of 270 customers[18]. For example, to obtain a 210kW turn down of load upon a network constraint, 270 participating customers would be required to this turn down. In the real world, this will also be dependent on the amount of diversity in customer turn down behaviour. Further trials will provide evidence of this diversity.

Figure 17 – Half-hourly smart meter and baselined consumption profile for the average Octopus Energy trial household across the trial period (kW)



Snapback was observed post-event. Use of smart meter data means we are unable to discern the peak kW snapback value, but the average snapback was 0.45 kW over one hour. This is smaller than the pronounced snapback seen for Sero households as shown in ***Section 7.4.2,*** but not insignificant. This could be attributed to a diversity in customer behaviour for time of turning on their heat pump after the event, or to customers turning down their temperature set point for the event rather than turning off their heat pumps, or to a presumed diversity in water heating behaviour and schedules that is not present in the Sero households.

Since Octopus Energy households made up the majority of trial one households, the event-by-event average turndown series shown in ***Figure 18*** looks almost identical to that of ***Figure 15***, but with a slightly higher overall average turndown of 1.53 kWh per participating household per event. ***Figure 18*** also compares the event-by-event average turndown between event participants and event non-participants.

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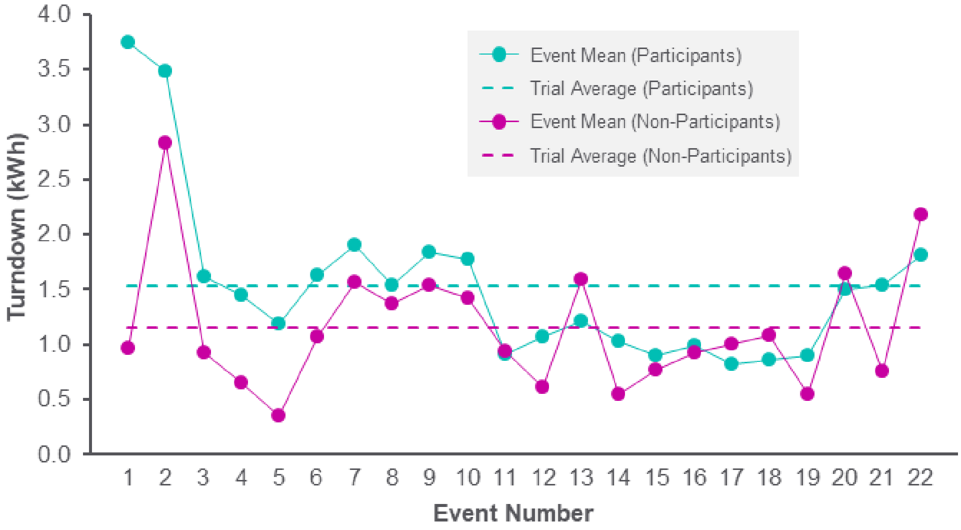
[18] kW has been derived from half hourly smart meter data so represents an average kW figure for each half hour period. In future trials, it is anticipated than HP specific monitoring will be installed in a sample of homes to allow us to understand real power demand and therefore the network impact of events.

Figure 18 – Event average Octopus Energy household turndown during the event period per measurable event participant and non-participant

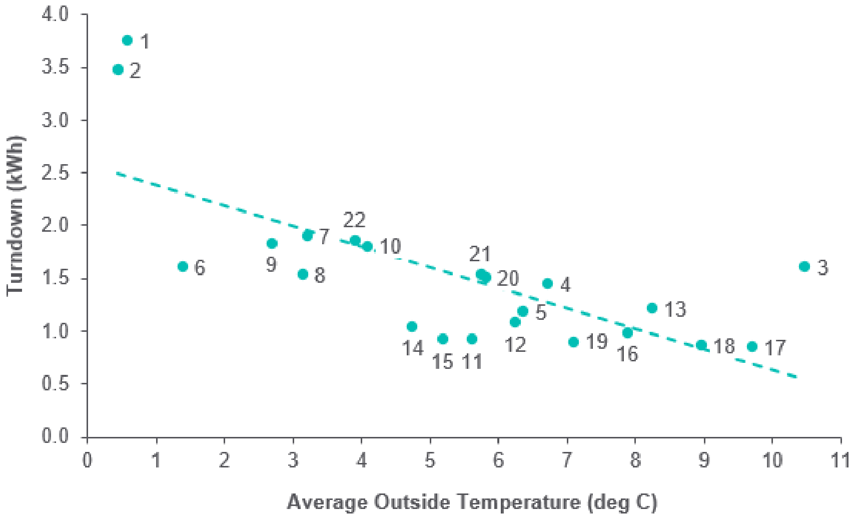


Whilst participation rates were high, this alone does not explain why the per event turndown averaged with all recruited household is so close to the turndown averaged per participating household. The figure shows that average (mean) non-participant turndown was also measured above 0 kWh for every event.

Although there are significant difficulties in accurately baselining customer consumption over small groups of individuals or over short periods of time, this data could also indicate a wider behavioural change among trial households that arises as an effect of being in the trial In some cases, being a part of the trial and aware of an event may have stimulated the delivery of demand response from other sources by customers who did not participate in turning down or off their heat pump. There is anecdotal evidence that some participants avoided using their oven and generally tried to minimise their electricity usage during events just to see if they were capable of changing their practices.

Understanding specific heat pump turn down versus inherent variation in home consumption versus unintended behavioural effects is a key area that will be examined in more detail, with larger sample sizes, in trial two.

Figure 19 – Event-by-event household turndown per participating Octopus Energy household across 5-7pm plotted against the average outside temperature between 5-7pm[19]



Although temperatures for each household varied greatly within each event day, the average of those local temperatures (which is similar to the central temperature that was used to select event days) is shown in ***Figure 19*** alongside the average turndown measured for each event. An inverse linear relationship of temperature and flexibility is expected, as the operating efficiency (the amount of electricity used to produce a unit of heat) of a heat pump decreases with decreasing temperatures. When it is colder out, heat pumps will both generate more heat in order to maintain the home's temperature set point and will begin to consume additional electricity in order to generate each unit of that heat. There is therefore a greater amount of consumption that could be shifted out of the event period (i.e. a greater turndown is possible at lower external temperatures).

The ability of heat pumps to reduce demand during events on very cold days is of particular importance to National Grid as these are the conditions in which demand shifting is most likely to be required. Trial two will explore this relationship in greater detail.

7.4.2 Sero Participants

Sero's trial results were enhanced by the ability to measure heat pump consumption directly alongside smart meter consumption. ***Figure 20*** illustrates half-hourly heat pump and smart meter consumption for the average trial household across both event and non-event days. Recall that all Sero households fully participated in all 22 events. On average, there was 0.61 kWh of heat pump turndown per participant per event.

In ***Figure 20***, the event turndown can clearly be seen between 5-7pm as the heat pump consumption drops close to zero.

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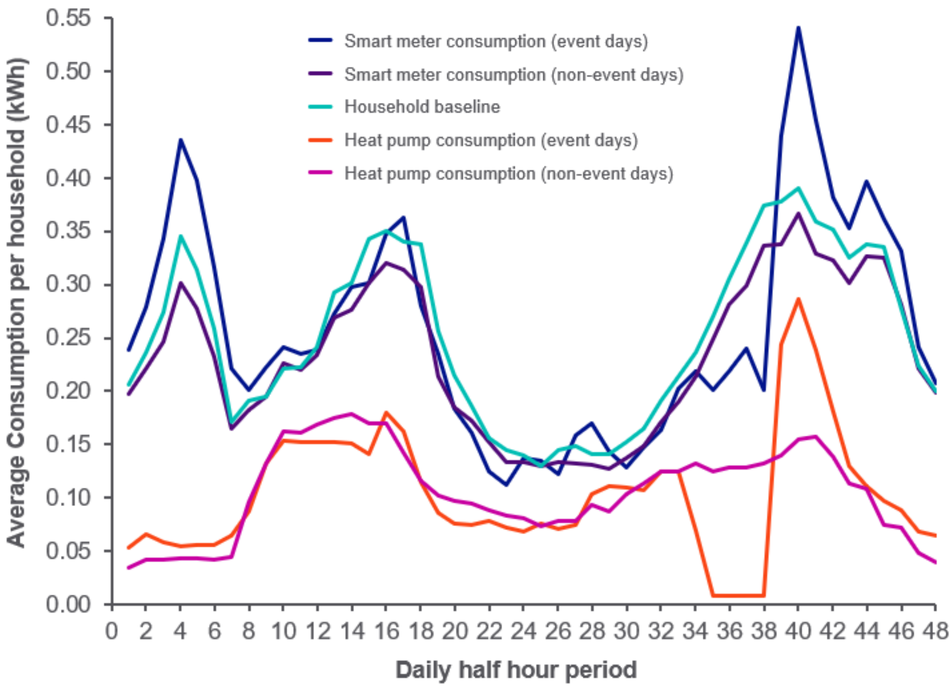
[19] External temperature taken from the nearest weather station to each household's postcode. Temperature between 5-7pm averaged. This was then averaged across all households who participated in each event.

Figure 20 – Half-hourly consumption profile for the average Sero home across the trial period, for both smart meter and heat pump consumption on both event and non-event days, plus the smart meter baseline (kWh)



Even more stark, however, is the spike, or *snapback*, which occurs at 7pm when all households' heat pumps were automatically turned back on. Heat pump consumption in the 7-8pm window was almost double that on non-event days.

At the smart meter level, rising non-event day demand between 5-7pm is replaced by flatlining household demand on event days. The aforementioned snapback is equally visible at the smart meter level as at the heat pump consumption level.

Two main reasons have been raised for this snapback:

- Sero's aggregator control involved fully switching the heat pump off, resulting in a large instantaneous energy need once the compressor turned back on.
- Sero household hot water settings resulted in water needing to be heated immediately post-event, increasing immediate heat pump demands. There was no automated pre-heating period built in to account for the events.

Several methods for reducing this snapback have been proposed for trial two:

- Using temperature set points rather than a crude heat pump switch off/on should minimise the snapback by reducing the energy needed to fire up the compressor.
- As home digital twin simulation results detailed in ***Section 8.2*** demonstrate, optimising heat pump demand profiles to account for upcoming events could reduce overall heat pump consumption (e.g., by pre-heating).
- Changing domestic hot water set points and heating demand profiles could also reduce the post-event snapback.

From a network perspective, efforts to reduce this snapback will be a crucial element of trial two since the post-event spikes could end up posing more of a threat to network stability than the 5-7pm demand if the Sero results were replicated across thousands of homes.

Figure 21 provides a view on kW turndown. On average, there was an approximate 0.3 kW reduction in heat pump consumption for participating households per event. The average snapback was 0.55 kW over the one-hour after the events.

Figure 21 – Half-hourly consumption profile for the average Sero home across the trial period, for both smart meter and heat pump consumption on both event and non-event days, plus the smart meter baseline (kW)

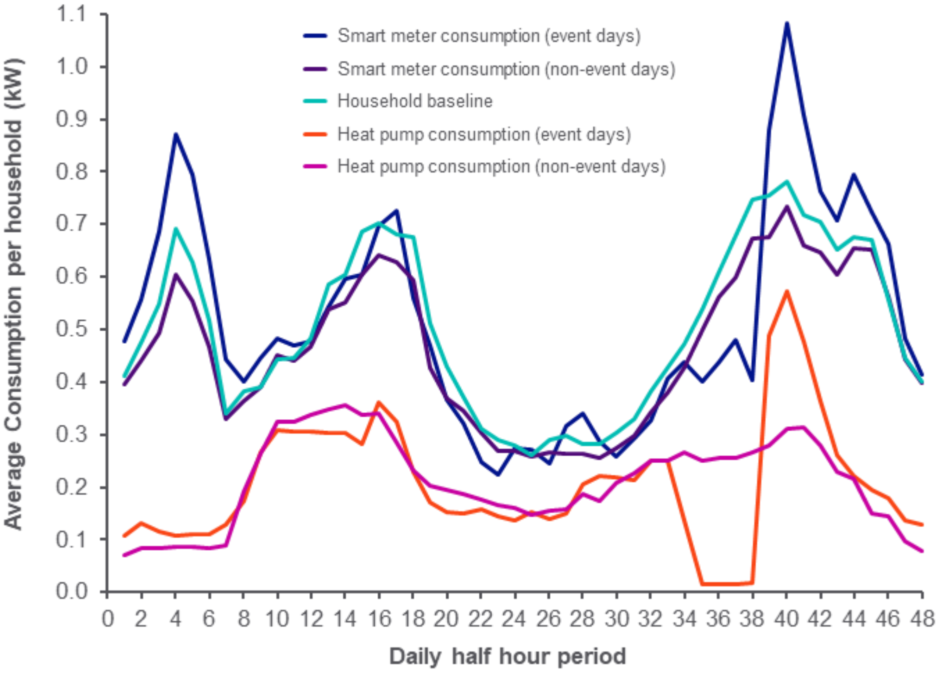
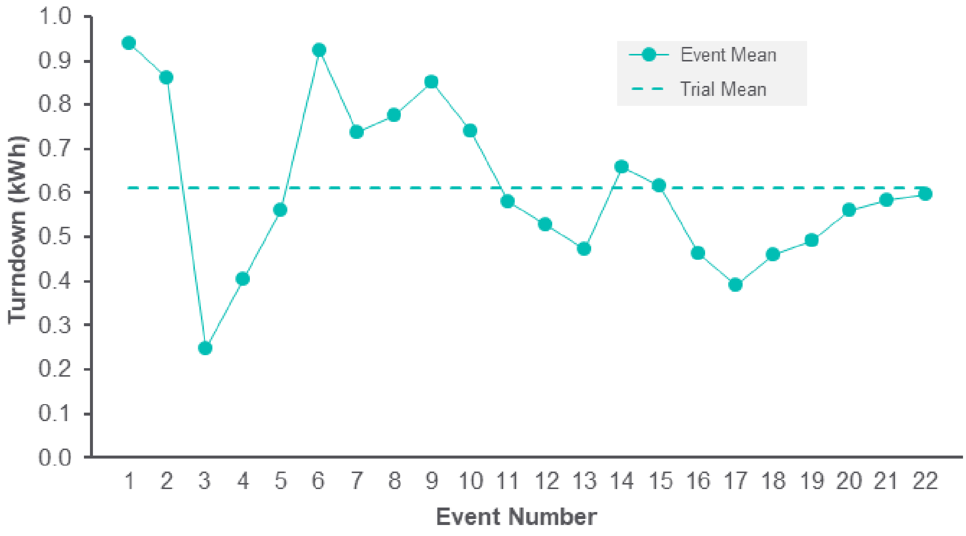


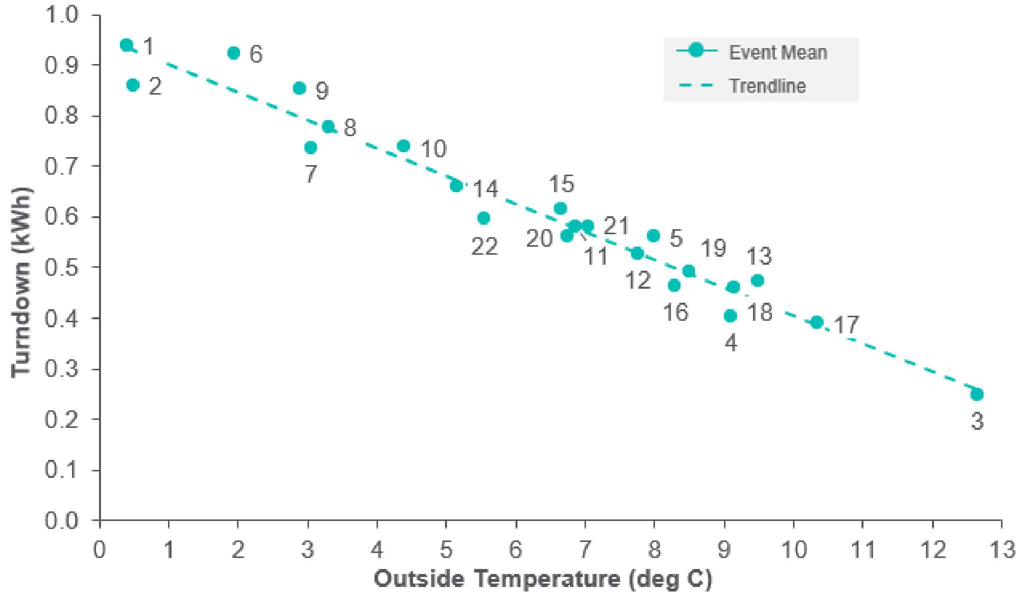
Figure 22 shows the average per event heat pump kWh turndown. The average across the trial was 0.61 kWh per household per event.

Figure 22 – Event-by-event average heat pump turndown per participating Sero household between 5-7pm



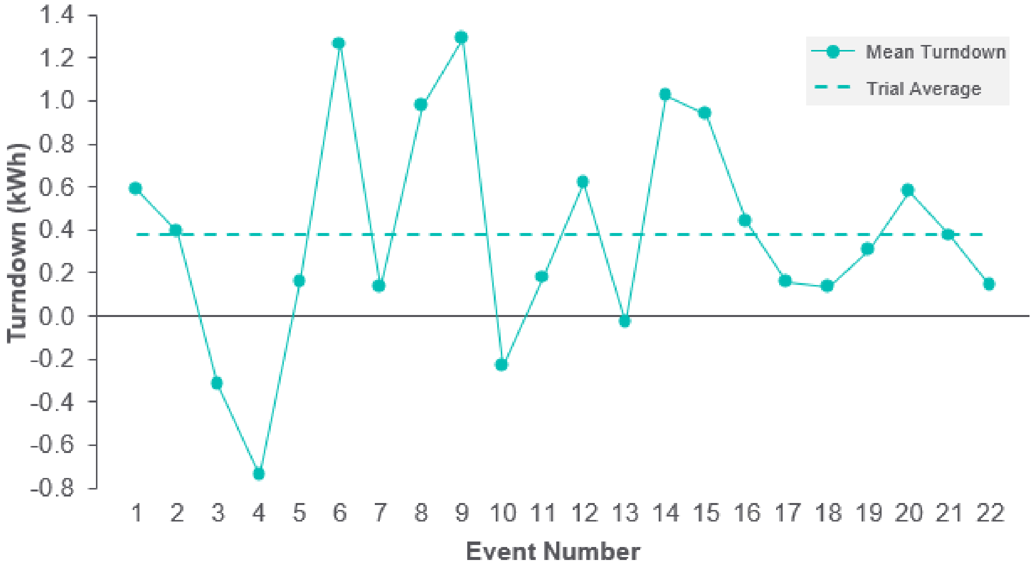
Whilst the turndown appears to fluctuate quite randomly, the turndown becomes remarkably predictable when plotted against each event's external temperature during the event period, as illustrated in ***Figure 23***. The relationship between the two is almost perfectly linear – as the temperature increases, the achievable kWh turndown decreases. This predictability will be a benefit to aggregators providing heat flexibility services though there will still be an element of uncertainty around the accuracy of temperature forecasts and participation rates.

