Department for Energy Security & Net Zero

Smart Energy Savings Competition (SENS): Smart Energy - Smart Thermostat (SEN-ST)

Trial Level Evaluation Report

June 2023

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Rationale for and objectives of the SENS Competition

Smart meters are replacing traditional gas and electricity meters in homes and small businesses across Great Britain as part of an important upgrade to the national energy infrastructure, underpinning the cost-effective delivery of Government's Net Zero commitment. They are a critical tool in the transition to a low carbon energy system, for example helping consumers to use energy when renewable generation is available. Prior to the Competition, BEIS found that smart meters would result in average reductions of 3% for electricity customers, 2.2% for gas credit customers, and 0.5% for gas pre-payment customers[1].

Early evaluation and research showed that such savings can be realised through access to near real time feedback (via In-Home Displays, IHDs), energy efficiency advice at the point of installation, and accurate bills[2]. The Smart Energy Savings Innovation (SENS) Competition was developed on the assumption that more sophisticated uses of energy consumption data can deliver additional savings to those already achieved by having a smart meter installed in the home.

The SENS Competition led by the former Department for Business, Energy and Industrial Strategy (BEIS) committed up to £6.25 million, to support the development, trialling and evaluation of innovative feedback products and services that use smart meter data to help domestic consumers reduce their energy consumption. SENS was launched February 2019, with trials concluding end of March 2022 (extended by one-year due to COVID-19 impacts).

The objectives of the Competition were to:

- Identify innovative products and services using smart meter data that can deliver energy savings in homes, in excess of those currently identified in the smart meter impact assessment, for either the Great Britain population or specific groups within it.
- Ensure that solutions are attractive and valued by consumers and are easily available (using existing technologies and delivery channels or cost-effective new hardware).
- Support the development of a domestic market for energy management products and services, securing investment from technology providers, energy suppliers, and third parties.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831716/smart-meter-roll-out-cost-benefit-analysis-2019.pdf

[2] https://www.gov.uk/government/publications/smart-metering-early-learning-project-and-small-scale-behaviour-trials

Overview of the SENS product

The Smart Thermostat (SEN-ST) project was delivered by Green Energy Options (GEO) Limited in partnership with Shell Energy Retailed Limited. SEN-ST was an “energy-aware” smart thermostat which combined control of heating and hot water with smart meter data to provide trialists with increased insight into their energy usage. Trialists were able to view and control their heating remotely, either through their GEO IHD (this varied from a standard IHD by combining with the smart thermostat interface) or GEO mobile application, with both having similar functionality. By accessing household gas and electricity smart meter data, trialists with the SEN-ST product accessed information about their level of energy consumption (used for heating) in the previous week, how much they would need to spend to maintain the level of comfort in the coming week, and what the monetary value of changing their level of comfort (e.g. by one Celsius) would be. The product aimed to reduce gas energy consumption (all homes in the trial were heated by gas boilers), increase home comfort level and increase general awareness in energy usage which may facilitate further behavioural change.

Evaluation approach and methodology

The Competition appointed a separate Trial Design and Evaluation Lead (TDEL) team, led by Ipsos, in conjunction with Energy Saving Trust, Manchester Metropolitan University and the University of Edinburgh to conduct an independent evaluation of the Competition and the individual products and services trialled through the Competition.

This trial-level evaluation sought to test whether the SEN-ST product was successful in realising its primary objective of reducing gas energy consumption. The evaluation employed a Randomised Controlled Trial (RCT) design, whereby a control group received the baseline smart meter consumer proposition (i.e. a smart meter installation, access to near real time feedback on gas and electricity used via an IHD, and energy efficiency advice delivered at the point of installation) and an intervention group, whom in addition to, and alongside the above, received the SENS-ST smart thermostat product (comprising the GEO IHD display, a boiler switch and an internal temperature sensor). The intervention also included a smartphone app which provided similar functionality to the GEO IHD. The eligible sample frame included all dual fuel households within the Shell Energy Retail Limited customer base whom as yet did not have a smart meter. Signing up to take part in a SENS trial was entirely voluntary, and consent could be withdrawn at any time without giving a reason. The trial took place between December 2020 and end March 2022.

The primary energy consumption analysis was assessed through an Intention to Treat (ITT) regression framework, where the average gas consumption was controlled by a number of independent variables, predominantly pre-trial consumption and the trial group. Further to this, a specific Treatment on the Treated (TOT) effect was assessed to estimate the effect from those who received the intervention. Further exploratory sensitivity analysis was carried out on the ITT to assess the effect of dilutors.

This analysis was supported by a package of wider research activities including a baseline and endline quantitative telephone survey with intervention and control group trialists (exploring attitudes to energy, energy usage and management behaviours, uptake of energy efficiency measures, views of smart metering and engagement with the trials and products / services).

Furthermore, in-depth qualitative interviews were carried out with 15 intervention group trialists and covered their experiences of use of the intervention, as well as more general questions about energy use and budgeting.

Outcomes for trialists trialling the product

The energy consumption analyses of SEN-ST showed a statistically significant reduction in daily gas consumption between the intervention and control group with an effect size of 5.0% ± 3.9% (95% Confidence Interval, $p<0.05$) for the primary Intention to Treat (ITT) analysis. The estimated effect size for those who actually received the intervention was 14% ±10.9% (95% Confidence Interval, $p<0.05$), from a TOT analysis. Further exploratory sensitivity analysis was carried out to examine the effect of the dilutors (those that did not receive the SEN-ST product and did not actively refuse), included in the main body of the report).

Survey and interview evidence suggested that the reduction in gas consumption was due to the improved levels of control offered by the thermostat, along with the energy consumption feedback it provided. The thermostat allowed trialists to reduce heating hours or lower heating temperatures while retaining similar levels of thermal comfort. Analysis of the smart thermostat data supported these conclusions for mechanisms for energy reduction. There was mixed evidence for an improvement in thermal comfort, with people generally able to heat their home to comfortable levels prior to the trial and some people found it difficult by the end of the trial, however, this may be due to external factors such as price increases and increased awareness of energy use.

The energy consumption feedback provided by the GEO IHD and smartphone app allowed customers to better understand and control their energy use and the associated costs of energy. Evidence suggested that this was achieved through a combination of enhanced knowledge (regarding consumption and costs) and control. Homeowners were able to reduce the setpoint temperature on their thermostats/ reduced heating hours but retained thermal comfort, which likely led to the achieved gas reductions. While some trialists found they were able to reduce usage from this knowledge, others found they had already done as much as they thought they could do to minimise this.

The increased visibility of costs that SEN-ST offered allowed trialists to understand how much they were spending on energy and budget accordingly. There was some anecdotal evidence in the interview responses of behavioural change leading to reduction in electricity usage through increase energy awareness, however this was not supported by the analysis of the smart meter consumption data which showed no effect.

Conclusions

Overall, the SEN-ST product achieved the intended outcomes of gas consumption energy savings. There was robust evidence of a reduction in gas energy use of 5.0% ± 3.9% (95% Confidence Interval, $p<0.05$) in the intervention group (ITT analyses), as well as an increased awareness of energy usage and how much they spent on energy. Despite various challenges during the trial (e.g., COVID-19), meaning that the SEN-ST trial did not achieve the number of recruited trialists with installations as initially planned (with an effective sample size achieved that was 25% that of initial recruitment targets - the expected sample size required to detect the expected impact), a significant effect upon consumption was still detected. The product made a consistent and significant impact for the trialists who received it, also demonstrated by the high Treatment on Treated effects and supported by the survey and interview evidence.

There was no change in electricity use between the intervention and control groups during the trial, indicating no spill over effect from offsetting reduced gas use with increased electricity usage. However, there was some anecdotal evidence that trialists who received the intervention were using less energy elsewhere. The majority of the gas consumption savings came through the reduction in energy required to heat the home, with little mention of other gas uses in the interview responses. The innovative nature of the product combining heating controls with smart meter energy consumption data showed a clear means to reduce consumption while educating end users on energy use more generally. The high satisfaction rate with the product also highlighted that trialists found it an engaging and useful product.

1 Introduction

The Smart Energy Savings (SENS) Innovation Competition (from here on referred to as 'SENS' or 'the Competition') led by the former Department for Business, Energy and Industrial Strategy (BEIS) committed up to £6.25 million, to support the development, trialling and evaluation of innovative feedback products and services that use smart meter data to help domestic consumers reduce their energy consumption.

Following a competitive application process, eight projects were selected to receive Phase One Competition (matched) grant funding to support the development of their products and/or service. Following a stage-gate review process, five projects, were taken through to Phase Two, to trial and evaluate their products and/or services in homes across Great Britain. The Competition was launched in February 2019, with trials concluding end of March 2022 (extended by one-year due to COVID-19 impacts).

Ipsos, in partnership with Energy Saving Trust, Manchester Metropolitan University and the University of Edinburgh were commissioned by BEIS as the Trial Design and Evaluation Lead (TDEL), to undertake an independent evaluation of the Competition, including separate trial evaluations for each of the individual projects, and to implement a wider package of research. Separately, BEIS awarded a grant to the Smart Energy Research Laboratory (SERL) based at University College London (UCL), for the collection and provision of secure access to energy consumption data from trial households (with customer consent) to the TDEL for their analyses. BEIS also appointed an independent Project Management lead, AECOM, to oversee Competition Partner's project delivery and grant funding milestones.

This report is part of a package of reports published for the Competition, including an overarching competition-level evaluation report, a technical evaluation report and five separate trial-level evaluation reports (of which this is one report).

1.1 Purpose of this report

This report presents findings from the evaluation of the SENS 'Smart Energy - Smart Thermostat' (SEN-ST) project which was taken through to Phase Two of the Competition and trialled in domestic households across Great Britain. The report presents the analysis of energy consumption data and other primary and secondary data that were used to answer the primary research question of the SENS SEN-ST trial (as well as analysis of other secondary outcomes presented in more detail in chapter five), as detailed in the box below.

What is the additional gas saving achieved from the SEN-ST smart thermostat, over and above the baseline smart meter consumer proposition (ie. a smart meter, an In-Home Display (IHD), and energy efficiency advice provided at install)?

Subsequent chapters of this report provide a summary of the SEN-ST smart thermostat product and overall trial design (chapter two) and trial evaluation methodology (chapter three). The overall evaluation findings relating to the primary outcome are presented in chapter four including triangulating evidence across the energy consumption analysis, qualitative and quantitative research strands. In addition, evidence from the analysis of secondary outcomes is presented in chapter five. Finally, chapter six presents the key conclusions from the trial evaluation.