Figure 23 – Mean event heat pump turndown per participating Sero household between 5-7pm plotted against average external temperature[20]



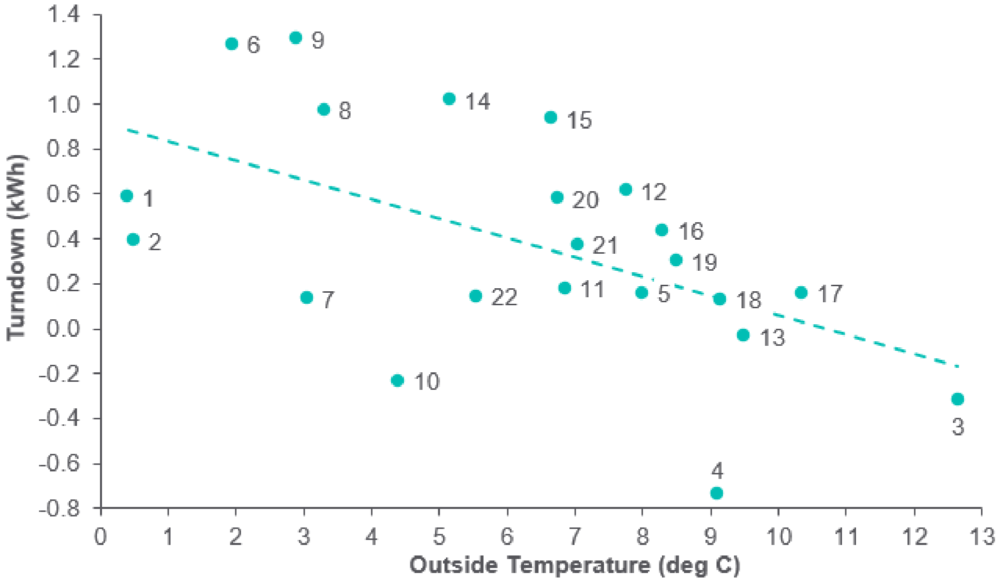
At the smart meter level, the average household turndown per event was smaller, at 0.38 kWh. The household turndown per event fluctuated more than the heat pump turndown, as shown in ***Figure 24***. The turndown-temperature relationship is correspondingly less convincingly linear for household turndown than heat pump turndown, but the trend remains discernible, as seen in ***Figure 25***. This less direct correlation is due to the influence of other sources of electricity consumption varying more unpredictably during event periods against each household's baseline.

Figure 24 – Event-by-event average household turndown between 5-7pm per participating Sero household



[20] Note that all Sero households were located on one new-build estate, so the external temperature was consistent across all participating households.

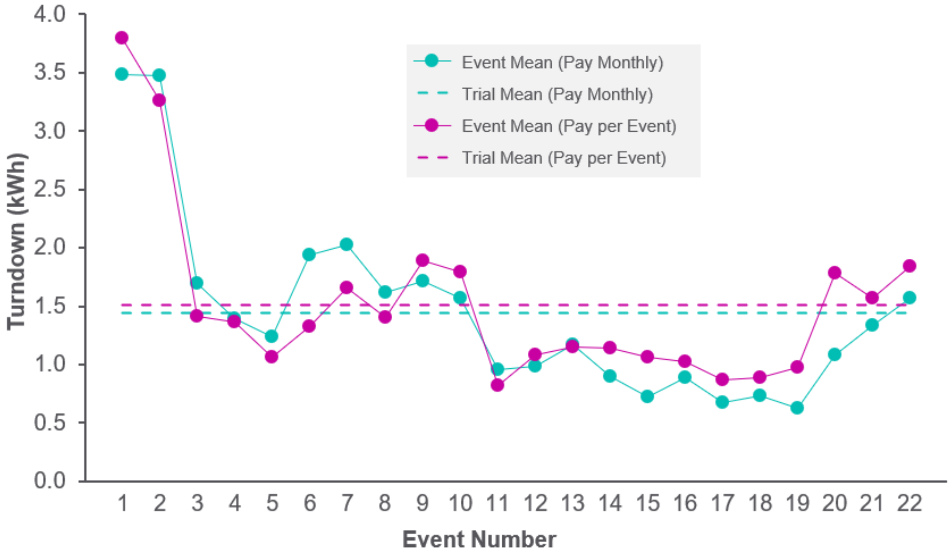
Figure 25 – Mean event household turndown per participating Sero household between 5-7pm plotted against average external temperature



7.4.3 Turndown by Payment Type

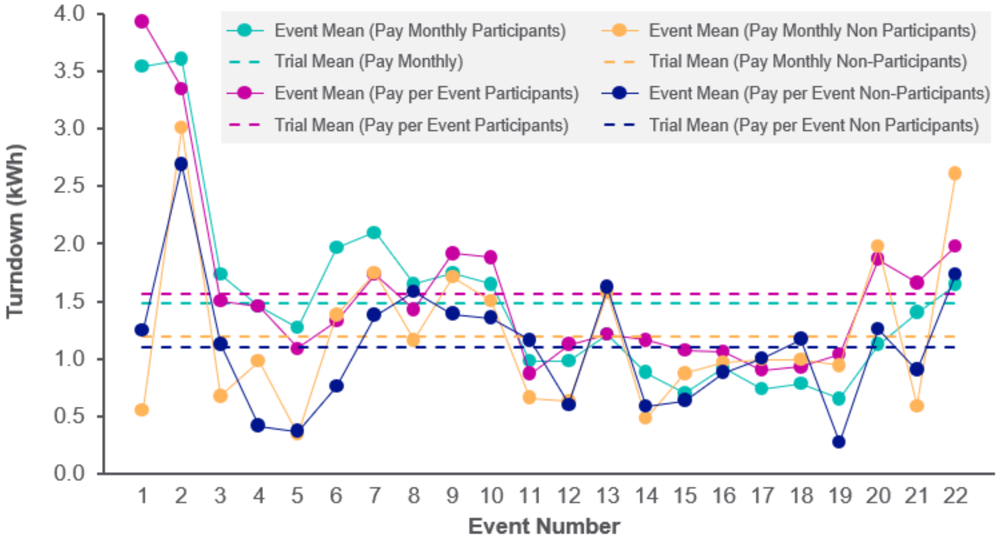
As illustrated in ***Figure 26***, there was no significant difference between the average event turndown provided by pay monthly and pay per event households.

Figure 26 – Event-by-event average turndown between 5-7pm per participating household per event by payment type



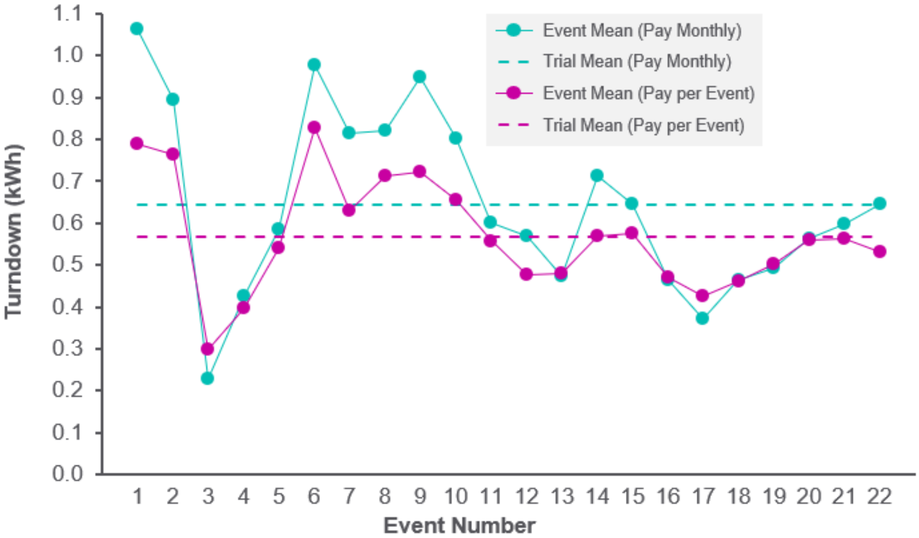
For the Octopus Energy participants, the turndown differential between participating and non-participating households per event was narrower for the pay monthly group than the pay per event group at 0.3 kWh versus 0.45 kWh, as shown in ***Figure 27***. However, the non-participant group sizes were relatively small (<40 households) for several events, so the differences between the payment groups cannot be given too much weight.

Figure 27 – Event-by-event average turndown between 5-7pm per participating and non-participating Octopus Energy household by payment type



For Sero's smaller cohort, the pay monthly group's heat pump turndown was marginally higher (0.64 kWh compared to 0.57 kWh). However, both groups were smaller than 10 households, with only three pay per event households for the first half of the trial, so the differences illustrated in ***Figure 28*** are insignificant.

Figure 28 – Event-by-event average heat pump turndown between 5-7pm per participating Sero household by payment type



7.4.4 Turndown by Control Type

The Octopus Energy aggregator control cohort was only three households, deemed too small to generate meaningful insights. The aggregator control turndown results presented in this section are therefore only those collected from the Sero households. Since these households were very similar (e.g., all EPC-A), their household turndown was significantly smaller than the average Octopus Energy household, as shown in ***Figure 29***. Trial two will aim to achieve more balance between the aggregator and customer control cohorts to make them more directly comparable.

Figure 29 – Event-by-event average turndown between 5-7pm per participating household, broken down by control type

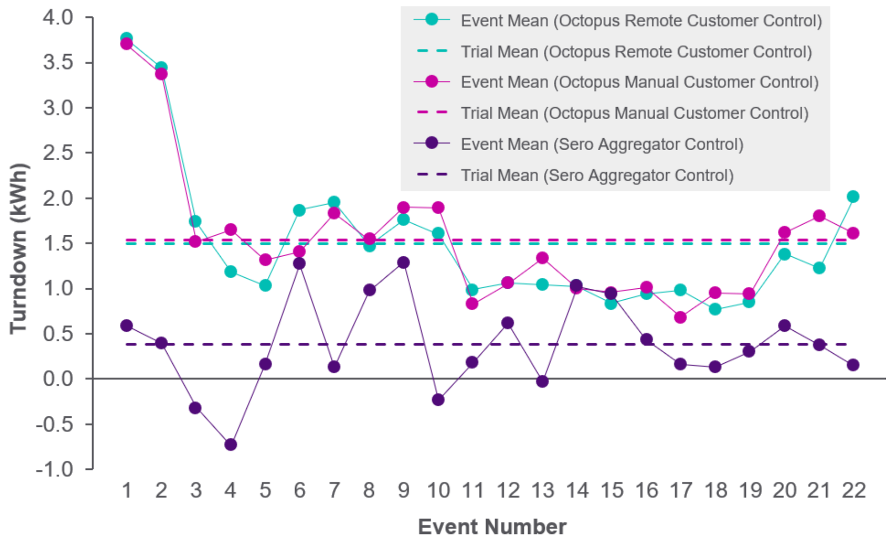


Figure 29 also shows that there is no meaningful difference in the average household turndown provided between the remote customer control and manual customer control participants, 1.50 kWh and 1.54 kWh per participating household per event, respectively. This similarity in turndown amount can be attributed to the fact that both control types were evenly spread across the two payment types.

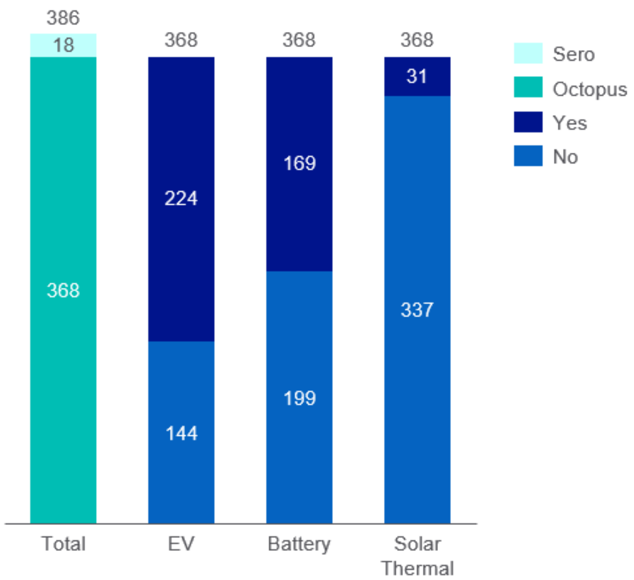
Accounting for the turndown provided by households who chose not to participate explicitly in each event (although, as discussed above, still provided measurable turndown) does not change the picture. Each average falls by a similar ~0.05 kWh per recruited household per event.

Trial two will continue to explore whether these two types of customer control influence participation rates or behaviours, but these trial one results indicate that customers behaved similarly, regardless of whether they needed to manually switch off their heat pump or whether they could do so remotely.

7.4.5 Impact of Other Low Carbon Technologies

Many recruited trial one households owned additional LCTs as shown in ***Figure 30.*** Over half of trial one households had an electric vehicle (EV), almost half had a battery, and almost 10% had a solar thermal system.

Figure 30 – Breakdown of recruited trial one households by adoption of other low carbon technologies



Households with EVs provided a higher per event average turndown than those without, providing 1.65 kWh per participating household per event versus 1.34 kWh for those without. This disparity could be explained by the fact that participating households generally appeared to provide turndown from sources additional to the heat pump, or by existing behaviours whereby time of use tariffs encourage customers to shift as much demand as possible into the overnight period, leaving less residual (non-heat pump) demand during the event period.

For solar thermal, households with and without the technology provided an average turndown of 1.43 kWh and 1.54 kWh per event, respectively. This is an insignificant difference, particularly given the relatively small sample size of those with solar thermal.

At a first glance, owning a battery also appeared to have an insignificant impact on turndown. The overall per participating household per event kWh turndown figures were very similar for households with and without batteries,1.49 kWh and 1.58 kWh, respectively.

However, segmenting households based on their implied baselined battery usage revealed a more nuanced picture. The number of households during each event period having a baseline profile forecasting that they would use <0.4 kWh electricity during that period was analysed. These households were assumed to be forecasted as being off-grid between 5-7pm, instead relying on their batteries for electricity.

At least 35 Octopus Energy households were baselined to be off-grid between 5-7pm for at least half of trial one event days. The number of these households who indicated in the post-event survey that they had participated by turning off their heat pump fluctuated between 20 and 35 households per event.

Figure 31 – Event-by-event turndown per participating Octopus Energy household baselined to use <0.4 kWh for at least half of events, those baselined to use >0.4 kWh for at least half of events, and those baselined to use >0.4 kWh for all events

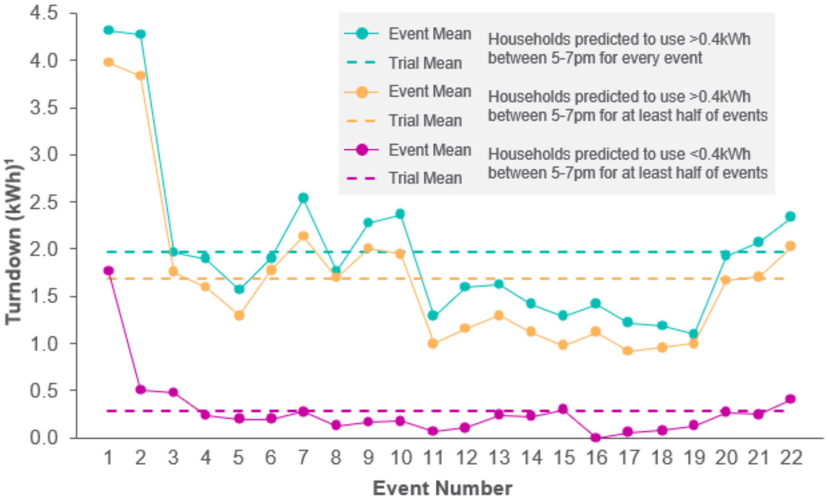


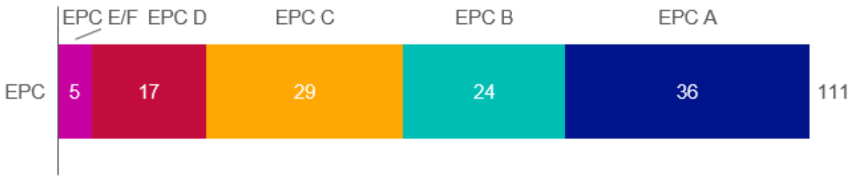
Figure 31 shows that the turndown impact of these households was measurably lower than for those who were baselined to be using grid electricity for at least half of events (0.29 kWh per household per event vs 1.68 kWh). Those baselined to use more than 0.4 kWh for all events provided an average per event turndown of 1.97 kWh.

How a household with a battery chooses to use it therefore has a significant impact on the amount of turndown it can provide by turning down/off their heat pump.

7.4.6 Impact of EPC Rating

All 18 Sero households were new-build EPC A homes, while Octopus Energy households demonstrated a larger range of EPC ratings. Ignoring households with no EPC, and only considering EPC data if its certification was dated after the heat pump installation, 93 Octopus Energy trial one homes had valid EPCs. The EPC breakdown is shown in ***Figure 32*** below.

Figure 32 – Breakdown of trial one households by EPC rating[21]



Whilst households were skewed towards the three highest EPC bands, there were still 22 households with an EPC of D or below. For the purposes of the analysis, the E/F group was ignored due to the small sample size and the rest split into EPC A/B and C/D groups.

Figure 33 – Event-by-event average turndown between 5-7pm per participating household, broken down by EPC rating

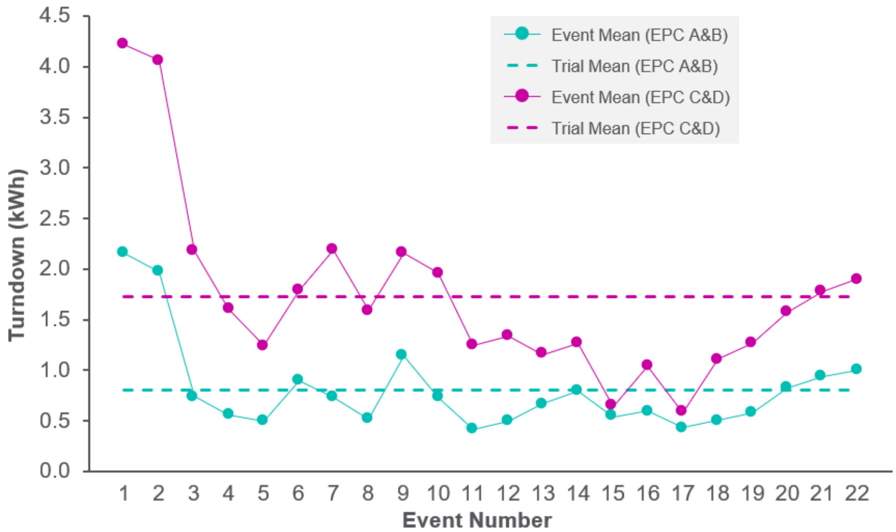


Figure 33 demonstrates that analysing the event-by-event turndown by participating households along these lines highlights a clear trend. The turndown is demonstrably higher for homes with a lower EPC. The average C/D home provided more than double the household turndown of the average A/B home,1.72 kWh per event vs. 0.81 kWh per event. This is likely due to the heat pump having to work harder to heat a home with a leakier fabric. The Sero homes were all highly insulated new-build homes rated EPC A, with an average per event household turndown of 0.38 kWh. Removing these homes from the EPC A/B grouping raises the average when just considering the Octopus Energy homes to 0.98 kWh.

Whilst no specific questions were asked about the EPC ratings or the fabric of trial one households in the trial one surveys, the topic emerged during the focus groups and interviews. No clear trend emerged between greater levels of insulation and a change in participant behaviour. However, it was notable that several of the interviewees who mentioned that they had a well-insulated home also highlighted that they did not suffer from 'cold-spots' in their homes after switching from their previous gas boiler system to their current heat pump system. This was a complaint of some participants who had also noted their level of insulation was less than desirable. One interviewee stated that a heat pump installer had told them a heat pump would be of no use in their home because they could not insulate the home enough. Having proceeded with the installation regardless, they noted their new heat pump system provides them with a 'moderate heat which is comfortable, loads of hot water, but we still have cold spots'. It was also notable that the same interviewees who reported having a substantial level of insulation did not report any discomfort during the two-hour event period.

[21] A home's EPC data was only included if its certificate dated after the date of heat pump installation. This is because heat pump installation may have involved changes to the fabric of the house which (likely) improved the EPC rating.