2 Summary of trial

This chapter provides an introduction to the SEN-ST intervention, including its core functionality and mechanisms for behaviour change as presented through its Theory of Change. The core features of the trial design are also presented here.

2.1 The SEN-ST intervention

The SENS SEN-ST intervention was delivered by Green Energy Options (GEO) Limited, in partnership with Shell Energy Retail Limited who managed the recruitment of domestic customers to the trial.

Table 1: SENS SEN-ST delivery partners and product description

Project Title	Competition delivery partner(s)		SENS product
	Lead	Partner(s)	
Smart Energy-Smart Thermostat (SEN-ST)	Green Energy Options (**GEO**) Limited	Shell Energy Retail Limited	A smart thermostat installed (alongside and connected to a smart meter system) that provided trialists with an understanding of their whole home energy consumption, as well as control over their heating and hot water. The product consisted of three hardware devices: the display (a variant of GEO's Trio II IHD platform with various upgrades), a boiler switch (an upgraded version of GEO's Cosy boiler switch) and a temperature sensor. SEN-ST allowed households to view and control their heating remotely, either through the GEO IHD or GEO mobile application. By accessing household gas and electricity smart meter data, households with the SEN-ST product had access to information about their level of energy consumption (used for heating) in the previous week, how much they would need to spend to maintain the level of comfort in the coming week, and what the monetary value of changing their level of comfort (e.g. by one Celsius) would be. This combination of heating controls and higher levels of energy awareness via tailored feedback was expected to reduce gas consumption.

The purpose of the SEN-ST project was to develop and trial an 'energy-aware' smart thermostat,[3] developed as a cost-effective solution that also included a (Smart Metering Equipment Technical Specifications) SMETS-compliant[4] IHD and a mobile phone app. The SEN-ST product utilised households' smart meter data to provide them with additional insights into their energy consumption patterns and control over their heating and hot water with the aim of supporting energy-saving behaviours through more efficient household use of heating and hot water.

The SEN-ST smart thermostat was installed by a smart meter installer alongside the smart meter installation, reducing the cost of providing a smart heating solution (compared to the typical retrofit approach requiring a separate installation visit). This is then expected to lead to environmental and economic benefits from reductions in energy use.

The SEN-ST 'product' consisted of three hardware devices: The display (a variant of GEO's Trio II IHD platform with various upgrades), a boiler switch (an upgraded version of GEO's Cosy boiler switch which simplifies installation and reduces costs) and a temperature sensor. Development and testing of the technology was completed in Phase One of the project before it was later trialled across homes under Phase Two. GEO's existing 'Cosy Hub' firmware was also modified and adapted to the new Trio II hardware. Lastly, new mobile apps (Android and iOS) called 'GEO Home' were developed in Phase One of the Competition which combined smart meter energy data with heating controls for the smart thermostat. This allowed users to both control their heating and see insights into how much energy they were using/how much it would cost.

2.2 Aims of the intervention and how it was expected to achieve these

Several intended primary and secondary outcomes were identified at the outset of the trial (see Table 2 below for details). This information is also summarised in the Theory of Change diagram presented in Figure 6 (see Annex A).

[3] Utilised smart meter data to provide insights to households.
[4] All home area network (HAN) communications should be based on 'open' standards (as defined by EU interoperability framework/ ICT strategy).

Table 2: Primary and secondary outcomes of the SEN-ST intervention

Primary/ Secondary	Outcome to be evaluated
Primary	Reduction in gas consumption
Secondary	Changes in electricity consumption (assessed to see any spill over effects resulting from e.g. substitution of electric heating)
	Improved individual perceptions of home comfort
	Improved household budgeting

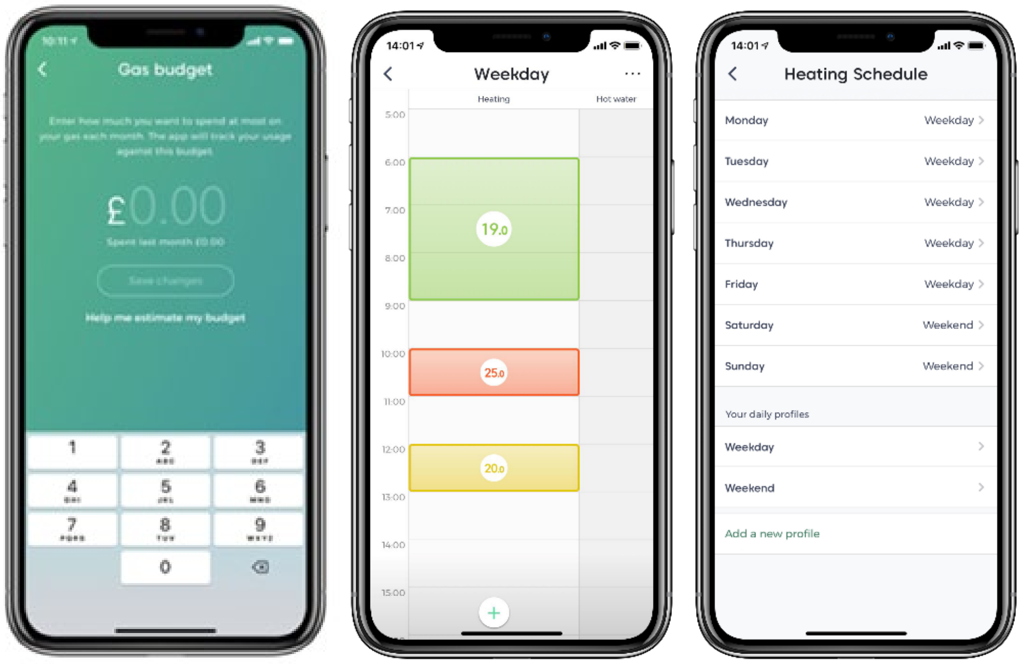
The core functions of the SEN-ST intervention were to provide SENS intervention group households with:

- Greater access to heating controls: SEN-ST was intended to allow households to view and control their heating remotely through for example, a mobile app (see Figure 2 overleaf) or smart speaker. Additionally, information about heating was provided through the household's SEN-ST IHD (Figure 1). Therefore, there were more mechanisms for and easier access to heating controls (including remote access) open to households with the SEN-ST product.
- More information about cost of heating: Households with the SEN-ST intervention were given access to information about their level of energy consumption in the last week and how much the household would need to spend to maintain the level of thermal comfort in the coming week. It also allowed households to observe the monetary value of changing their level of thermal comfort (for example the saving from reducing the heating in their house by one degree Celsius). This was based on previous consumption and external weather forecast data.[5]

[5] The types of information provided by the smart thermostat (above that provided by the smart meter) were actual cost information of space and water heating; anticipated cost (in monetary terms) of maintaining current level of comfort (heating levels) based on weather forecast information; anticipated cost implications of altering levels of comfort (heating levels) based on weather forecast information.

Figure 1: Examples of information presented through the SENS-ST smart thermostat. The device combined smart meter data (see left) and heating data

Figure 2: Examples of information presented in the GEO Home App



As households with the intervention had easy access to more detailed and tailored data on utility and costs of heating patterns, they were expected to be better informed of – and more confident in - how to maintain their level of thermal comfort or reduce their energy consumption. As households made use of the improved access and level of information during the trial, it was anticipated that they would begin to change their behaviour in the following ways:

- Using a thermostat to control the heating (previously may not have had one).
- Changing settings on their thermostat (whereas previously they left the setting unaltered).
- Not having the heating on when no one is home.

- Changing boiler settings in advance of external temperatures changing.
- Make trade-offs about comfort and expenditure.

Such behaviour changes were expected to lead to two direct outcomes:

- Increased comfort (as a result of setting the desired temperature).
- Reduced gas consumption.
- Reduced cost of energy bills (as a direct result of a decrease in gas consumption).

For these outcomes to materialise, a number of assumptions needed to hold true during the trial period (see Theory of Change, Figure 6 in Annex A). First, the household needed to engage with the technology successfully and accurately. Second, the technology needed to provide accurate information to households. Third, the temperature sensor and IHD needed to be positioned in locations which provided appropriate data (e.g. temperature sensor not next to a heat source) and accessibility to the user. Fourth, the advice given needed to be tailored to the household context (i.e. be considered useful by the occupants).[6] These assumptions were tested as part of the evaluation.

2.3 Design of the SENS SEN-ST trial

2.3.1 Randomised Control Trial

To test the effectiveness of the SEN-ST product in reducing gas energy consumption, the trial was designed as a Randomised Control Trial (RCT). The 'treatment' group were given access to SEN-ST's packaged intervention (see above) plus the baseline smart meter consumer proposition (smart meter, IHD and energy efficiency advice at install) IHD, and the control group received the baseline smart meter consumer proposition only.

Both the treatment and control group were comprised of households using any of Shell Energy's Business as Usual (BAU) tariffs. Due to the randomised nature of the trial, it was expected that the percentage of households on each tariff were comparable in the treatment and control groups. The BAU tariff model for Shell included account access via an app and periodic contact between Shell Energy and the household (via email, letter, SMS and telephone) to provide information about tariffs, bills and other customer information. The treatment and control group both received the same BAU model from Shell Energy.

2.3.2 Eligible trialists

The sampling frame for the trial included all dual fuel households within the Shell Energy (supplier partner) customer base whom as yet did not have a smart meter. This included customers from across the whole of Great Britain, including urban, suburban and rural households.

[6] Advice given focused on achieving energy cost savings through more energy efficient behaviours, for example, " consider lowering your overnight temperature setpoint by 2 degrees to save an estimated £17.50 this month".

Shell Energy customers were eligible for recruitment into the trial if they:

- Did not already have smart gas and electricity meters (SMETS1 or SMETS2) installed in their property,
- Already had gas boilers installed in their homes, and;
- Were dual-fuel credit customers. No pre-pay customers were eligible to take part in the trial.

2.3.3 Recruitment strategy

Recruitment was led by Shell Energy Retail Ltd, including developing the recruitment materials and the format of the consent form (using standardised opt-in consent forms that were GDPR (General Data Protection Regulation) and SEC (Smart Energy Code) compliant, developed by UCL and TDEL). Once the materials were agreed and finalised, Shell Energy sent mass recruitment emails to all eligible Shell Energy customers between August 2020 and February 2021 to invite them to participate in the SENS trial. The overall trialist customer journey is shown in Figure 3.

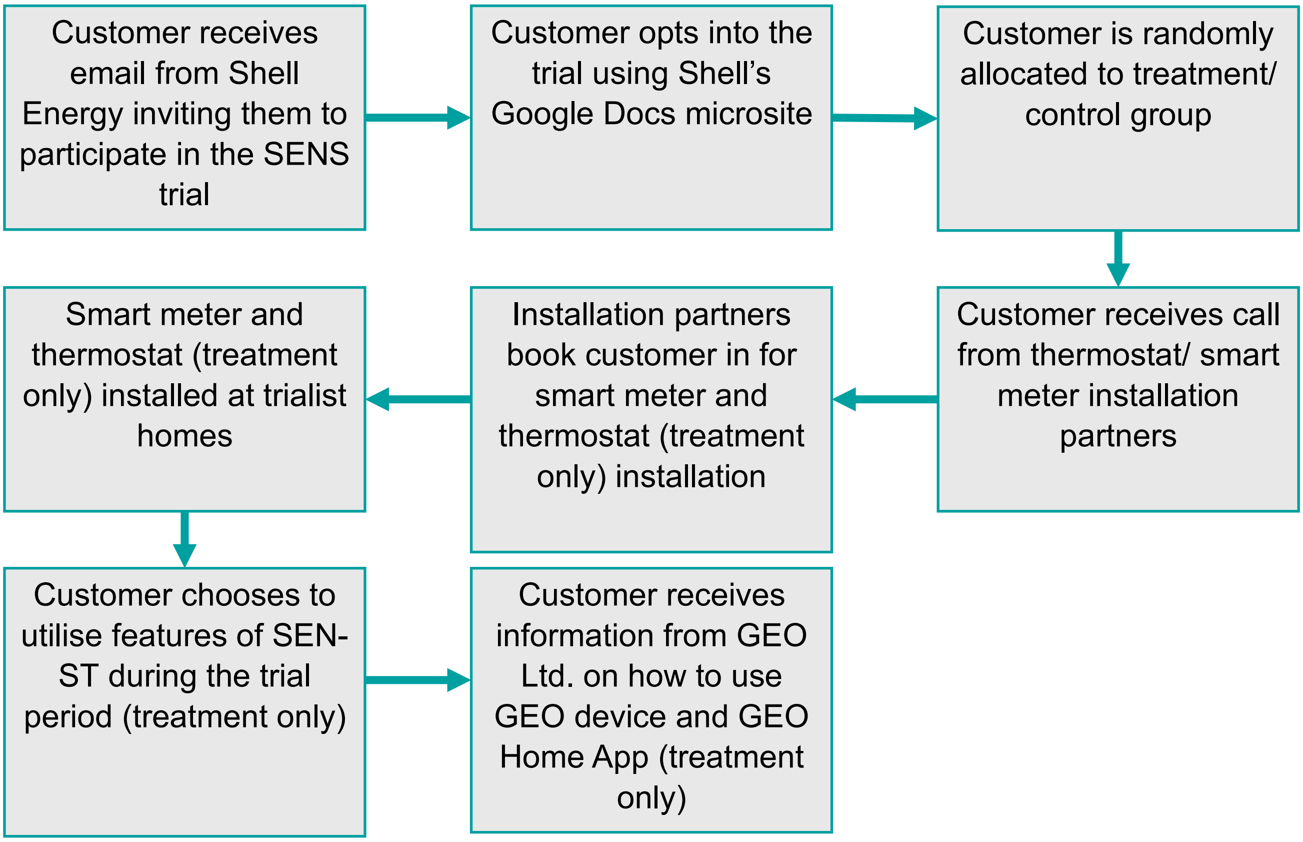
Signing up to take part in a SENS trial was entirely voluntary, and consent could be withdrawn at any time without giving a reason. To assess the primary aim of the project, trialists gave opt-in consent to provide access to their smart meter data for the evaluation, using a virtual 'secure lab' analysis environment, provided by UCL. This smart meter data was used by TDEL and UCL SERL solely for the evaluation. Trialists also consented to providing pre-consumption data through Shell Energy.

Shell Energy customers were provided with an email link to opt-in to the trial, at which point they provided the various opt-in consent permissions to be onboarded onto the trial. Please see chapter 4 of the Technical Report, for full details on obtaining consent. At least two follow-up emails were also sent several weeks after the initial invitation to maximise take-up. As an incentive, Shell Energy offered all trialists to receive either the SEN-ST intervention (if randomly allocated to the intervention group) or a £30 Amazon voucher (if randomly allocated to the control group).

Once trialists opted-in to the trial, they were randomly allocated by TDEL to either the intervention or control group to ensure a good distribution of property characteristics and demographics between the two groups. At this point, trialists' contact details were securely sent to Smarter Metering Services (SMS), whom were responsible for installing the smart meters along with the SEN-ST package.[7]

[7] SMS were contracted by Shell Energy to install smart meters to their customers

Figure 3: Trialist customer journey



Planned recruitment targets were estimated by TDEL from the outset, of the expected sample sizes required to detect the expected impact from the SEN-ST intervention. Based on an anticipated 7% reduction in gas consumption (based on evidence from previous research)[8] and the variability in gas consumption that could be explained by pre-trial consumption data, the trial needed to recruit and retain 810 trialists in both the intervention and control groups. To account for an assumed 19% drop-out rate (expected average number of households switching energy supplier according to Shell Energy records, moving home or actively withdrawing within a 12-month period), the initial recruitment targets were therefore set at 1,000 in both the treatment and control group.