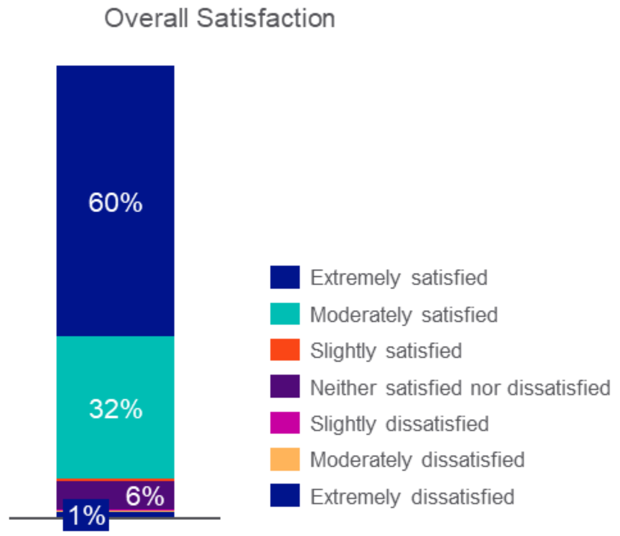
Participants with low levels of insulation, on the other hand, did report some discomfort: 'But in terms of the trial because my house is not well insulated and on a cold day the house…. we are also close to the coast, so we have a lot of wind. It gets cold.' Trial two will further explore the impact of energy efficiency and home fabric on demand response from domestic heating.

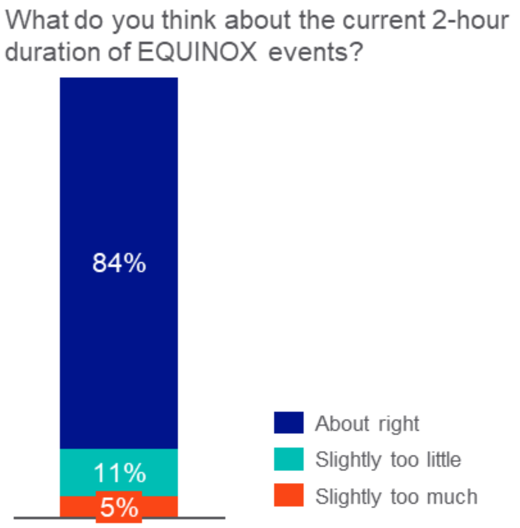
7.5 Participant Feedback

The trial one survey was utilised to understand participant experience and satisfaction with the trial. It also provided insights into the demographics of the participants and their motivations to take part. Analysis of this survey, alongside the focus groups and interviews, has helped the EQUINOX project team to gather areas for learning and improvement in trial two this winter.

Overall, results of the survey were positive. Customer satisfaction with trial one was high as shown below in ***Figure 34***, and participants were positive about the overall trial design while also providing helpful insights which can inform trial two design.

Figure 34 (left) – Breakdown of overall satisfaction with trial one participation
Figure 35 (right) – How participants felt regarding the two-hour duration of EQUINOX events





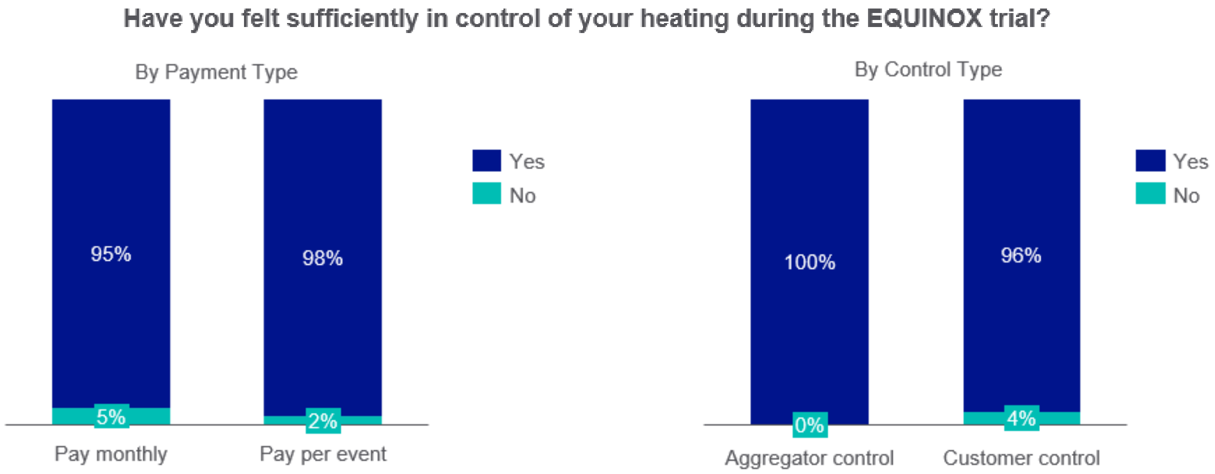
For example, when asked for their opinion on the two-hour event duration in trial one, 84% selected 'About right' as shown in ***Figure 35***. Of those 16% who responded differently, 11% expressed interest in slightly longer events, whilst 5% would have preferred slightly shorter events. Satisfaction with the two-hour event duration was corroborated in focus groups and interviews, in which all trial participants expressed that they were happy with this event length. However, several noted that longer event times would have caused them problems or made them reluctant to participate at all due to the prolonged drop in household temperature it would create. One stated that 'I'm glad it wasn't three or four hours, with the rate the house was losing heat. If this was a four-hour period on the really cold days, I don't know if I could ever have got the house warm enough to still be comfortable after four hours of no heating'. This feedback was especially prevalent amongst retirees and elderly participants.

Participants were also generally very satisfied with the frequency of events, with 75% viewing the three events per week as 'Neither too much or too little'. The majority of focus group and interview feedback again expressed contentment with the trial one arrangement. Two participants mentioned that they were expecting events to occur more frequently, while another noted that they would have preferred more consistency in when events were scheduled to occur. Finally, regarding the time of day during which events took place, several of those interviewed highlighted that the 5-7pm time window selected was preferred. A common theme was that since this coincided with their evening cooking, the heat from their stove ensured participants remained sufficiently warm and they therefore felt no impact from having their heat pump turned off. Others noted that if events were to take place during the morning, then they would experience a level of discomfort which might make them less likely to participate.

Participants were also asked about processes or logistics related to the trial to understand where improvements could be made. When asked about their satisfaction with the timing of the event notifications, 92% indicated they were happy with how far in advance they were notified about event periods. Participants were also generally satisfied with the method of notification, with 86% confirming they were satisfied with the current method. However, it is important to note that Octopus Energy and Sero used different notification methods. Octopus Energy only notified participants by email, whilst Sero notified participants by both email and text. All Sero customers indicated they were satisfied with the notification method, whilst Octopus Energy customers cited some room for improvement and indicated that additional notification methods (preferably text) would be preferred. This is an important learning that will be taken on board for trial two.

Participants almost unanimously felt in control of their heating regardless of their payment or control type, as shown in ***Figure 36***.. Following the UK-wide survey[22] where people expressed concern over not being in control of their heating whilst participating in a trial such as EQUINOX, this feedback and the fact people almost unanimously felt in control is extremely positive.

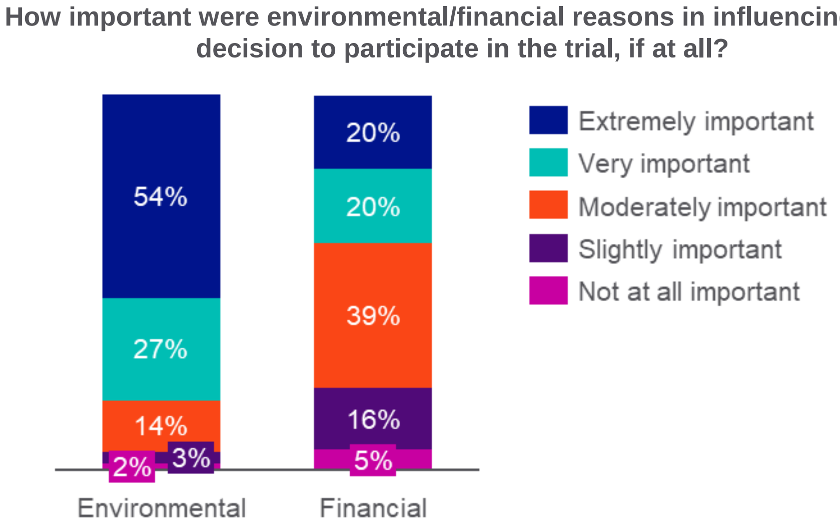
Figure 36 – Participant feedback regarding feeling sufficiently in control of their heating during the trial



In addition to providing feedback on the trial design and processes, the trial one survey was a forum to learn more about customers and their motivations for participating. When asked why they signed up for the trial, 81% of participants reported that environmental reasons were either 'Extremely important' or 'Very important' in influencing their decision to participate in the trial, as shown in ***Figure 37***. This compares with only 40% who stated that financial reasons were 'Extremely important' or 'Very important' in determining their participation.

[22] Customer Perceptions on Unlocking Flexibility from Heat, 2022

Figure 37 – Importance of environmental/financial reasons in influencing trial participation



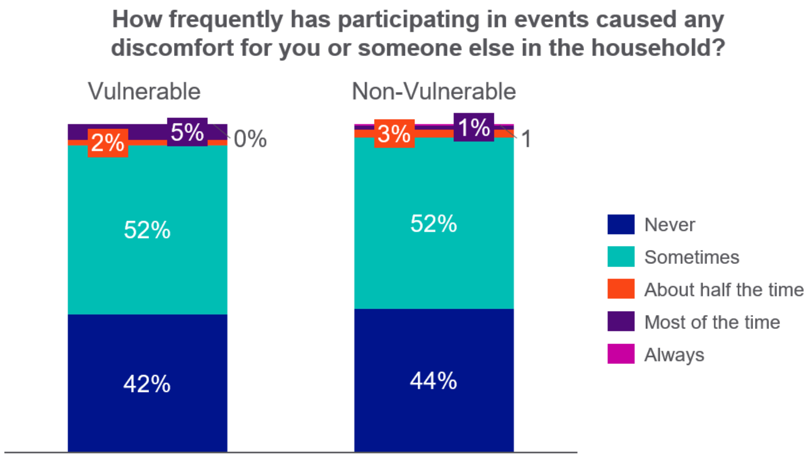
Qualitative responses from interviews and focus groups provided some additional nuance here. Wanting to contribute to the green energy transition was an overarching theme. Related motivations included concerns over how the UK's electricity network is managed, a desire to help increase the uptake of heat pumps across the UK, and the ability to contribute to research in these areas. This can be attributed to the fact that a disproportionate number of trial one participants worked in the energy or environment sectors.

Several interviewees noted that payment was a motivating factor in their participation, but very few cited it as their primary motivator and instead saw it as a secondary benefit, or even an afterthought. Some focus group participants even noted that they had forgotten about the financial rewards entirely. This aligns with the demographics of trial one participants, who are wealthier and more concerned about climate change impacts that the average UK citizen. Of those who were financially motivated, however, the context of the current energy crisis was an important subfactor, with one noting that 'Obviously the money off the bills was quite attractive with the way bills were going'. Likewise, several noted that the intersection between their current energy tariff and the structure of the trial made participation attractive, particularly the Octopus Energy Cosy and Agile tariffs.

There were also interesting intersections between social and financial rationalisations. Some noted that participation would give them a better understanding of how to improve their heat pump's performance, whilst another stated that participation was '[their] way of giving a bit of something back and repaying what we got given' after receiving a government grant towards the installation of their heat pump.

A final motivation captured in the focus groups and interviews was how easy participants felt it was to participate. One noted that 'communication was pretty good and it was just an offer…...I thought, "Oh yes, that's worth a go"', with another stating that 'It didn't really require anything on my part to take part, so I just thought why not'.

Figure 38 – Responses to the trial one survey question asking how frequently event participation caused discomfort for someone in the household, broken down by households with or without customers with vulnerabilities

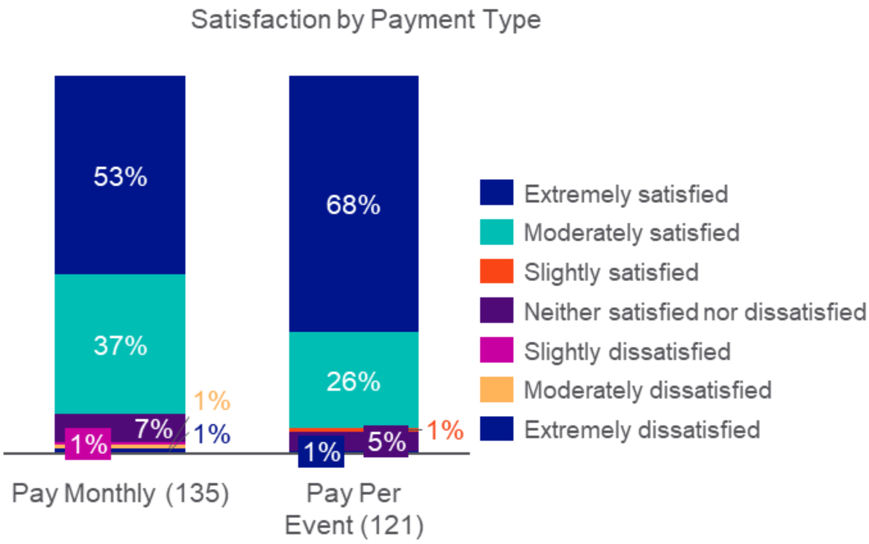


Overall, the analysis indicated no significant adverse effects caused by events for the majority of households identified as having one or more vulnerability indicators. There was little difference between groups in terms of reporting discomfort from events. 94% of customers identified as having one or more vulnerability indicators reported that participating in events never, or only sometimes, caused discomfort, compared to 96% of customers without any of these characteristics. A slightly higher proportion of these households (5% vs 2%) did however report feeling discomfort most of the time or always as shown in ***Figure 38***. These results must be considered in the context of trial one demographics, which is not representative of the average UK household. Trial two will consider a broader range of indicators for vulnerability and focus on recruiting a more diverse set of customers.

7.5.1 Feedback by Payment Type

Trial one survey data was segmented by the participant’s payment type to explore whether any elements of participant experience and satisfaction differed based on if a customer was paid monthly or paid per event.

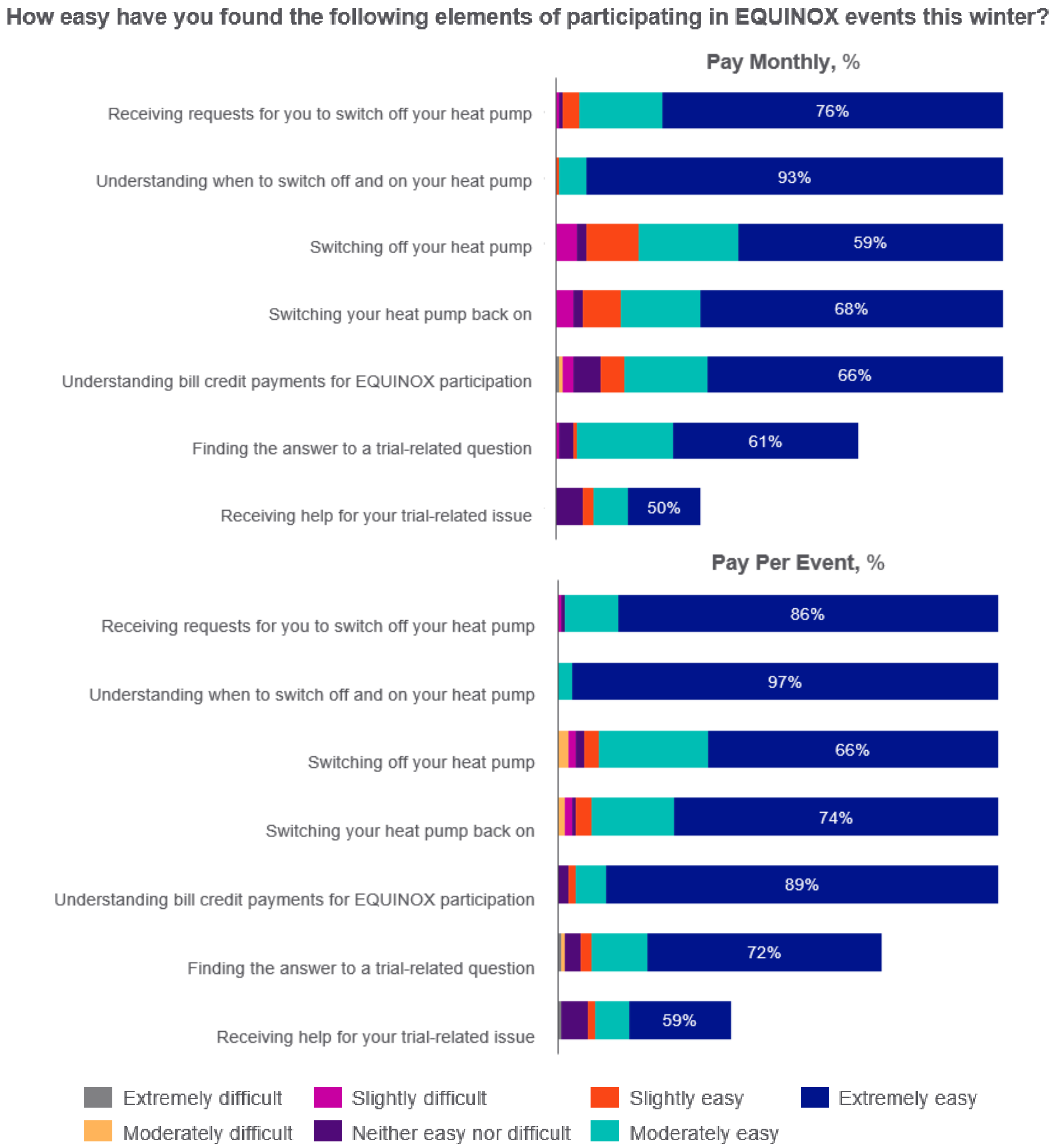
Figure 39 – Breakdown of responses by household payment type to trial one survey question on their satisfaction



While most participants were satisfied with the trial, when looking at the data by payment types, customers paid per event were slightly more satisfied than those paid monthly. Overall, 94% of pay per event customers were 'Extremely satisfied' or 'Moderately satisfied' compared to 90% of pay monthly customers as shown in ***Figure 39***. However, this 4% difference is small and only around 1% from either payment method were dissatisfied.

When asked about their experiences with different trial related processes, survey results were broadly consistent across payment groups as shown below in ***Figure 40***. One exception, however, were the responses related to understanding bill credit payments for participation in the trial. There was a 23% difference in those who found it 'Extremely easy' between payment groups with 89% of pay per event customers finding it 'Extremely easy' compared to 66% of pay monthly customers. This may have been due to the fact that the per event payment directly corresponded to participation in each event, whereas monthly payments got the same amount each month for participating regardless of the number of events.