Table 3 gives a summary of the recruitment target planned versus that which was achieved, including withdrawals during the trial. It should be noted that only 151 members of the intervention group received the smart thermostat due to issues at the installation stage.

[8] https://www.bi.team/publications/evaluating-the-nest-learning-thermostat/

Table 3: Summary of recruitment and analysis sample sizes (target and achieved)

Recruitment stage	Intervention group	Control group	Total
Recruitment number target initially set out by TDEL	1000	1000	2000
Number of households / customers that agreed to participate in trial, i.e. share their energy consumption data (intervention / control)	1292	1275	2567
Number of households / trialists who went on to have a successful SEN-ST product/ SM install (treatment group), or a successful SM install (control group). It should be noted that only 151 members of the intervention group received the SEN-ST smart thermostat (and smart meter) due to issues at the installation stage.	492	513	1005
Final achieved sample (sample that had consented to participate in the trial at the end of the trial period, accounting for churn of trialists, i.e. withdrawals)	394	396	790

There were a number of factors that impacted SEN-ST recruitment including:

- COVID-19 impacts and changes in the wider retail market (see SENS Evaluation Competition Report).
- The limited number of trained SMS engineers available to install smart thermostat alongside installation of the smart meter within the required timeframe.
- A long lag time (c. 40 days) between households consenting to the trial and them booking in their smart meter and SEN-ST smart thermostat installation. As recruitment and installation partners required all installs to be completed by February 2021, some households that consented were unable to have installations.
- Households who consented to take part in the trial did not routinely or quickly respond to requests from the installation partners to book in their smart meter and SEN-ST thermostat installation. This led to a large number of intervention group households having a smart meter installed but without a smart thermostat being installed.
- Issues at the point of smart thermostat installation: For example, where the trialist had a heating system that was incompatible with the smart thermostat.

Due to missing/ insufficient data, other properties were excluded for the following reasons:

- Smart meter not connected via SERL. In some cases, there were issues in connecting the smart meters to the SERL environment. This was thought to be due to the meter not being enabled correctly at the time of onboarding.
- Missing pre-trial consumption data from Shell. This was one of the key control variables required to assess the reduction in energy usage accurately.
- Insufficient data in SERL for analysis (where over 50% of readings were complete across trial period). The trial period ran from December 2020 to March 2022. However, trialists did not all start in December 2020 due to staggered installations. Therefore, trial periods varied on a home-by-home basis. See Figure 10 in Annex C for the distribution of the number of days with gas readings.

3 Methodology

This section describes the methodological approach to implementing the Randomised Controlled Trial design, including the approach to random allocation, data collection methods and statistical methods employed for the energy consumption analysis. More information is provided in the accompanying Technical Report published alongside this report.

3.1 Assignment of intervention

A Randomised Controlled Design (RCT) was employed. This used a batch randomisation technique to allocate trialists between the treatment and control group. The Trial Design and Evaluation Lead (TDEL) generated the allocation sequence. Once trialists had signed up to the trial opting into the required consents, Shell Energy / SMS securely provided TDEL with a list of anonymised newly recruited trial trialists, identified by their Meter Point Access Number (MPAN). Trialists in each batch were then assigned a random number (using a computerised random allocation software tool). Following this, two lists were sent to Shell Energy / SMS: treatment group trialists and control group trialists to take forward.

3.2 Data Collection

The evaluation utilised a range of primary data collection sources to provide evidence against the primary and secondary research questions for the SEN-ST trial.

3.2.1 Energy consumption data

Gas and electricity consumption data was collected (with consent) to cover two periods:

- During the trial: Gas and electricity consumption data was securely provided to TDEL via SERL (responsible for managing the collection and provision of smart meter data from trialists with their consent to TDEL for the purposes of the evaluation) at 30-minute resolution for the trial period.
- Before the trial: Pre-trial energy consumption data that was not available from SERL (as trialists did not have a smart meter installed before the trial) was provided to TDEL by Shell Energy for a period of up to 12 months before the start of the trial, using information from quarterly / annual bills and meter readings for the 12 months preceding the trial. This energy pre-consumption data was used as a control variable in the analysis.

3.2.2 Engagement data

The Competition partner lead, GEO Ltd. collected data (with consent) on how intervention group trialists used the SEN-ST smart thermostat. This supported TDEL in its understanding of how intervention group trialists were interacting with the smart thermostat. The types of metrics captured included:

- The temperature set points of the smart thermostat at 30-minute resolution during the trial period.
- The property's temperature at 30-minute resolution during the trial period.

3.2.3 Quantitative telephone survey with trialists

All trialists (from both intervention and control group) were invited to take part in a baseline (March – July 2021) and endline (March 2022) telephone survey to ascertain attitudes to energy, energy usage and management behaviours, uptake of energy efficiency measures, views of smart metering and engagement with the trials and products / services. More details on the timings and key topics explored are included in the accompanying Technical Report.

In the intervention group, only trialists who went on to have a successful SEN-ST smart thermostat and smart meter installation were made available for survey contact. Of the 151 trialists who received the full intervention package (smart meter plus SEN-ST), 66 responded during the baseline survey and of these, 22 completed the endline telephone survey, with most indicating they actively engaged with the intervention. In the control group, of 490 who could have been surveyed, 187 responded at baseline with 73 of those completing endline surveys.