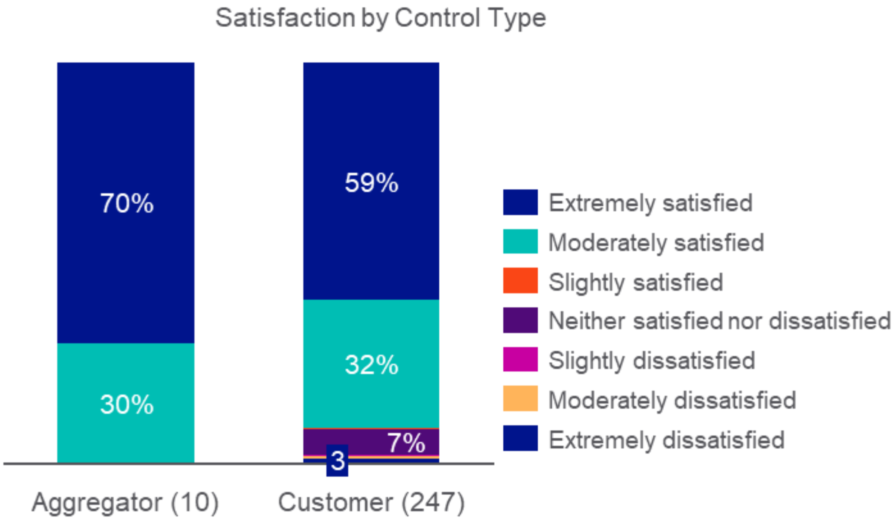
Figure 40 – Breakdown of trial one survey participants' feedback on different elements of event, segmented by payment types (paid monthly or paid per event)



7.5.2 Feedback by control type

Trial one survey results were also segmented based on control types to understand the impact of the control type on customer satisfaction with the trial.

Figure 41 – Breakdown of trial one survey participants' feedback on satisfaction, segmented by control type



Interestingly all (100%) of the aggregator control households who completed the trial one survey were 'Extremely satisfied' or 'Moderately satisfied' with the trial, compared to 91% of customer control households, as seen ***Figure 41***.

Further trial one survey data segmentation by participant control type (i.e., aggregator control or customer control), is presented in ***Figure 42*** and ***Figure 43***. It is worth noting the significant difference in number of households in the aggregator control group for trial one and therefore in the number of survey respondents (10 for aggregator control vs. 247 for customer control). This combined with the high efficiency of most of the aggregator control homes makes it difficult to draw concrete conclusions from across these two groups. Direct comparison should be easier in trial two, which should see a significant increase in the number of aggregator control households.

Figure 42– Breakdown of trial one survey feedback regarding customer experience by participants of household under customer control (including manual and remote customer control)

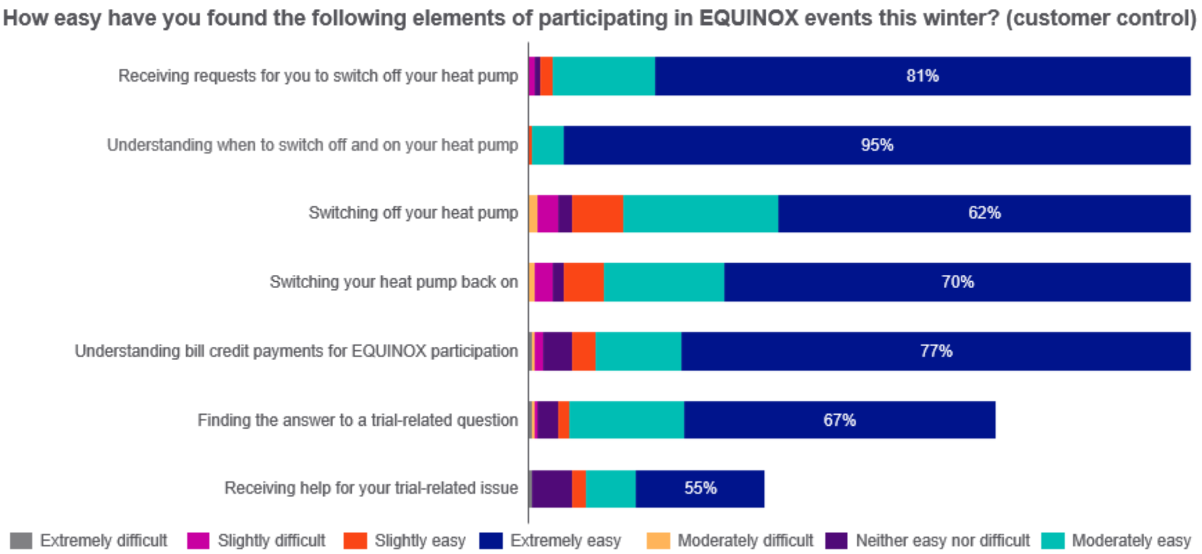
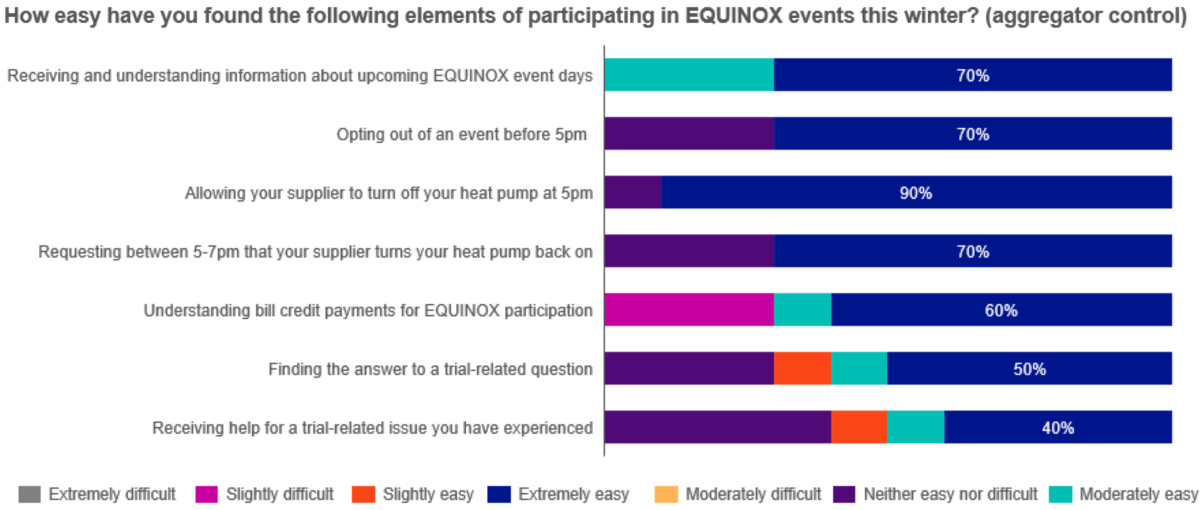


Figure 43 – Breakdown of trial one survey feedback regarding customer experience by participants of household under aggregator control



It is notable that aside from three respondents who found the payment system to be tricky to understand, no customer control participants reported finding any elements of trial logistics difficult. It is a similar story for aggregator control participants, who almost universally reported finding all elements easy. 90% of them found allowing their supplier to turn their heat pump off at 5pm to be 'Extremely easy'.

Proportionately, more aggregator control participants (30%) struggled to understand bill payments as compared to customer participants (1.6%). Moreover, the mean percentage of participant households who selected 'Extremely easy' or 'Moderately Easy' across the seven 'ease of participation questions' asked within surveys stood at 73% for aggregator control households, compared with 90% for customer control households. This indicates greater levels of ease in understanding and navigating trial elements in customer control households.

Within customer control households, manual customer control participants expressed more discomfort than remote customer control participants during events, with 56% of manual customer control participants responding that they experienced discomfort 'Sometimes' compared with only 48% of remote customer control participants. Additionally, manual customer control participants found receiving help for trial-related issues more difficult, with only 44% finding the process 'Extremely easy' compared to 68% of remote customer control participants.

For responses across all other survey questions, differences in experience between the manual and remote customer control cohorts were minimal. The mean values across the seven 'ease of participation questions' show that 89% of manual customer control participant households found participation 'Extremely easy' or 'Moderately Easy' compared to 91% of remote customers. To reiterate, the same value for aggregator control households stood at 73%. This potentially indicates that there is a sweet spot in terms of the level of control participants are happy to relinquish to automation and the ease of participation. At a minimum, it highlights that participants did not seem to have an issue with adjusting their heat pump settings in-person during event hours.

Responses during the interviews and focus groups add nuance to participant feelings towards the two control methods. Firstly, some remote customer control participants indicated that had manual customer control been their only option, they may not have participated at all. One noted 'I thought I might have to go and switch the thing off in the cupboard and then switch it back on and if that had been part of it, it just wouldn't have been worth it for me. The fact that basically you just sign up and forget about it, yeah, it's the ideal thing to participate in for me', whilst another firmly stated, 'If it was a thing that had required me to actually do something every day like go and switch the heat pump off, I wouldn't have done it'.

Furthermore, several participants expressed a desire for greater levels of automation when it came to control. One noted that 'My only comment…. was that next year if it could be controlled through the Homely App that would be great. I wouldn't even have to switch it off at the trial'. Another manual participant stated that having the option for remote control would have ensured their full participation in an event which they partially missed after arriving home after the event had begun.

Regardless, none of the manual customer control participants interviewed indicated dissatisfaction with their control method, with many highlighting the ease with which they integrated the process into their daily routine. One stated ‘we’ve always got alarms set on our phones to tell us when to put the bins out, and all this sort of thing. So, it’s just another one, you know? You were expecting it anyway. As soon as it pings off, I’ll turn the heat pump off. So, we’d just go down and turn it off. No problems at all’.

There were also others that expressed hesitancy to hand over complete control of their heat pump to an Artificial Intelligence (AI) controlled system, stating ‘The Homely [App], I don’t know, I do and don’t like Homely because it’s doing some stuff but I also quite like knowing what things are doing. I don’t totally like letting the AI do everything…… I feel out of control sometimes. Yes, so I’m always trying to watch the data. That’s why I caught it the first time. I was like, “Hey, it didn’t actually switch it off when I needed it off. I’ll do it myself”’, to which another participant noted ‘I’d agree with that.’ Another two participants, when questioned on whether they would be happy with a separate party controlling their heat pump remotely, responded ‘Well it depends who is controlling it’ and ‘For me I think as long as you have ultimate override…...But yes, other than that if it’s doing something and I don’t notice the impact, great. As much as I’m adverse to the AI doing everything if I don’t notice it, it’s okay.’

Trial two will continue to analyse customer controlled household turndown and feedback along this manual vs. remote control axis, to enable deeper insights to be unlocked.

8. Simulations

The purpose of the EQUINOX simulation modelling work was to inform the design of the real-world trials by investigating the impact of particular types of intervention using realistic simulation models (digital twins) of homes. Simulated homes were specified to be reasonably representative of the trial homes, with the aim of detailed simulations closing the gap between smart meter data and the occupant surveys. Simulating the same scenarios with and without EQUINOX interventions can help to inform the baselining methodology, as the true impact of the intervention can be measured. The results also give insight into the impact of different heat pump control systems, such as automatic preheating before an intervention. Overall, the simulation work enables better interpretation of the trial results and also allows for the intervention strategy to be refined so that the best use is made of the real homes over the trial periods.

8.1 Methodology

8.1.1 Digital Twin Selection

Ten digital twins of generic archetypes were created for the trial one simulations, each specified to be reasonably representative of the trial one homes. The geographical locations for every archetype were determined using the distribution of homes provided by Octopus Energy shown in ***Figure 44***.

Each archetype was also assigned a house type, which span the full range of house types in the data provided. Randomly sampling each archetype in line with typical UK housing stock provided representative heating rates, thermal masses, and other house thermal properties. A variety of household heating and hot water requirements were simulated in terms of setpoints, schedules, and annual heat and hot water demands. Realistic heating schedules were chosen such that different intersections with the 5-7pm EQUINOX events were covered. Heat pumps were sized such that they were capable of sufficiently heating each house. ***Table 7*** shows the full list of archetypes.

Figure 44 – Region colouring shows recruited EQUINOX (Octopus Energy) homes by postcode area. Sampled digital twin archetype locations from the probability density are marked by ⌂. Weather stations marked by (☀/☁)

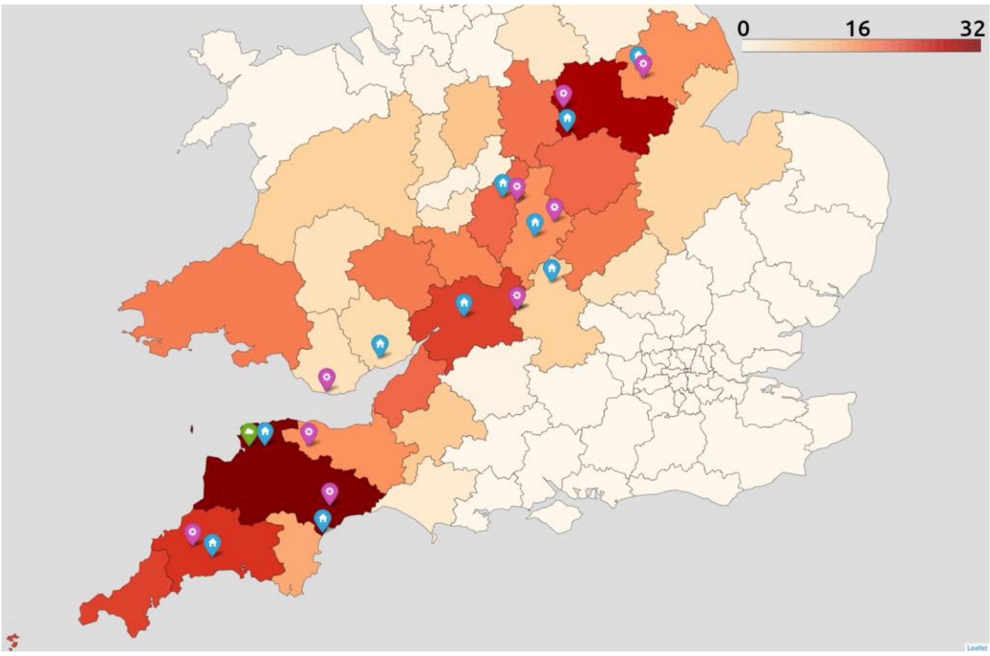


Table 7 – Archetypes used for simulations

No.	House Type	Location	AM Heating Period	PM Heating Period	Setpoint	Heat Pump Rating
1	2 Bed Detached	Liskeard	7:00-8:30	13:30-22:00	18	5 kW
2	5 Bed Detached	Nottingham	7:00-9:00	16:00-22:00	19	12 kW
3	4 Bed Terrace	Birmingham	7:00-8:30	17:00-22:00	17	8 kW
4	3 Bed Terrace	Lincoln	6:30-8:15	18:00-22:00	20	8 kW
5	3 Bed Detached	Banbury	7:00-8:45	19:00-22:00	21	8 kW
6	4 Bed Detached	Gloucester	7:00-8:30	20:00-22:00	18	8 kW
7	2 Bed Semi	Newport	All day (7:00-22:30)		19	5 kW
8	4 Bed Semi	Leamington Spa	7:00-8:30	19:30-23:00	17	8 kW
9	3 Bed Semi	Dawlish	7:00-8:00	17:00-21:30	20	5 kW
10	6 Bed Detached	Barnstaple	6:30-8:30	17:30-22:00	21	12 kW

8.1.2 Simulating Interventions

The response of a heat pump to an EQUINOX intervention depends on how it was operating in the first place and how it is being controlled. Here, three control strategies were simulated:

- Standard controls: timeclock with optimum start (necessary for comparable comfort levels)
- Standard controls: with and without weather compensation (on flow temperature)
- Theoretically optimised controls: dynamical flow temperature to minimise running cost

Standard manufacturer controls were assumed to have an "optimum start" thermostat, where the house is preheated at the maximum flow temperature. Weather compensation is where a higher flow temperature is targeted at lower external temperatures, usually with a linear "heat slope" relationship. All modern heat pumps will have weather compensation available as an option in the standard manufacturer controls, though the installer or householder will sometimes choose to disable it in favour of a fixed maximum flow temperature. Smarter control systems can replace the weather compensation curve with a dynamically chosen flow temperature.

In addition, three different types of intervention were simulated:

- Manual: participant gets a message and switches heat pump off (standard controls only)
- Direct: heat pump is switched off remotely for the time period (standard controls only)
- Optimised: controls manage the intervention, including preheat and enforcing comfort limits (optimised controls only)

For manual interventions, it was necessary to model the behaviour of the householder, namely how likely they are to respond to the turn-off message and how promptly they act. Information about how this was modelled can be found in ***Appendix D***: Additional Details on Simulations.

The event days were chosen in a way that was comparable to the real methodology of choosing event days (see ***Section 5.6.2***) but ensured a fair comparison of various baselining methodologies. This was achieved by randomly selecting two or three events per week until the maximum of 25 event days was reached. This was repeated until event days and non-event days had the same mean external temperature across all homes. More information can be found in ***Appendix D***: Additional Details on Simulations.

Two different methods of evaluating the demand shift due to an intervention were explored: a “perfect” and a “baselined” comparison, as shown below in ***Table 8***. The perfect comparison measured what would have happened in the simulation had the intervention not occurred. The baselined comparison uses the methodology described in BSC P376 ‘Utilising a Baselining Methodology to set Physical Notifications’ (average demand over the last 10 non-event weekdays corrected for the in-day demand at 1-4pm). Although the perfect comparison is not possible in the real world, it provides valuable insight into the accuracy of the baselined comparison.

Table 8 – Ratio of "perfect" to "baselined" methods of evaluating demand shift

Home	Direct	Manual	Optimised
1	0.89	0.81	0.68
2	1.15	1.18	0.79
3	1.38	1.76	0.81
4	1.24	1.47	0.83
5	0.95	0.93	0.75
6	0.86	0.82	0.80
7	0.97	0.96	0.73
8	1.14	1.22	0.85
9	1.00	0.98	0.77
10	1.03	0.98	0.77
Mean	**1.06**	**1.11**	**0.79**

8.2 Findings

8.2.1 Before Interventions Are Added

The figures in this section show a comparison between the three control strategies in the absence of intervention.

Figure 45 – Standard controls strategies graph without weather compensation in the absence of intervention

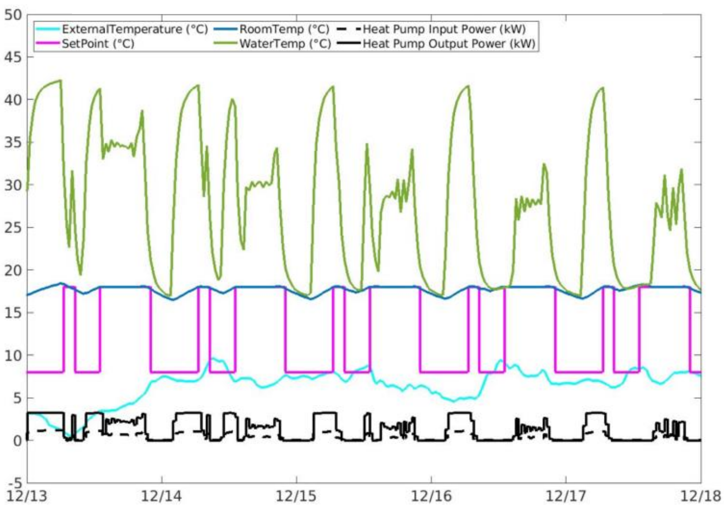


Figure 45 shows an example simulation output for standard manufacturer controls without weather compensation. This is assumed to be an “optimum start” thermostat that pre-warms the house at maximum flow temperature.

Figure 46- Standard controls strategies graph including weather compensation in the absence of intervention

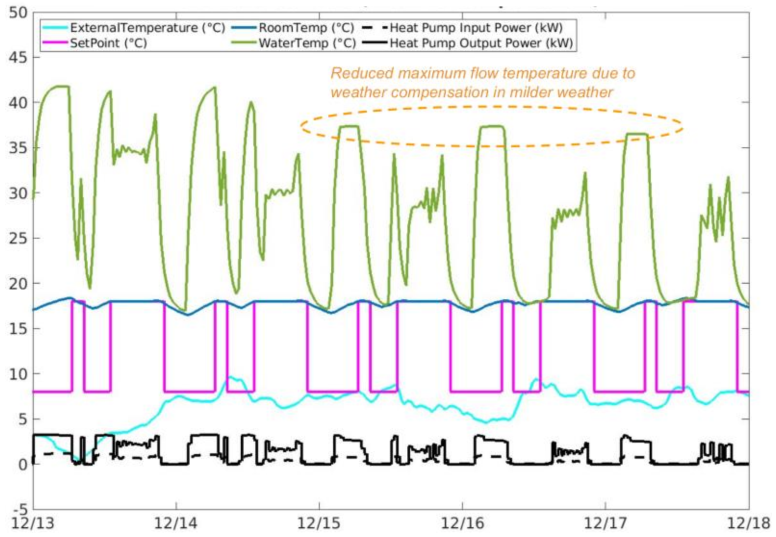


Figure 46 shows an example simulation output for standard manufacturer controls with weather compensation. Heat pump maximum flow temperatures are limited in milder weather to improve the coefficient of performance (CoP).

Figure 47 – Optimised controls strategies graph in the absence of intervention

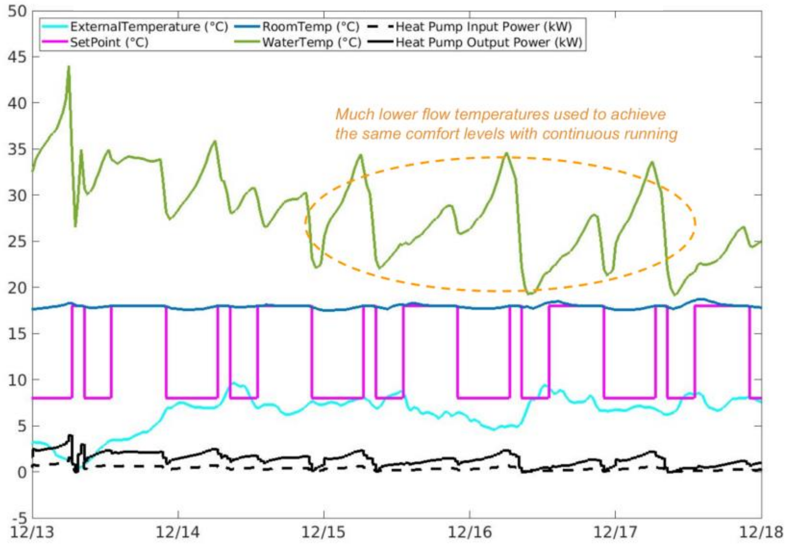


Figure 47 shows an example simulation output for theoretically optimised controls. The flow temperature is dynamically chosen to achieve the same comfort levels at lowest running cost.

Summary metrics from the simulations (before interventions are applied) are shown in Appendix D: Additional Details on Simulations.

The key findings are:

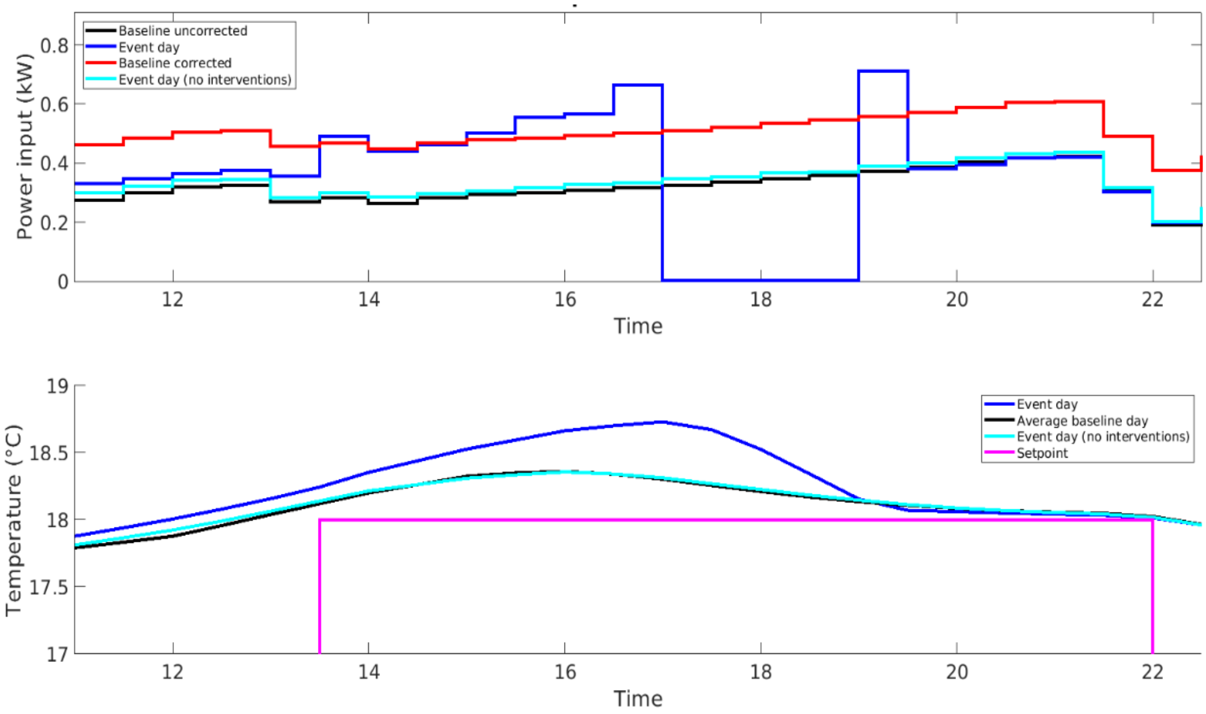
- Weather compensation only makes 1% difference in consumption to heat pumps modelled with standard controls with optimum start time clocks. Note that this is largely due to weather compensation only affecting the optimum start period in these simulations, which is a relatively short proportion of the time.
- Weather compensation is much more significant for heat pumps controlled to run continuously 24/7, a reasonably common control method but not included in this modelling work.
- As a consequence of the limited impact weather compensation had on the simulations, we only considered control scenarios where weather compensation was enabled to simplify the results.
- Optimised controls provided 12% savings against standard controls. By dynamically choosing lower flow temperatures, optimised controls achieved a higher CoP and lower costs, whilst maintaining the same comfort levels.
- Trial two will look to build on these findings with a new commercial arrangement testing how optimisation can be utilised by the 'smart home' aggregator to achieve the required demand reduction in the most efficient manner.

8.2.2 After Interventions Are Added

A comparison was done between the three control strategies after interventions were added. The key findings are:

- Direct and optimised intervention strategies both achieve full demand reduction during the EQUINOX events, however Manual interventions are predicted to give 30% less demand reduction.
- The lower manual demand reduction can be attributed to the many external factors which can impact the participants ability to turn off their heat pump at the required time (e.g., traffic, shift work etc.) rather than heat pump performance.
- Trial two is looking to further distinguish whether participants with app-based controls (still "Manual") are able to provide a more reliable demand reduction than those who are physically switching their heat pump off.
- The thermal discomfort arising from Direct and Manual control can be completely avoided by using Optimised controls which pre-warm, at the expense of 1% additional electricity consumption.
- Unsurprisingly, "discomfort" is greatest for the Direct and Manual control homes where the heat pump is simply turned off without any pre-work to ensure the house is ready for the event. In comparison, Optimised controls result in very little "discomfort" due to the preheating. ***Table 9*** shows this evaluation in terms of total degree-hours below setpoint over the trial period.
- Further simulations may also explore how the notice period provided to the household affects their decision making around pre-warming.
- Trial two intends to explore whether allowing Sero to optimise their set of automated homes when given the event schedule in advance, and whether guidance to manual control customers method of reducing HP demand, will still result in an overall increase in electricity consumption and presence of snapback.
- The baselining methodology (P376) gives very similar results to the "perfect" comparison (scenario where no interventions occurred), with exactly balanced external temperatures.
- P376 will on average overestimate the reduction in energy usage with optimised controls due to pre-heating within the 1-4pm in-day adjustment period. However, the average baseline adjustment for Direct and Manual controls is closer to zero due to the balance of weather between event and non-event days. This is shown in ***Figure 48*** and ***Table 9.***
- This provides confidence in continuing to use P376 for trial two alongside control groups like those used in a randomised control trial set-up.
- Findings from trial one demonstrated snapback following interventions. The Octopus Energy household results, with diversity in method of manual control, broadly align with the magnitude of snapback seen in these digital twin simulations shown in ***Figure 48.***

Figure 48 – Average heat pump electrical power consumption for space heating (top) and average room temperature (bottom) for Optimised interventions. This is averaged across all event days for a single home (House 1)



[23]

Table 9 – Evaluation of the discomfort experienced by homeowners over the trial period, using a metric of the total "degree-hours" below desired room temperature setpoint

Home	Direct	Manual[24]	Optimised
1	35	18	0
2	29	22	0
3	18	11	0
4	38	23	0
5	39	29	0
6	34	24	0
7	41	29	6
8	40	29	0
9	46	32	1
10	61	41	4
Mean	**38**	**26**	**1**

[23] Homes being optimised were pre-heated above the set-point to ensure the set-point was maintained during an event.
[24] The manual group has been modelled to include random behavior. See ***Appendix D*** for more details.

This demonstrates that the optimised approach which includes pre-heating is very effective at reducing the impact on customer's room temperatures during an event which in turn is likely to reduce customer discomfort and increase ongoing participation rates.

9. DFES Analysis Using Trial Data

9.1 Current DFES Approach

National Grid currently uses profiles from the Customer Led Network Revolution (CLNR[25]) project to acquire an unabated and a thermal storage profile for heat pumps. These are multiplied by a scaling factor (which replicates the percentage of retrofits versus efficient homes), thus adapting them to give a profile that changes per year and per future energy scenario. The baseline DFES profiles can be seen in ***Figure 49*** and ***Figure 50***.

Figure 49 – Non-hybrid heat pump profiles in baseline year

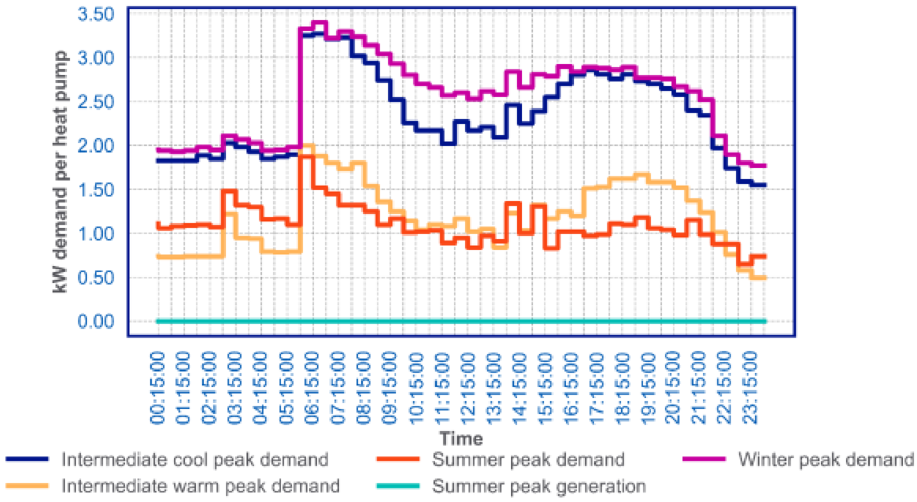
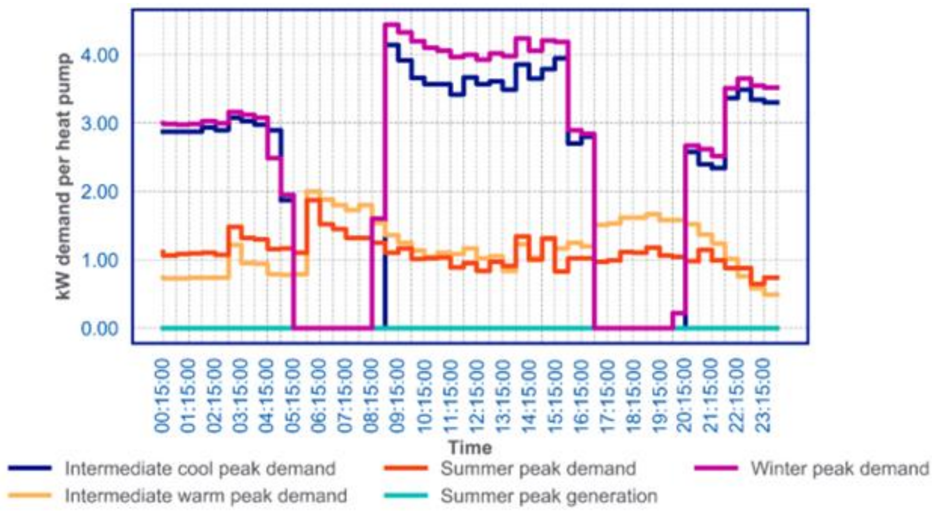


Figure 50 – Non-hybrid heat pump profiles with thermal storage



9.2 Comparing Profiles with EQUINOX

As the above profiles were created using the outputs from a project which concluded in 2015, data from trial one was examined to determine whether it could be used to improve the profiles used in the DFES process. Data from 16 of the trial one Sero households (without flexibility incentives), was used to create a 'Sero profile' and compared to the DFES profiles for the years up to and including 2050. Each DFES profile will have a ratio of retrofit homes to efficient homes baked into it which is based upon projections of what the National Grid network is expected to look like. It is currently assumed that more efficient homes will connect to the National Grid network first, followed by additional retrofit

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[25] www.networkrevolution.co.uk

households to 2050. Therefore, this comparative exercise was undertaken to see which year the Sero profile best aligns to the DFES profiles given that the Sero estate contains only efficient, technologically advanced homes. ***Figure 51*** to ***Figure 54*** display the 2023, 2028, 2030 and 2050 comparisons.

Figure 51 – Heat pump profile comparison 2023

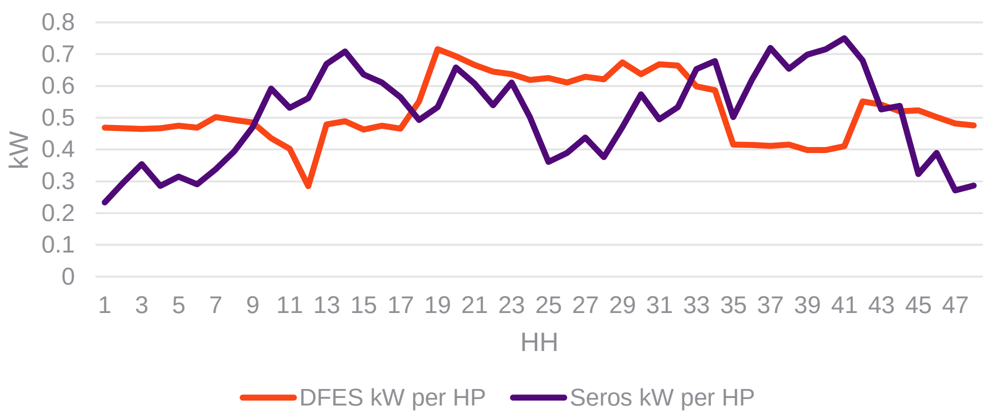


Figure 52 – Heat pump profile comparison 2028

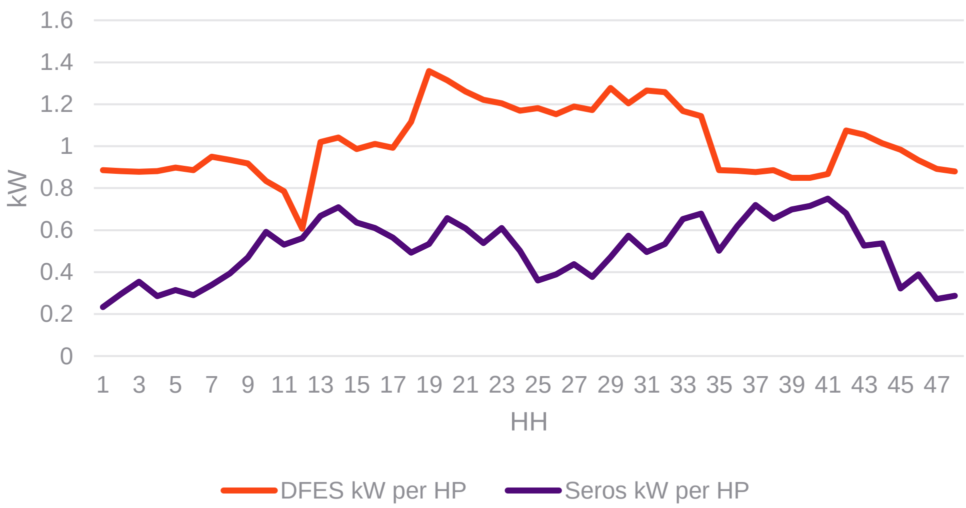


Figure 53 – Heat pump profile comparison 2030

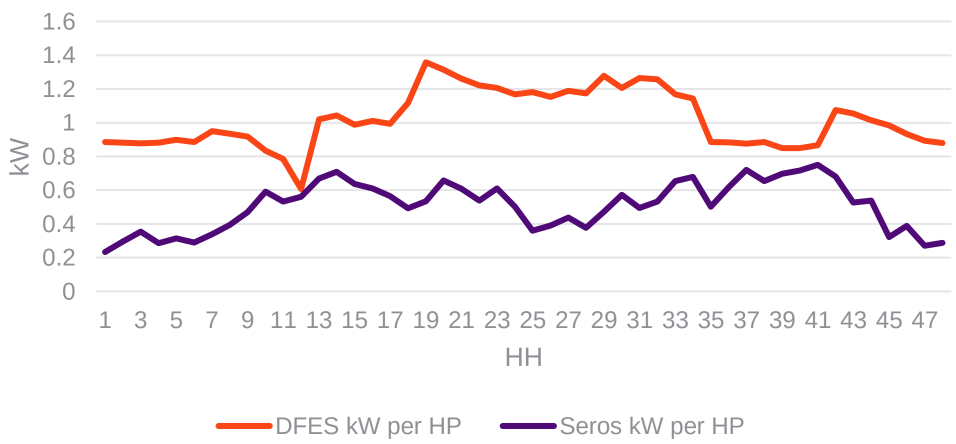
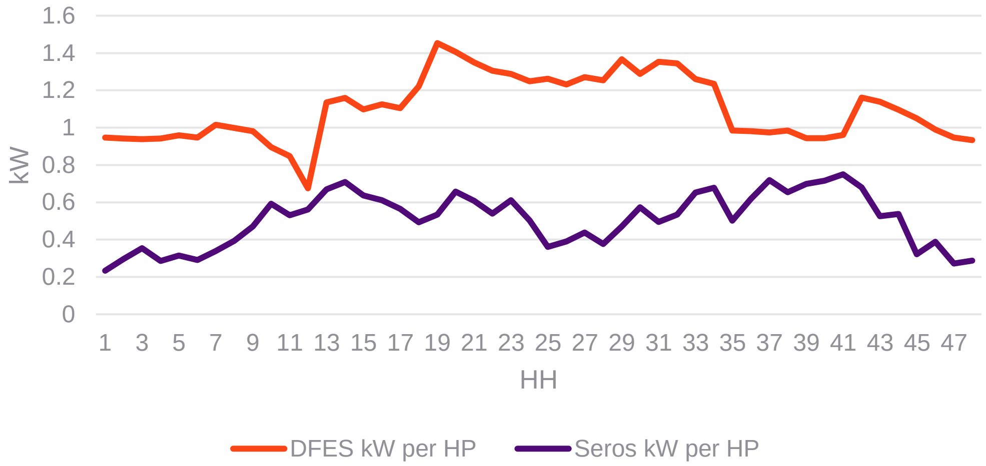


Figure 54 – Heat pump profile comparison 2050



It appears that for 2023 the Sero and DFES profiles are of the same order with the Sero profile having a marginally higher absolute peak value. However, the Sero profile is notably higher than the DFES profile during the morning and evening peaks. This suggests that if the Sero profile is more accurate, then National Grid could be underestimating the impact of heat pumps at critical times and underestimating constraints and future flexibility/reinforcement requirements.