One sample t-tests between baseline and endline survey percentages were conducted for the survey findings at the Competition level only (aggregated across all trialists) but not at individual trial level, to determine whether the change was statistically significant at conventional significance levels. Unless explicitly stated, any reported changes (baseline to endline) are indicative only and have either not undergone statistical significance testing or were not found to be statistically significant. It is also unlikely that any reported changes are statistically significant, given the number of respondents surveyed.

3.2.4 User in-depth interviews

TDEL also conducted in-depth qualitative interviews with 15 consented trialists in the intervention group who had been given access to the SEN-ST Smart Thermostat packaged intervention over the trial period. These were recruited from those who completed the endline surveys so there is some overlap with survey responses.

The interviews were semi-structured and typically lasted 45-60 minutes. The interviews covered their experiences of use of the intervention and how they found it, as well as more general questions about energy use and budgeting. A range of quotas across different demographics and household characteristics were sought, covering householder age, property age, income and some characteristics of heating deemed relevant to the product. Further details of this can be found in chapter seven of the Technical Report.

3.3 Data analysis

3.3.1 Data quality and cleaning

Initial data cleaning was conducted on the data where required, as follows:

- Energy Consumption Data – before the trial. The pre-baseline electricity and gas (EAC and AQ) annual usage estimates provided by the Competition Partner were converted to a daily mean by dividing by 365, to match the units used for the evaluation period energy consumption data.
- Energy Consumption Data – evaluation period. Mean daily estimates of electricity and gas use were calculated for each trialist's participation period using the available smart meter data for their properties. Smart meter data were cleaned and used to produce the estimates following an approach similar to that used by SERL for its data and statistical releases (see Elam, Webborn et al., 2022, and Few, Pullinger et al., 2022).[9] The approach is described in the Technical Report.

3.3.2 Statistical analyses of energy consumption

Analysis of the primary outcome measures of energy consumption, was tested using a regression framework. In this type of analysis, the effect of different 'independent' variables (e.g. pre-consumption, trial group) on our 'dependent' variable (i.e. the one we are investigating - gas consumption) can be examined. The framework used included prior energy consumption in the baseline model as a control variable and the other stratification variable, region, as another control variable. A binary indicator distinguishing treatment and control group membership was included in the model and will carry the impact effect mean difference. Other variables of interest were tested and are documented in the next chapter. The impact effect coefficient was significance tested $p<0.05$.

The final sample sizes used in the analyses are presented in Table 4.

[9] Elam, S., Webborn, E., McKenna, E., Oreszczyn, T., Anderson, B., Few, J., Pullinger, M., European Centre for Medium-Range Weather Forecasts, Ministry of Housing, Communities and Local Government, Royal Mail Group Limited. (2022). *Smart Energy Research Lab Observatory Data, 2019-2021: Secure Access*. [data collection]. *5th Edition.* UK Data Service. SN: 8666, [DOI: 10.5255/UKDA-SN-8666-5](https://doi.org/10.5255/UKDA-SN-8666-5); Few, Pullinger, McKenna, Elam, Webborn and Oreszczyn (2022) Smart Energy Research Lab: Energy use in GB domestic buildings 2021. Variation in annual, seasonal, and diurnal gas and electricity use with weather, building and occupant characteristics. (SERL Statistical Reports: Volume 1), https://serl.ac.uk/key-documents/reports/.

Table 4: Summary of trialist numbers used at the analysis stage

Analysis stage	Intervention group	Control group	Total
Number for properties remaining in SERL – (properties excluded due to issues connecting to smart meter).	375	376	751
Sample numbers once those with no pre-trial consumption data are excluded (required for analysis)	339	343	682
Sample numbers for gas consumption ITT. Excludes properties with insufficient gas meter data. (i.e. Missing or incomplete data). [10]	261	254	515
Sample numbers for electricity consumption ITT. Excludes properties with insufficient electricity meter data. (i.e. Missing or incomplete data)	217	223	440
Households diluting gas consumption ITT (i.e. those who did not receive the intervention package but did not actively refuse it)	121	5	126
Households diluting electricity consumption ITT (i.e. those who did not receive the intervention package but did not actively refuse it)	119	4	123
Households remaining in ITT group who received the SEN-ST intervention package. Used to assess Treatment-on-the-Treated effect.	93	5	98

[10] Group used for primary ITT analysis. Those without sufficient data had to be removed from the analysis.

Analysis was undertaken to estimate the effect of the intention-to-treat (ITT). This is a measure of difference between those trialists that were allocated to receive the intervention compared to those who did not. A total of 261 trialists in the intervention and 254 in the control were used in the ITT which includes homes that did not receive the intervention but should have. The average treatment effect (ATE) size is determined from the coefficient on the trial group control variable within the regression model.

Further ITT analysis was undertaken on the electricity consumption (using a similar regression framework but utilising electricity consumption rather than gas) to test for any spill over effects outcomes in overall energy consumption.

Treatment on Treated analysis was conducted to account for those who were offered the treatment and who received it (due to a large number of trialists in the treatment group that did not receive the intervention as intended).