For 2028 and 2050 the DFES and Sero profiles become increasingly different reflecting the expected retrofit uptake of heat pumps in less thermally efficient homes. If it is possible to extract retrofit heat pump profiles from the later trials in EQUINOX then it should be possible to create blends from these profiles to make a more meaningful comparison with the 2030 and 2050 DFES profiles.

For a series of Primary Substations (both rural and urban), the impact of using the Sero profile rather than the DFES profile was assessed. The percentage loading of the Firm Capacity (FC) at each substation for the years 2028, 2035 and 2050 was calculated, see the tables below for the results[26].

Table 10 – Cairns Road

	2028		2035		2050	
Profile	**MW**	**% of FC**	**MW**	**% of FC**	**MW**	**% of FC**
DFES	49.30	93.86	87.28	163.09	121.58	226.20
Sero	48.66	92.72	85.44	159.72	114.02	212.27

Table 11 – Truro Shortlanesend

	2028		2035		2050	
Profile	**MW**	**% of FC**	**MW**	**% of FC**	**MW**	**% of FC**
DFES	31.04	136.82	54.51	238.76	66.85	292.51
Sero	30.20	133.17	51.73	226.67	60.29	263.94

[26] Note: MW = Total MW demand at the Primary; % of FC = Loading expressed as a % of the Firm Capacity for the given Primary (MVA is accounted for)

Table 12 – Cardiff East

	2028		2035		2050	
Profile	MW	% of FC	MW	% of FC	MW	% of FC
DFES	24.12	80.40	38.77	129.24	68.75	229.17
Sero	23.79	79.29	37.70	125.67	63.94	213.12

Table 13 – Merthyr East

	2028		2035		2050	
Profile	MW	% of FC	MW	% of FC	MW	% of FC
DFES	25.05	83.53	36.05	120.19	51.69	172.32
Sero	24.78	82.64	35.14	117.15	47.00	156.69

Table 14 – Lichfield 132/11kV dummy

	2028		2035		2050	
Profile	MW	% of FC	MW	% of FC	MW	% of FC
DFES	60.36	83.83	88.34	122.70	126.04	175.06
Sero	59.43	82.54	86.63	120.32	119.00	165.28

Table 15 – Lye 11kV dummy

	2028		2035		2050	
Profile	MW	% of FC	MW	% of FC	MW	% of FC
DFES	43.64	33.83	72.84	56.19	130.66	100.60
Sero	43.05	33.38	70.74	54.58	118.51	91.26

Table 16– Melton Mowbray 11KV S STN

	2028		2035		2050	
Profile	MW	% of FC	MW	% of FC	MW	% of FC
DFES	22.29	99.11	41.03	179.59	62.52	272.62
Sero	21.81	97.07	39.71	173.89	57.41	250.48

Table 17 – West Bridgford 33 11kV S STN

	2028		2035		2050	
Profile	**MW**	**% of FC**	**MW**	**% of FC**	**MW**	**% of FC**
DFES	31.93	104.75	56.58	185.54	72.54	237.86
Sero	31.45	103.16	55.73	182.75	68.11	223.34

These results show that if the Sero profile is applied to all heat pumps, the loading at each Primary Substation is reduced by a small margin. This is significant at Lye, where by 2050 the loading is only 91% compared to 101%, meaning that reinforcement plans can be deferred.

This exercise also prompted a potential need for a review of the scaling factors used in the DFES process, which have a high impact on the profiles. As can be seen in the figures above, the DFES profile changes to become much more onerous as a result of the predicted retrofit/efficient house split.

Due to the limited heat pump monitoring data that could be collected from trial one, it is unlikely that the Sero profile can be used to improve the DFES profiles in the short term. However, this exercise will look to be repeated using trial two data as it is anticipated the number of homes that have direct heat pump monitoring data that can be collected will increase, and the project team intend to install Low Voltage monitoring within Distribution Substations supplying clusters of EQUINOX participants.

10. Key Learnings and Next Steps

This section summarises the key learnings from trial one and outlines next steps, with a focus on key points for the second trial scheduled for winter 2023/24.

10.1 Key Learnings

As a proof-of-concept of customers being flexible with their low-carbon heating, trial one was a success. Participation rates were consistently high, aggregated turndown provision was clearly visible on event days when comparing metered and baseline consumption, households found the trial experience satisfying, and households found the events generally comfortable and easy to navigate. Households also gave clear preferences on maximum event length (two hours) and frequency (two to three times per week), and overwhelmingly felt in control of their domestic heating.

The key learnings from trial one are summarised below:

- The response to trial one amongst participants was overwhelmingly positive. Households felt in control of their heating, generally remained comfortable, and were satisfied with the simple trial design. Households were motivated to participate for environmental reasons in addition to financial motivations.
- Trial one has shown that households can provide significant turndown when asked to shift their domestic heat pump habits with a day-ahead notice. Doing so did not compromise customer safety or comfort.
- Household participation in events was consistently high throughout the trial, with minimal fatigue observed. Households paid after each event participated more consistently than those paid upfront monthly payments. No households pulled out of the trial once they had signed up.
- The most common reason for non-participation in events was no one being home to action the request for heat pump turndown. Not realising that there was an event and it being too cold outside were also relatively commonly cited reasons.
- Households with residents identified as having potential vulnerabilities did not appear to face any additional difficulties in navigating the trial. Although these households were not less likely to participate in events, they were slightly more likely to feel discomfort.
- Trial one provided tentative evidence that households with aggregator controlled heat pumps can provide more predictable flexibility than households whose heat pumps were turned down by customers (customer controlled) and that many customers valued not having to do this for themselves rather than feeling uncertain about having a third party control their heating system.
- Temperature of event days, presence of additional low-carbon technologies, and EPC rating all seemed to impact turndown rates.
- The trials showed significant snapback for the Sero households and smaller snapback for the Octopus Energy households but pre-heating homes before an event should be able to reduce the degree to which heating load increases after an event at the same time as reducing the likelihood of customers experiencing actual discomfort or anticipating discomfort. The scale of snapback within the Octopus Energy was comparable to the scale seen in the simulated intervention digital twin work carried out.

The trial also provided an opportunity for suppliers to finetune their baselining approaches, improving settlement processes for future flexibility trials and BaU offerings to customers. This will enable networks to have more confidence in the flexibility provided by suppliers/aggregators.

10.2 Next steps

Trial two planning is already underway and has been informed by the key learnings from trial one. This section outlines areas of focus for trial two.

1. **Progress towards a BaU flexibility product:** To better simulate a BaU flexibility product, trial two will pay households per kWh of turndown they provide instead of a fixed amount per event. In addition, customers will receive different notice periods for events that align with the National Grid standard flexibility products. These changes in trial design will help determine how domestic heating flexibility can best fit current DNO flexibility portfolios.

2. **Develop new commercial arrangements:** The move to a per kWh payment system necessitates the development of three new commercial arrangements, which will explore a mix of availability and utilisation payments. Payment amounts will be varied to explore how households respond to different price signals and how these responses impact the viability of domestic heating flexibility for distribution networks.
3. **Further investigate relationship between temperature and turndown:** To build on the finding that higher temperature means lower turndown[27], suppliers will forecast how many households they think will be needed to meet a per event kWh target defined by National Grid. Suppliers will continue to investigate predictability of flexibility across other conditions such as presence of other LCTs and home EPC rating.
4. **Optimise aggregator control and compare to customer control:** While trial one had a limited sample size for aggregator control households, trial two expects to recruit more heat pumps with aggregator control capabilities to enable direct comparisons on participation rate and amount of flexibility provided by different heat pump control groups.
5. **Minimise snapback effect:** Work will be done to minimise the snapback effect in aggregator control and manual control households seen during trial one. Within aggregator controlled households, this will include trialling new methods of varying the HP demand, including adjusting temperature set point. In manual control households, this will include creating a guide on how best to participate in HP flexibility events.
6. **Recruit households that are more representative of the UK population:** The households who participated in trial one are considered early adopters of heat pumps and are not representative of the UK population, although they are representative of the current heat pump owner population. Trial two will focus on recruiting from a wider demographic pool where possible, with a focus on different home types, home ownership status, and households with vulnerabilities. This will enable us to understand the diversity in flexibility delivery that will be seen in the future, and demonstrate the effect of HPs on After Diversity Maximum Demand (ADMD) once rolled out into more households.
7. **Improve communication with participants throughout the trial:** A strong theme that emerged in trial one customer research was that customer would have liked to understand why certain days were chosen for events and how their flexibility was valuable for National Grid. Trial two will work to provide households with more regular updates on their collective turndown achievements and more context on different elements of the trial design.

Overall, we are pleased by the plethora of useful learnings provided by the first EQUINOX trial. They have identified specific elements to further investigate and provide a solid foundation for our second trial. We look forward to continuing to explore how to unlock flexibility from residential low carbon heating and sharing our findings with stakeholders.

[27] See ***Section 7.4*** for more detail

Appendices

Appendix A: Glossary

AI	Artificial Intelligence
API	Application Programming Interface
ADMD	After Diversity Maximum Demand
BaU	Business as Usual
BEE	Building Energy Engine
CLNR	Customer Led Network Revolution
CMZ	Constraint Managed Zones
CoP	Coefficient of Performance
DFES	Distribution Future Energy Scenario
DFS	Demand Flexibility Service
DNO	Distribution Network Operator
DSO	Distribution System Operator
EPC	Energy Performance Certificate
EQUINOX	Equitable Novel Flexibility Exchange
ESO	Electricity System Operator
EV	Electric Vehicle
FC	Firm Capacity
FSP	Final Submission Pro Forma
HTTP	Hypertext Transfer Protocol
IoT	Internet of Things
LCT	Low Carbon Technology
MQTT	Message Queuing Telemetry Transport
NEA	National Energy Action
NGESO	National Grid Electricity System Operator
SPEN	Scottish Power Energy Networks
SPERL	Scottish Power Energy Retail
TSO	Transmission System Operator
UAT	User Acceptance Testing
WMCA	West Midlands Combined Authority

Appendix B: Trial One Event Timetable and Temperatures

Table 18 - Tracker of event and non-event days throughout the trial one period

Date	Day of Week	Day Type	Number Devices Participating (Octopus)	Number Devices Participating (Sero)	Total Devices (Both)	Forecast Avg Temp	Forecast Temp Band	Actual Avg Temp	Actual Temp Band	Actual temp - Forecast temp
12/12/2022	Monday	Non Event			0	0.5	Cold	-2.00	V. Cold	-2.50
13/12/2022	Tuesday	Event	334	10	344	1.25	Cold	-1.25	V. Cold	-2.50
14/12/2022	Wednesday	Non Event			0	2.5	Cold	-2.25	V. Cold	-4.75
15/12/2022	Thursday	Event	301	10	311	2.75	Cold	-1.00	V. Cold	-3.75
16/12/2022	Friday	Non Event			0	2.5	Cold	-0.50	V. Cold	-3.00
19/12/2022	Monday	Event	312	10	322	4.5	Cold	12.00	Warmer	7.50
20/12/2022 … 06/01/2023	Tuesday … Friday	Trial Break								
09/01/2023	Monday	Non Event			0	7.25	Mild	6.00	Mild	-1.25
10/01/2023	Tuesday	Non Event			0	9.00	Mild	12.00	Warmer	3.00
11/01/2023	Wednesday	Event	341	11	352	8.25	Mild	8.50	Mild	0.25
12/01/2023	Thursday	Non Event			0	7.00	Mild	7.63	Mild	0.63
13/01/2023	Friday	Event	333	11	344	6.50	Mild	6.25	Mild	-0.25
16/01/2023	Monday	Event	324	11	335	3.75	Cold	0.25	Cold	-3.50
17/01/2023	Tuesday	Non Event			0	3.50	Cold	-0.38	V. Cold	-3.88

18/01/2023	Wednesday	Event	302	13	315	4.50	Cold	1.50	Cold	-3.00
19/01/2023	Thursday	Non Event			0	6.50	Mild	1.38	Cold	-5.13
20/01/2023	Friday	Event	294	13	307	7.00	Mild	2.38	Cold	-4.63
23/01/2023	Monday	Non Event			0	8.50	Mild	0.88	Cold	-7.63
24/01/2023	Tuesday	Event	315	13	328	7.00	Mild	1.75	Cold	-5.25
25/01/2023	Wednesday	Non Event			0	7.50	Mild	6.88	Mild	-0.63
26/01/2023	Thursday	Non Event			0	7.00	Mild	5.50	Mild	-1.50
27/01/2023	Friday	Event	307	13	320	6.75	Mild	2.50	Cold	-4.25
30/01/2023	Monday	Event	300	13	313	7.50	Mild	5.75	Mild	-1.75
31/01/2023	Tuesday	Event	232	13	245	7.75	Mild	6.25	Mild	-1.50
01/02/2023	Wednesday	Non Event			0	7.50	Mild	7.38	Mild	-0.13
02/02/2023	Thursday	Event	307	13	320	8.50	Mild	8.13	Mild	-0.38
03/02/2023	Friday	Non Event			0	7.50	Mild	8.00	Mild	0.50
06/02/2023	Monday	Non Event			0	4.00	Cold	5.88	Mild	1.88
07/02/2023	Tuesday	Event	317	17	334	3.75	Cold	4.75	Cold	1.00
08/02/2023	Wednesday	Non Event			0	3.50	Cold	4.63	Cold	1.13
09/02/2023	Thursday	Event	293	18	311	3.00	Cold	4.38	Cold	1.38
10/02/2023	Friday	Non Event			0	3.75	Cold	8.00	Mild	4.25
13/02/2023	Monday	Non Event			0	7.50	Mild	7.13	Mild	-0.38
14/02/2023	Tuesday	Non Event			0	8.00	Mild	8.88	Mild	0.88
15/02/2023	Wednesday	Event	297	18	315	7.75	Mild	6.38	Mild	-1.38
16/02/2023	Thursday	Non Event			0	9.75	Mild	8.25	Mild	-1.50

17/02/2023	Friday	Event	289	18	307	8.00	Mild	10.00	Warmer	2.00
20/02/2023	Monday	Event			0	9.75	Mild	8.25	Mild	-1.50
21/02/2023	Tuesday	Event			0	9.25	Mild	6.63	Mild	-2.63
22/02/2023	Wednesday	Non Event			0	7.50	Mild	5.63	Mild	-1.88
23/02/2023	Thursday	Non Event			0	7.50	Mild	5.00	Mild	-2.50
24/02/2023	Friday	Non Event			0	7.50	Mild	7.38	Mild	-0.13
27/02/2023	Monday	Event			0	5.25	Mild	5.25	Mild	0.00
28/02/2023	Tuesday	Non Event			0	4.75	Cold	5.88	Mild	1.13
01/03/2023	Wednesday	Event			0	5.50	Mild	4.50	Cold	-1.00
02/03/2023	Thursday	Non Event			0	6.00	Mild	4.63	Cold	-1.38
03/03/2023	Friday	Non Event			0	6.25	Mild	3.38	Cold	-2.88
06/03/2023	Monday	Non Event			0	4.50	Cold	5.88	Mild	1.38
07/03/2023	Tuesday	Non Event			0	3.25	Cold	3.13	Cold	-0.13
08/03/2023	Wednesday	Non Event			0	3.50	Cold	0.25	Cold	-3.25
09/03/2023	Thursday	Event			0	5.25	Mild	9.38	Mild	4.13
10/03/2023	Friday	Non Event			0	5.00	Mild	2.38	Cold	-2.63

Table 19 – Segmentation of event days and non-event days throughout the trial period into different forecast and actual temperature bands

Temperature Bands		Temperature Type (Forecast)			Temperature Type (Actual)		
Name	Temperature (°C)	Days Considered	Events	Non Event	Days Considered	Events	Non Event
Warm	>10	0	0	0	3	2	1
Mild	9 to 10	4	2	2	1	1	0
Mild	8 to 9	5	3	2	7	3	4
Mild	7 to 8	15	5	10	4	0	4
Mild	6 to 7	5	2	3	6	4	2
Mild	5 to 6	4	3	1	8	2	6
Cold	4 to 5	5	2	3	5	3	2
Cold	3 to 4	8	3	5	2	0	2
Cold	2 to 3	3	1	2	3	2	1
Cold	1 to 2	1	1	0	3	2	1
Cold	0 to 1	1	0	1	3	1	2
Very Cold	-1 to 0	0	0	0	3	1	2
Very Cold	-2 to -1	0	0	0	2	1	1
Very Cold	-3 to -2	0	0	0	1	0	1

Appendix C: Trial One Results Tables

Table 20 – Measurable[28] household numbers per event, broken down by different groups of households

Measurable household numbers per event by grouping

Trial One Household Grouping	Event Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Trial Average
Overall																							
All households (inc. non-participants)	349	347	337	348	354	344	353	336	343	342	332	325	343	348	341	347	328	322	329	339	337	351	341
Event participants (henceforth 'participants')	304	294	285	321	316	320	295	269	295	290	282	239	298	295	292	284	268	275	212	272	265	278	284
Octopus Energy participants	294	284	275	310	305	309	282	256	282	277	269	226	285	280	274	266	250	257	194	254	247	260	270
Octopus Energy non-participants	45	53	52	27	38	24	58	67	48	52	50	86	45	53	49	63	60	47	117	67	72	73	57
Sero participants	10	10	10	11	11	11	13	13	13	13	13	13	13	15	18	18	18	18	18	18	18	18	14
By Control Type																							
All Remote Customer Control (inc. non-participants)	159	157	159	156	158	153	164	146	154	160	146	151	143	152	152	157	134	151	153	152	151	162	153
Remote Customer Control participants	147	135	131	144	142	141	134	119	133	130	119	106	126	128	123	126	113	125	96	122	113	123	126
Remote Customer Control non-participants	12	22	28	12	16	12	30	27	21	30	27	45	17	24	29	31	21	26	57	30	38	39	27
All Manual Customer Control (inc. non-participants)	173	172	164	176	179	175	172	172	171	165	168	156	183	176	168	169	173	149	157	163	165	167	169
Manual Customer Control participants	144	144	142	163	158	165	146	133	145	143	146	117	155	148	149	137	134	129	98	126	132	134	140
Manual Customer Control non-participants	29	28	22	13	21	10	26	39	26	22	22	39	28	28	19	32	39	20	59	37	33	33	28
Sero participants	10	10	10	11	11	11	13	13	13	13	13	13	13	15	18	18	18	18	18	18	18	18	14
By Payment Type																							
All Pay Monthly (inc. non-participants)	176	176	162	178	171	165	168	157	165	163	156	147	160	178	154	169	156	152	148	166	165	173	164
All Pay Monthly participants	149	146	133	162	154	153	140	125	139	137	129	95	138	145	132	138	125	129	80	135	128	137	134
Octopus Energy Pay Monthly participants	146	143	130	158	150	149	134	119	133	131	123	89	132	137	123	129	116	120	71	126	119	128	128
Octopus Energy Pay Monthly non-participants	27	30	29	16	17	12	28	32	26	26	27	52	22	33	22	31	31	23	68	31	37	36	30
Sero Pay Monthly Participants	3	3	3	4	4	4	6	6	6	6	6	6	6	8	9	9	9	9	9	9	9	9	7
All Pay per Event (inc. non-participants)	173	171	175	170	183	179	185	179	178	179	176	178	183	170	187	178	172	170	181	173	172	178	177
All Pay per Event Participants	155	148	152	159	162	167	155	144	156	153	153	144	160	150	160	146	143	146	132	137	137	141	150
Octopus Energy Pay per Event participants	148	141	145	152	155	160	148	137	149	146	146	137	153	143	151	137	134	137	123	128	128	132	142
Octopus Energy Pay per Event non-participants	18	23	23	11	21	12	30	35	22	26	23	34	23	20	27	32	29	24	49	36	35	37	27
Sero Pay per Event Participants	7	7	7	7	7	7	7	7	7	7	7	7	7	7	9	9	9	9	9	9	9	9	8
By Low Carbon Technology (Octopus Energy only)																							
Participants with battery	138	132	124	142	138	142	134	115	124	127	121	103	125	130	122	121	114	119	86	120	119	126	124
Participants without battery	156	152	151	168	167	167	148	141	158	150	148	123	160	150	152	145	136	138	108	134	128	134	146
Participants with EV	183	173	173	191	183	187	175	161	174	173	169	143	180	173	173	165	154	162	122	163	160	156	168
Participants without EV	111	111	102	119	122	122	107	95	108	104	100	83	105	107	101	101	96	95	72	91	87	104	102
Participants with solar thermal	28	28	24	29	26	28	28	21	24	24	25	23	27	27	24	24	25	26	21	23	26	26	25
Participants without solar thermal	266	256	251	281	279	281	254	235	258	253	244	203	258	253	250	242	225	231	173	231	221	234	245
By EPC Rating																							
Participants with EPC A/B homes	47	44	46	45	44	48	44	38	45	44	43	36	45	47	47	46	40	47	38	47	47	45	44
Octopus Energy Participants with EPC A/B homes	37	34	36	34	33	37	31	25	32	31	30	23	32	32	29	28	22	29	20	29	29	27	30
Octopus Energy Participants with EPC C/D homes	45	43	40	42	44	44	40	35	39	40	35	33	40	41	43	36	38	36	25	30	33	32	38
By Baselined Event Period Consumption																							
Participants predicted to use <0.4kWh between 5-7pm for at least half of events	31	30	30	34	34	30	35	27	27	28	25	20	25	27	26	28	26	29	23	32	30	34	29
Participants predicted to use <0.4kWh between 5-7pm for any events	136	139	128	142	147	142	135	115	130	131	125	99	126	132	125	116	112	116	89	122	117	127	125
Participants predicted to use <0.4kWh between 5-7pm for fewer than half of events	105	109	98	108	113	112	100	88	103	103	100	79	101	105	99	88	86	87	66	90	87	93	96
Participants predicted to use >0.4kWh between 5-7pm for at least half of events	263	254	245	276	271	279	247	229	255	249	244	206	260	253	248	238	224	228	171	222	217	226	241
Participants predicted to use >0.4kWh between 5-7pm for all events	158	145	147	168	158	167	147	141	152	146	144	127	159	148	149	150	138	141	105	132	130	133	145

[28] Measurable participants do not include trial participants with sub-zero baselined (predicted) consumption during that event, and those whose smart meter did not provide a full set of half-hourly meter readings for that event (both of which invalidate estimates for that household's turndown).

Table 21 – Measurable kWh turndown per event per household and aggregated turndown across the trial, broken down by different groups of households[29]

Measurable kWh turndown per event per household by grouping																								
Trial One Household Grouping	Event Number																						Trial Average	Trial Total (MWh)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
Overall																								
All households (inc. non-participants)	3.29	3.29	1.45	1.32	1.06	1.58	1.78	1.48	1.77	1.64	0.89	0.93	1.22	0.95	0.89	0.95	0.82	0.86	0.74	1.48	1.31	1.80	1.43	10.79
Event participants (henceforth 'participants')	3.64	3.37	1.55	1.38	1.14	1.62	1.83	1.51	1.81	1.68	0.88	1.04	1.16	1.03	0.91	0.96	0.78	0.82	0.85	1.43	1.46	1.71	1.48	9.37
Octopus Energy participants	3.74	3.48	1.61	1.45	1.18	1.63	1.91	1.53	1.83	1.77	0.92	1.07	1.21	1.03	0.90	0.99	0.83	0.86	0.90	1.49	1.53	1.81	1.53	9.25
Octopus Energy non-participants	0.97	2.82	0.93	0.65	0.36	1.07	1.56	1.36	1.54	1.43	0.93	0.62	1.60	0.55	0.76	0.92	1.00	1.08	0.55	1.65	0.75	2.17	1.15	1.42
Sero participants	0.59	0.39	-0.32	-0.74	0.16	1.27	0.13	0.97	1.29	-0.23	0.18	0.61	-0.03	1.02	0.94	0.44	0.16	0.13	0.30	0.58	0.38	0.14	0.38	0.12
By Control Type																								
All Remote Customer Control (inc. non-participants)	3.42	3.40	1.62	1.14	0.98	1.82	1.84	1.56	1.67	1.56	0.88	0.91	1.11	0.82	0.81	0.95	1.00	0.79	0.68	1.53	1.07	1.95	1.43	4.88
Remote Customer Control participants	3.76	3.44	1.73	1.18	1.03	1.87	1.96	1.47	1.75	1.60	0.99	1.06	1.05	1.02	0.84	0.94	0.98	0.77	0.85	1.38	1.22	2.01	1.50	4.26
Remote Customer Control non-participants	-0.72	3.20	1.11	0.61	0.55	1.25	1.34	1.94	1.11	1.38	0.43	0.56	1.61	-0.23	0.70	0.99	1.11	0.90	0.40	2.13	0.64	1.76	1.04	0.62
All Manual Customer Control (inc. non-participants)	3.30	3.23	1.38	1.57	1.18	1.35	1.83	1.41	1.89	1.83	0.90	0.95	1.37	1.03	0.94	0.98	0.74	0.99	0.86	1.53	1.59	1.81	1.49	5.55
Manual Customer Control participants	3.70	3.37	1.52	1.65	1.32	1.41	1.83	1.54	1.90	1.89	0.83	1.05	1.33	1.00	0.96	1.01	0.68	0.95	0.94	1.61	1.80	1.61	1.54	4.80
Manual Customer Control non-participants	1.35	2.55	0.47	0.66	0.18	0.34	1.85	0.96	1.86	1.49	1.39	0.65	1.59	1.17	0.83	0.86	0.94	1.27	0.71	1.25	0.77	2.64	1.17	0.74
Aggregator Control	0.59	0.39	-0.32	-0.74	0.16	1.27	0.13	0.97	1.29	-0.23	0.18	0.61	-0.03	1.02	0.94	0.44	0.16	0.13	0.30	0.58	0.38	0.14	0.38	0.12
By Payment Type																								
All Pay Monthly (inc. non-participants)	3.14	3.34	1.60	1.31	1.15	1.86	1.92	1.61	1.66	1.53	0.99	0.85	1.23	0.84	0.71	0.88	0.74	0.80	0.47	1.11	1.24	1.60	1.39	5.09
All Pay Monthly participants	3.48	3.48	1.70	1.39	1.24	1.94	2.02	1.62	1.72	1.56	0.95	0.98	1.17	0.90	0.72	0.88	0.68	0.73	0.63	1.08	1.34	1.57	1.44	4.39
Octopus Energy Pay Monthly participants	3.54	3.60	1.74	1.45	1.27	1.96	2.10	1.65	1.74	1.65	0.98	0.98	1.21	0.88	0.70	0.92	0.74	0.78	0.65	1.12	1.40	1.65	1.49	4.33
Octopus Energy Pay Monthly non-participants	1.24	2.69	1.13	0.42	0.37	0.76	1.37	1.58	1.39	1.36	1.16	0.61	1.62	0.58	0.63	0.88	1.00	1.17	0.27	1.26	0.90	1.73	1.10	0.70
Sero Pay Monthly Participants	0.48	-2.42	0.06	-0.85	-0.19	1.24	0.33	1.03	1.16	-0.30	0.52	0.96	0.21	1.16	0.94	0.36	-0.12	0.03	0.46	0.54	0.55	0.45	0.30	0.06
All Pay per Event (inc. non-participants)	3.46	3.22	1.32	1.34	0.98	1.33	1.67	1.36	1.87	1.75	0.80	1.00	1.20	1.06	1.03	1.02	0.89	0.91	0.97	1.82	1.37	2.00	1.47	5.71
All Pay per Event Participants	3.79	3.26	1.41	1.36	1.06	1.33	1.65	1.41	1.89	1.79	0.82	1.09	1.15	1.14	1.06	1.03	0.87	0.89	0.98	1.78	1.56	1.84	1.51	4.98
Octopus Energy Pay per Event participants	3.94	3.35	1.50	1.45	1.09	1.33	1.73	1.43	1.92	1.88	0.87	1.12	1.21	1.16	1.07	1.06	0.90	0.93	1.04	1.86	1.66	1.98	1.57	4.91
Octopus Energy Pay per Event non-participants	0.55	3.00	0.68	0.98	0.35	1.38	1.74	1.17	1.71	1.50	0.66	0.63	1.57	0.48	0.87	0.97	1.00	0.99	0.94	1.98	0.60	2.60	1.20	0.72
Sero Pay per Event Participants	0.79	1.39	-0.43	-0.61	0.40	1.42	0.01	0.96	1.44	-0.16	-0.09	0.34	-0.22	0.69	0.92	0.52	0.45	0.24	0.15	0.63	0.21	-0.15	0.40	0.07
By Low Carbon Technology (Octopus Energy only)																								
Participants with battery	3.83	3.33	1.75	1.46	1.17	1.46	1.86	1.22	1.79	1.90	0.85	1.13	1.25	0.98	0.81	0.96	0.85	0.93	1.03	1.53	1.14	1.48	1.49	4.13
Participants without battery	3.66	3.61	1.50	1.44	1.19	1.78	1.95	1.79	1.87	1.67	0.98	1.02	1.18	1.06	0.98	1.02	0.81	0.81	0.79	1.47	1.90	2.13	1.57	5.12
Participants with EV	3.96	3.80	1.76	1.50	1.37	1.81	2.04	1.69	1.98	1.98	1.02	1.16	1.31	1.10	0.95	0.97	0.80	0.94	0.99	1.66	1.65	1.81	1.65	6.18
Participants without EV	3.39	2.97	1.37	1.38	0.89	1.35	1.69	1.26	1.60	1.43	0.74	0.91	1.04	0.91	0.83	1.02	0.87	0.74	0.74	1.20	1.31	1.83	1.34	3.07
Participants with solar thermal	3.39	3.23	1.02	1.40	1.16	1.68	1.30	1.02	1.84	2.13	0.97	1.83	1.01	1.12	0.79	0.39	0.69	0.62	0.84	1.48	1.55	2.11	1.43	0.81
Participants without solar thermal	3.78	3.50	1.67	1.46	1.18	1.63	1.97	1.58	1.83	1.74	0.91	0.98	1.23	1.02	0.92	1.05	0.84	0.89	0.90	1.50	1.53	1.78	1.54	8.44
By EPC Rating																								
Participants with EPC A/B homes	2.16	1.97	0.74	0.55	0.50	0.90	0.73	0.52	1.14	0.73	0.42	0.50	0.67	0.80	0.54	0.60	0.43	0.51	0.57	0.83	0.94	1.00	0.81	0.79
Octopus Energy Participants with EPC A/B homes	2.58	2.43	1.03	0.97	0.61	0.79	0.99	0.28	1.08	1.14	0.52	0.43	0.95	0.69	0.29	0.70	0.66	0.74	0.82	0.98	1.28	1.57	0.98	0.67
Octopus Energy Participants with EPC C/D homes	4.22	4.06	2.18	1.61	1.24	1.79	2.19	1.60	2.15	1.96	1.25	1.34	1.16	1.26	0.64	1.04	0.58	1.11	1.27	1.57	1.77	1.90	1.72	1.47
By Baselined Event Period Consumption (Octopus Energy only)																								
Participants predicted to use <0.4kWh between 5-7pm for at least half of events	1.76	0.51	0.48	0.23	0.20	0.20	0.28	0.13	0.17	0.18	0.07	0.10	0.24	0.22	0.29	0.00	0.06	0.08	0.12	0.27	0.25	0.41	0.29	0.19
Participants predicted to use <0.4kWh between 5-7pm for any events	3.08	2.64	1.21	0.93	0.76	1.30	1.23	1.25	1.31	1.11	0.49	0.40	0.68	0.59	0.45	0.45	0.35	0.47	0.66	1.03	0.93	1.28	1.03	2.92
Participants predicted to use <0.4kWh between 5-7pm for fewer than half of events	3.46	3.23	1.44	1.15	0.93	1.60	1.56	1.59	1.61	1.37	0.59	0.47	0.79	0.68	0.49	0.59	0.44	0.60	0.84	1.30	1.17	1.60	1.25	2.73
Participants predicted to use >0.4kWh between 5-7pm for at least half of events	3.97	3.83	1.75	1.60	1.30	1.79	2.14	1.70	2.01	1.95	1.00	1.16	1.31	1.11	0.97	1.11	0.92	0.96	1.00	1.67	1.71	2.03	1.68	9.06
Participants predicted to use >0.4kWh between 5-7pm for all events	4.31	4.28	1.96	1.89	1.57	1.91	2.53	1.76	2.28	2.36	1.29	1.59	1.63	1.42	1.28	1.41	1.21	1.19	1.10	1.92	2.07	2.33	1.97	6.33

[29] There is an error associated with the baseline method used to calculate kWh turndown, which decreases as group size increases. Median error at a group size of 20 is 0.49kWh; median error at a group size of 30 is 0.40kWh and continues to decrease to median error of 0.29kWh at a group size of 100. This error must be taken into account when considering whether there is a difference in outcomes between groups, particularly if group sizes are small.

Table 22 – Standard deviation of measurable kWh turndown per event per household, broken down by different groups of households

Standard Deviation for measurable kWh turndown per event per household by grouping																							
Trial One Household Grouping	Event Number																						Trial Average
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Overall																							
All households (inc. non-participants)																							
Event participants (henceforth 'participants')																							
Octopus Energy participants	3.64	3.79	2.53	2.27	2.32	2.96	2.98	2.79	2.78	2.67	1.85	2.00	2.15	1.99	2.09	1.87	1.65	1.68	1.75	2.58	2.36	3.09	2.45
Octopus Energy non-participants	2.58	4.07	2.37	1.40	1.96	2.56	2.94	3.05	2.75	2.42	1.83	2.49	2.17	2.30	1.67	2.02	2.01	1.49	2.20	2.60	1.79	3.45	2.37
Sero participants																							
By Control Type																							
All Remote Customer Control (inc. non-participants)	5.55	3.86	2.59	2.12	1.96	3.12	2.96	2.87	2.74	2.18	1.84	2.22	2.03	2.06	2.07	1.78	1.75	1.39	1.86	2.58	1.99	2.75	2.47
Remote Customer Control participants	3.59	3.69	2.60	2.12	1.93	3.10	2.94	2.67	2.70	2.17	1.73	1.97	1.80	1.61	2.08	1.63	1.65	1.39	1.70	2.36	2.00	2.90	2.29
Remote Customer Control non-participants	1.85	4.83	2.15	0.81	1.73	2.79	2.84	3.55	2.55	2.18	2.00	2.62	2.96	2.19	2.06	2.30	2.25	1.38	2.03	3.00	1.73	2.17	2.36
All Manual Customer Control (inc. non-participants)	4.14	3.86	2.68	2.53	2.79	2.97	3.05	2.91	2.89	3.05	1.94	2.18	2.31	2.29	2.01	2.01	1.72	1.92	2.04	2.69	2.64	3.66	2.65
Manual Customer Control participants	3.73	3.83	2.49	2.38	2.63	2.85	3.04	2.92	2.89	3.07	1.94	2.06	2.41	2.30	2.11	2.07	1.65	1.94	1.81	2.80	2.62	3.26	2.58
Manual Customer Control non-participants	2.41	3.58	2.62	1.91	2.19	1.31	3.18	2.67	2.96	2.78	1.32	2.42	1.58	2.25	0.88	1.76	1.90	1.65	2.37	2.19	1.78	4.55	2.28
Aggregator Control																							
By Payment Type																							
All Pay Monthly (inc. non-participants)																							
All Pay Monthly participants																							
Octopus Energy Pay Monthly participants	4.02	3.89	2.92	2.26	2.06	3.08	3.35	3.17	2.98	2.41	1.84	2.14	2.32	1.94	2.30	1.91	1.63	1.46	1.52	2.27	2.31	3.22	2.50
Octopus Energy Pay Monthly non-participants	2.90	4.23	2.45	1.14	1.04	2.40	3.94	2.76	2.75	2.35	1.66	2.67	2.49	2.54	1.58	1.56	1.97	1.61	2.38	1.99	1.85	3.46	2.35
Sero Pay Monthly Participants																							
All Pay per Event (inc. non-participants)																							
All Pay per Event Participants																							
Octopus Energy Pay per Event participants	3.22	3.69	2.14	2.30	2.54	2.83	2.60	2.41	2.61	2.88	1.86	1.92	2.01	2.04	1.90	1.82	1.67	1.85	1.86	2.81	2.41	2.97	2.38
Octopus Energy Pay per Event non-participants	2.01	3.93	2.30	1.72	2.50	2.78	1.58	3.32	2.81	2.54	2.02	2.22	1.87	1.87	1.75	2.42	2.09	1.39	1.88	3.02	1.73	3.43	2.33
Sero Pay per Event Participants																							
By Low Carbon Technology (Octopus Energy only)																							
Participants with battery	3.69	3.67	2.72	2.20	2.19	3.20	2.93	2.72	2.45	3.07	1.75	1.99	1.97	1.57	1.70	1.68	1.54	1.41	1.80	2.87	2.39	3.07	2.39
Participants without battery	3.61	3.90	2.37	2.34	2.42	2.75	3.03	2.83	3.03	2.28	1.93	2.02	2.30	2.30	2.36	2.01	1.74	1.89	1.72	2.29	2.29	3.09	2.48
Participants with EV	3.74	3.83	2.62	2.47	2.52	3.19	3.12	3.02	2.90	2.86	2.06	2.06	2.38	2.24	2.33	1.97	1.47	1.84	1.75	2.58	2.62	3.42	2.59
Participants without EV	3.45	3.69	2.37	1.93	1.94	2.57	2.75	2.35	2.58	2.29	1.41	1.91	1.71	1.51	1.63	1.69	1.90	1.37	1.75	2.55	1.80	2.54	2.17
Participants with solar thermal	3.62	3.75	2.28	2.04	2.42	2.44	1.52	1.90	3.47	2.07	1.57	2.28	2.43	2.84	1.75	2.24	2.11	2.05	1.61	2.02	2.28	3.51	2.37
Participants without solar thermal	3.65	3.80	2.55	2.30	2.31	3.01	3.09	2.85	2.72	2.72	1.88	1.96	2.13	1.89	2.13	1.82	1.59	1.64	1.77	2.63	2.38	3.05	2.45
By EPC Rating																							
Participants with EPC A/B homes																							
Octopus Energy Participants with EPC A/B homes	3.12	3.67	1.9	1.83	1.28	2.52	1.74	2.37	2.52	2.7	1.35	1.51	1.82	1.35	1.73	1.51	1.42	1.15	0.99	1.64	1.79	2.32	1.92
Octopus Energy Participants with EPC C/D homes	3.26	3.38	2.4	1.94	2.55	2.65	2.58	2.47	2.44	2.22	1.77	1.43	1.57	1.51	2.28	1.36	1.4	1.6	1.79	1.86	2.24	1.93	2.12
By Baselined Event Period Consumption (Octopus Energy only)																							
Participants predicted to use <0.4kWh between 5-7pm for at least half of events	2.74	1.13	0.94	0.65	0.44	0.88	0.76	0.49	0.67	1.03	0.43	0.26	0.38	0.51	0.58	0.53	0.24	0.26	0.27	0.67	0.71	1.52	0.73
Participants predicted to use <0.4kWh between 5-7pm for any events	3.28	3.16	2.54	1.97	1.75	2.51	2.32	2.77	2.11	2.18	1.38	1.27	1.74	1.33	1.52	1.13	1.13	0.99	1.46	2.4	1.72	2.37	1.96
Participants predicted to use <0.4kWh between 5-7pm for fewer than half of events	3.34	3.29	2.82	2.18	1.95	2.72	2.59	3.08	2.26	2.34	1.51	1.41	1.92	1.46	1.68	1.24	1.27	1.11	1.65	2.71	1.9	2.54	2.13
Participants predicted to use >0.4kWh between 5-7pm for at least half of events	3.67	3.84	2.63	2.36	2.42	3.07	3.11	2.90	2.86	2.74	1.91	2.07	2.23	2.07	2.18	1.93	1.72	1.76	1.84	2.70	2.46	3.21	2.53
Participants predicted to use >0.4kWh between 5-7pm for all events	3.84	4.16	2.49	2.43	2.68	3.28	3.37	2.79	3.19	2.93	2.11	2.3	2.36	2.37	2.42	2.19	1.89	2.03	1.95	2.67	2.71	3.59	2.72

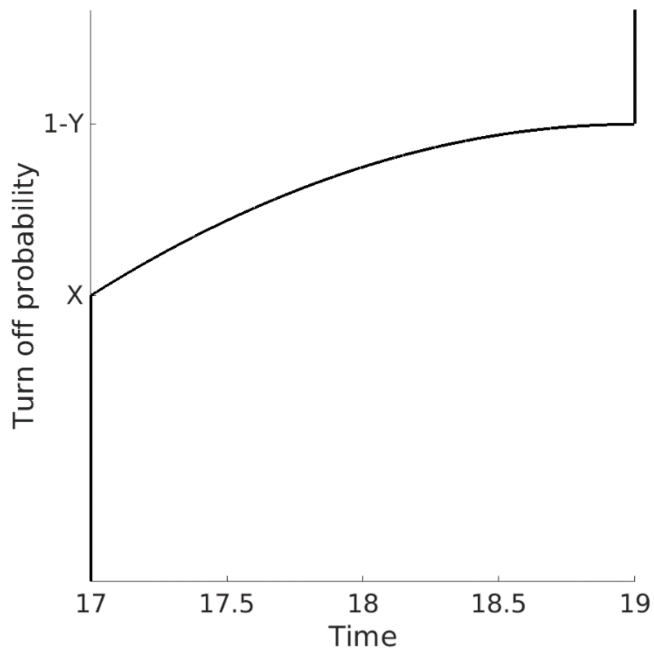
Appendix D: Additional Details on Simulations

Modelling Household Behaviour

Recall that simulations modelled three intervention types. For Manual interventions, it was necessary to model household behaviour, specifically how likely a household is to respond to a notification request to turn their heat pump off, and how promptly they act.

Figure 55 displays the approach of modelling a random manual response of when the heat pump is initially turned off during an event. Probabilities of X and Y were used to determine the reliability of the household. There is a 40-60% chance of turning the heat pump off straight away at 5pm (X) and a 10-30% chance of missing an event entirely (Y), with the remaining probability representing the householder turning off the heat pump late. These rates were based on initial customer feedback shared by Octopus Energy. X and Y are fixed and unique for each archetype, meaning the householder is likely to be consistently more or less reliable than average.

Figure 55 - Cumulative probability distribution of when the occupant turns the heat pump off initially in the Manual interventions case.



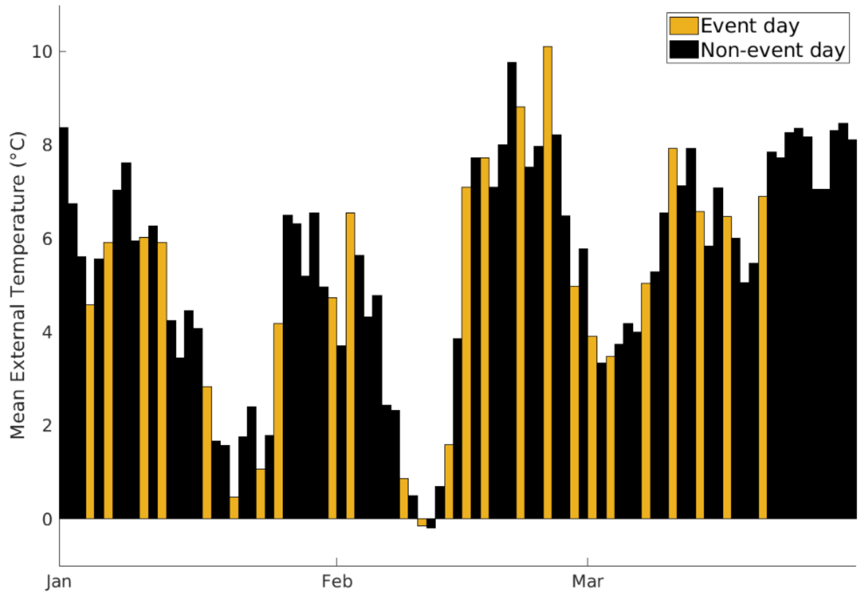
The modelling assumed that the heat pump is turned back on if the room temperature falls over 1°C under setpoint for all types of interventions, although a temperature shift this large rarely occurred in their simulations.

Choice of Simulated Event Days

The choice of event days for the simulations is shown in ***Figure 56***, which clearly shows that event days have been chosen to not be systematically warmer or cooler than non-event days. The average non-event day had a mean temperature of 4.92°C, whilst the average event day had a mean temperature of 4.91°C.

Note that this approach ensured that event days and non-event days were on average exactly comparable in terms of heating demand, and thus a "perfect" scenario for baselining, whereas in reality it was not possible to choose this perfect balance, as weather for the 2022/23 winter was not known in advance.

Figure 56 - Event days and non-event days plotted against mean external temperature



Comparison of Heat Pump Set Ups

Table 23 - Summary metrics from simulations of different control strategies between January and April (no interventions).

	No Weather Compensation			Weather Compensation			Optimised		
Home	Input Energy (kWh)	Mean water temp (°C)	CoP	Input Energy (kWh)	Mean water temp (°C)	CoP	Input Energy (kWh)	Mean water temp (°C)	CoP
1	872	33	3.35	866	33	3.38	798	28	3.36
2	2556	41	2.71	2476	40	2.81	2167	34	3.30
3	1235	34	3.25	1222	33	3.29	1084	27	3.85
4	1908	46	2.50	1870	44	2.56	1634	36	3.04
5	1943	43	2.59	1915	43	2.63	1658	35	3.14
6	1596	38	2.92	1576	38	2.96	1382	30	3.49
7	920	35	3.12	911	35	3.15	842	31	3.49
8	1511	41	2.73	1461	39	2.83	1239	31	3.45
9	1331	40	2.93	1328	40	2.94	1237	35	3.25
10	3562	44	2.78	3354	44	2.79	3139	38	3.07
Mean	**1723**	**39**	**2.89**	**1698**	**39**	**2.94**	**1518**	**33**	**3.38**

Appendix E: Trial One Survey Questions

Q1: How easy have you found the following elements of participating in EQUINOX events this winter?

Customer Control Questions
- Q1_1: Receiving requests for you to switch off your heat pump
- Q1_2: Understanding when to switch off and on your heat pump
- Q1_3: Switching off your heat pump
- Q1_4: Switching your heat pump back on
- Q1_5: Understanding bill credit payments for EQUINOX participation
- Q1_6: Finding the answer to a trial-related question
- Q1_7: Receiving help for your trial-related issue

Potential Responses:
- Extremely easy/moderately easy/slightly easy/neither easy nor difficult/slightly difficult/ moderately difficult/extremely difficult

Aggregator Control Questions
- Q1_1: Allowing your supplier to turn off your heat pump at 5pm
- Q1_2: Opting out of an event before 5pm (i.e. informing your supplier that they should not turn off your heat pump)
- Q1_3: Requesting between 5-7pm that your supplier turns your heat pump back on
- Q1_4: Receiving and understanding information about upcoming EQUINOX event days
- Q1_5: Understanding bill credit payments for EQUINOX participation
- Q1_6: Finding the answer to a trial-related question
- Q1_7: Receiving help for a trial-related issue you have experienced

Potential Responses:
- Extremely easy/moderately easy/slightly easy/neither easy nor difficult/slightly difficult/ moderately difficult/extremely difficult

Q2: How easy do you find operating your heat pump?
Potential Responses:
- Extremely easy / moderately easy / slightly easy / neither easy nor difficult / slightly difficult / moderately difficult / extremely difficult

Q3a: How important do you find the level of control over your heating?
Potential Responses:
- Extremely important / moderately important / slightly important / neither important nor unimportant / slightly unimportant / moderately unimportant / extremely unimportant

Q3b: Have you felt sufficiently in control of your heating during the EQUINOX trial?

Potential Responses:

- Yes / no

Q4: How frequently has participating in EQUINOX events caused any discomfort (for example, feeling too cold), for you or someone else in the household?
Potential Responses:

- Never / sometimes / about half the time / most of the time / always

Q5a: During this trial, there have been up to three EQUINOX events per week. What is your view on this frequency?
Potential Responses:

- Far too little / slightly too little / neither too much nor too little / slightly too much / far too much

Q5b: What frequency of EQUINOX events would you prefer?
Potential Responses:

- Daily / multiple times a week / once a week

Q6: What do you think about the current 2-hour duration of EQUINOX events?
Potential Responses:

- About right / slightly too little / slightly too much

Q7a: Have you chosen not to participate in at least one EQUINOX event?
Potential Responses:

- Yes / no / don’t know

Q7b: Why have you chosen not to participate in an EQUINOX event? (Select all that apply)
Additional sub-questions:
Potential Responses (Q7b_1):

- It was too cold outside on the day of the event / I did not realise there was an event on that day / there had been too many events recently / I or someone in the household was suffering from illness at that time / I had a technical issue on that day / I didn't know how to participate on that day / someone in my house felt too cold during a previous event / other

- Q7b_2: Other reasons for not participating in an EQUINOX event

Potential Responses (Q7b_2):

- [Open ended: respondent fills in as they feel is necessary]

Q7c: Why have you chosen to opt out of your supplier switching off your heat pump prior to the start of at least one EQUINOX event? (Select all that apply)
Potential Responses (Q7c_1):

- I did not realise there was an event on that day / Other

Additional sub-questions:

- Q7c_2: Other reasons for opting out

Potential Responses (Q7c_2):

- [Open ended: respondent fills in as they feel is necessary]

Q7d: What could incentivise you to participate more in EQUINOX events? (Optional)
Potential Responses:
- [Open ended: respondent fills in as they feel is necessary]

Q8a: In the EQUINOX events that you chose to participate in, have you ever chosen to switch your heat pump back on before 7pm during any EQUINOX events?
Potential Responses:
- Yes / No / Don't know

Q8b: Why have you chosen to switch your heat pump back on before 7pm for at least one EQUINOX event? (Select all that apply)
Potential Responses (Q8b_1):
- It was too cold outside on the day of the event / someone in my house felt too cold during the event / there had been too many events recently / I or someone else in the house was suffering from illness / other

Additional sub-questions:
- Q8b_2: Other reasons for partially participating in an Equinox event

Potential Responses (Q8b_2):
- [Open ended: respondent fills in as they feel is necessary]

Q9: How satisfied are you with the payment amounts for taking part in the trial?
Potential Responses:
- Extremely satisfied / moderately satisfied / slightly satisfied / neither satisfied nor dissatisfied / slightly dissatisfied / moderately dissatisfied / extremely dissatisfied

Q10: Are you satisfied with how far in advance you are being notified about event periods?
Potential Responses:
- Yes, the current timing of notifications is fine/no, I would prefer a longer notice period before events

Q11: Are you satisfied with how you are being notified of these events?
Potential Responses:
- Yes, email notifications work/no, I would prefer to be notified in another way/other

Q12.b_1: How important were environmental reasons in influencing your decision to participate in the trial, if at all?
Potential Responses:
- Extremely important/very important/moderately important/slightly important/not at all important

Q12.b_2: How important were financial reasons in influencing your decision to participate in the trial, if at all?
Potential Responses:
- Extremely important/very important/moderately important/slightly important/not at all important

Q13.a: Overall, how satisfied are you with the overall EQUINOX trial so far?
Potential Responses:

- Extremely satisfied/Moderately satisfied/Slightly satisfied/Neither satisfied nor dissatisfied/Slightly dissatisfied/Moderately dissatisfied/Extremely dissatisfied

Q13.b: Why are you satisfied with the trial so far?
Potential Responses:

- I feel I am doing my part and playing an active role in the green transition/The trial is simple to understand and take part in/The events are causing no discomfort to our household/The money to participate in the events is really helpful and makes participating in the events worthwhile/Other

Q13.c: Why have you been dissatisfied with the EQUINOX trial?
Potential Responses:

- [Open ended: respondent fills in as they feel is necessary]

Q15: Which of the following best describes your home?
Potential Responses:

- Detached house/Semi-detached house/Terraced (including end-terrace) house

Q16: Including yourself, how many people permanently live in your household?
Potential Responses:

- 1 / 2 / 3 / 4 / 5 / 6

Q17: Who do you share your household with, if any? (Select all that apply)
Potential Responses:

- Children / Children, Parents / Sole occupant / Sole occupant, Spouse/partner / Spouse/partner / Spouse/partner, Children / Spouse/partner, Children, Elderly relatives / Spouse/partner, Children, Parents/ Spouse/partner, Elderly relatives

Q18: Including yourself, how many people in your household meet the following criteria

- Q18_1: Over 65 years old
- Q18_2: Between 5 and 18 years old
- Q18_3: Under 5 years old
- Q18_4: Has a disability or long-term health condition

Potential Responses:

- 1 / 2 / 3 / 4

Q19: How long have you had a heat pump in your current home?
Potential Responses:

- 0-6 months / 6-12 months / 12-18 months / 18-24 months / 24 months or more

Q20: Why did you decide to get a heat pump? Select all that apply
Potential Responses:

- Environmental reasons / Economic reasons / I live off the gas grid / I purchased/moved into a property with a heat pump installed / I wanted to make use of the government grant / Other

Q21: Which of the following best describes your relationship with the property you live in?
Potential Responses:

- Own outright / Own outright with a mortgage or a loan / Rent from a housing association, housing cooperative, charitable trust, registered social landlord, council or local authority / Other

Q22: What is your annual household income, before tax and other deductions?
Potential Responses:

- £5,000 to £9,999 / £10,000 to £14,999 / £15,000 to £19,999 / £20,000 to £29,999 / £30,000 to £39,999 / £40,000 to £49,999 / £50,000 to £75,000 / £75,000 and over / Prefer not to say

Q23: Which of the following best describes how affordable you find your energy bills (or energy costs if you do not receive a bill) and other household bills?
Potential Responses:

- I can always afford to pay my energy bill (or top up my gas card/ electricity key), and other household bills, on time and do not need to conserve my energy or go without other things to do so / I can always afford to pay my energy bill (or top up my gas card/ electricity key), and other household bills, on time but only because I conserve my energy or go without other things to do so / I can always afford to pay my energy bill (or top up my gas card/ electricity key) on time, but sometimes struggle, or am late, paying other bills / I am often unable to afford to pay my energy bill (or top up my gas card/electricity key) on time / Prefer not to say

Q24: Energy Usage this Winter
Potential Responses:

- No, I have not changed how I heat my house / Yes, I have heated my house a bit less / Yes, I have heated my house significantly less / Yes, I have heated my house more this winter

Q25: Do you currently have, or have you ever had a job related to the energy industry or the environment?
Potential Responses:

- Yes / No / Don't know / Prefer not to say

Q26: How would you rate your knowledge on climate change?
Potential Responses:

- Extremely knowledgeable / Very knowledgeable / Moderately knowledgeable / Slightly knowledgeable / Neither knowledgeable nor unknowledgeable

Q27: Climate Change Worry
Potential Responses:

- Very worried / Somewhat worried / Neither worried or unworried / Somewhat unworried / Not at all worried

Appendix F: Post-Event Survey

This survey was sent via **email** to participating households (up to an hour after) after the event finished. Recipients had **24hrs** to answer the questions before the surveys were closed. There were two versions of the survey: one for customer control households and the second for aggregator control households.

Survey structure:

Based on responses to specific questions, participants would get a specific number of questions.

Table 24 – Post-Event Survey Structure

Question	Did not Participate	Only participated for part of the event	Participated for entire event
Q1	Yes	Yes	Yes
Q2a	Yes	No	No
Q2b	No	Yes	No
Q2c	No	Yes	No
Q3	No	Yes	Yes
Total no. of questions	**2**	**4**	**2**

Customer Control Post-Event Survey Questions

Q1: Were you able to turn your heat pump off (or all the way down) today?
If your heat pump was already off and you left it that way, that counts!
Potential Responses:

- Yes, for all of the event/yes, but only for part of the time/no, I kept my heat pump on/don't know

Q2a: Was there a reason you kept your heat pump on?
Potential Responses:

- My home was too cold when the trial started/it's cold outside and I was worried my home would get too cold/I did not realise there was an event/I didn't know how to participate/I forgot this event was happening today/someone in my home today is ill or sensitive to cold, so I didn't want the heating off/doing this last time made someone in my home too cold/nobody was home to turn off the heat pump/other

Q2b: Why did you only participate for part of the event?
Potential Responses:

- My home was too cold when the trial started/it's cold outside and I was worried my home would get too cold/I did not realise there was an event/I didn't know how to participate/I forgot this event was happening today/someone in my home today is ill or sensitive to cold, so I didn't want the heating off/doing this last time made someone in my home too cold/nobody was home to turn off the heat pump/other

Q2c: How long did you participate in this event?
Potential Responses:

- 0-30 mins / 31 mins-1 hour / 1 hour 1 min-1 hour 30 mins / 1 hour 31 mins-2 hours / don't know

Q3: How much did the event impact comfort levels (i.e., how warm or cool you felt) inside your home?
Potential Responses:

- No change in comfort levels/I or another householder felt moderate discomfort/I or another householder felt mild discomfort/I or another householder felt very uncomfortable/I or another householder felt uncomfortable

Aggregator Control Post-Event Survey Questions

Q1: Did you participate in today's event by allowing us to turn off your heat pump? ***Please note that if your heat pump was already off before the two-hour event started, keeping it off for the two-hour event period is a valid way to participate.***
Potential Responses:

- Yes, for all of the event/yes, for part of the event/no, not at all/don't know

Q2a: Why did you not participate in the event? Please select all that apply.
Potential Responses:

- I did not realise there was an event/I accidentally opted out/it was too cold inside my house today/it was too cold outside today/I didn't know how to participate/me or someone in the household is suffering from illness/there have been too many events recently/I was too cold during the last event/I could not, I was out of the house/I could not, my heat pump was already off/prefer not to say/don't know/other

Q2b: Why did you only participate for part of the event? Please select all that apply.
Potential Responses:

- I did not realise there was an event/I accidentally opted out/it was too cold inside my house today/it was too cold outside today/I didn't know how to participate/me or someone in the household is suffering from illness/there have been too many events recently/I was too cold during the last event/I could not, I was out of the house/I could not, my heat pump was already off/prefer not to say/don't know/other

Q2c: How long did you participate in this event?
Potential Responses:

- 0-30 mins / 31 mins-1 hour / 1 hour 1 min-1 hour 30 mins / 1 hour 31 mins-2 hours / don't know

Q3: How much, if at all, did the event impact comfort levels (i.e., how warm or cool you felt) inside your home?
Potential Responses:

- No change in comfort levels/I or another householder felt moderate discomfort/I or another householder felt mild discomfort/I or another householder felt very uncomfortable/I or another householder felt uncomfortable.

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