To explore the effect of diluters, further sensitivity analysis on the original ITT analysis was carried out. Dilutors are trialists from the intervention group who did not receive the SEN-ST product and did not actively refuse (or self-select to not receive) it. This 'sensitivity' ITT removed 121 out of 261 trialists from the treatment group and 5 out of 254 in the control group. It should be noted that this analysis may have introduced some non-random selection impacts which would affect the effect estimation. Therefore, these should be treated as exploratory in nature to provide additional narrative around the effect of the dilutors.

Despite having similar trends between intervention and control groups, the evaluation period varied between trialists, resulting in the primary outcome measures not being directly comparable between trialists, as they cover different time periods with different external conditions, such as weather. This makes interpreting the meaning of the estimated effect size from the regression model difficult. To account for this, an approximation was calculated of the size of effect that might be expected had all trialists had the same evaluation period. This was done using a similar regression model to the ITT but using the daily mean gas consumption per heating degree day (HDD) instead of simply daily mean gas consumption. The regression coefficient estimates were multiplied by the average total HDDs for all the trialists for the full year leading up to the end of the evaluation period. HDDs are "a measure of the extent to which external temperature over a given period fell below a level below which central heating is assumed to be required (in the UK, commonly taken to be 15.5°C). The HDD values are calculated based on the hourly external temperature data." This partially controls for the variation in average conditions arising from the differing evaluation periods. However, this annualised figure can only be considered indicative, and the robustness of this and the other regression model results are discussed in the results section in Chapter 4.

For further secondary analysis, the index of multiple deprivation (IMD) was incorporated into the regression model to test for any effects within these subgroups.[11] Further analysis of the effect of various heating behaviours on average gas use were tested using the SEN-ST smart thermostat data for those trialists who received the intervention. These variables included the

[11] IMD is a postcode level estimate of the levels of deprivation in a particular area. It does not indicate which properties are in fuel poverty, but it gives a likelihood that they are based on the area.

average set point temperature, average actual internal temperature and number of heating hours. These were tested using simple linear models for each individual variable to examine any trends within them. Limitations and caveats to these approaches are covered when the results are presented in the next section.

3.3.3 Secondary analyses

Analyses for the secondary outcomes evaluated in this trial, as well as supplementary analyses for the primary outcome, are based on the survey and interview data collected from a sub-sample of the intervention and control group trialists. In total, 253 trialists (66 intervention group and 187 control) were surveyed at baseline and 95 (22 intervention group and 73 control) at endline.

Due to the timing of these surveys, some care is needed in their interpretation. In particular, there were contextual changes between the baseline and endline that could influence responses and whose effects cannot be excluded, including the fact that the endline was during the heating season whilst many of the baseline surveys were during the non-heating season, and there had been substantial increases in energy prices over the period. The discussions of the survey findings in the results section below highlights these and other factors where relevant. In addition, the baseline survey was conducted (in some instances) two to three months after the Smart meter/ SENS-ST product install, potentially affecting the reliability of the baseline findings, due to possible recall issues.

Interview data with 15 intervention group trialists who received the full intervention has been used to supplement the survey results where relevant, to give a fuller qualitative insight into the thoughts of trialists in relation to the secondary outcomes.

4 Analysis of primary outcomes

This section describes the extent to which the results of the trial provide evidence that the expected primary outcomes of the SEN-ST smart thermostat were achieved, i.e. that the SENS-ST intervention package led to a reduction in gas consumption in treatment homes compared to control group homes. The principal source of evidence comes from an analysis of smart meter energy data from the trial period. Survey and interview data provide further context to the results of the energy analyses.

4.1 Validity of trial design assumptions

The regression was initially carried out controlling for the trial stratification variables (pre-trial consumption and region). Correlation between the gas pre-trial consumption and trial period data was tested with a Pearson’s R test. This found that 89% of the trial consumption can be explained by the pre-consumption data, agreeing with the pre-trial assumptions.

Given the reduction in the size of the data set from the data quality issues, the distribution of pre-trial consumption values was compared for similarity (to ensure the random nature of the trial was still valid) as shown in Figure 7 and Figure 8 in Annex C. The traces are similar in terms of shape and mean values, showing that there is a similar distribution of consumption values for both gas and electricity between the intervention and control group. Figure 13 and Figure 14 in Annex C graphically show the difference between intervention and control group gas consumption during the trial. Figure 9 shows the regional distribution of trialists between intervention and control groups, showing similar regional distributions between the two groups. These show that the recruitment stage resulted in a good randomisation and therefore distribution of trialists between the two groups. There is some risk that bias was introduced throughout the trial by dropouts who were less interested in saving energy. However, there is no way to assess this as withdrawals did not need to give a reason. The risk is considered to be low given the randomised nature of the trial and relatively equal withdrawals between intervention and control groups.

To assess if there might be any bias towards one or other group because of differences in heating season (typically October to March), the number of days of usable gas readings (Figure 10), the average daily HDDs during the trial period (Figure 11), and the distribution of gas readings per day (Figure 12) were compared between the intervention and control groups. All three show a similar means, shapes and distributions indicating that each group experienced similar climate conditions and had a similar distribution of data within the heating season. Therefore, these findings show that it is an appropriate assumption to use the daily average of the gas consumption figures in our regression framework.

4.2 Full data set analysis (ITT group)

The main impact effect tested was the offer of treatment, i.e. the ITT impact. A regression framework was set up, initially controlling for pre-trial consumption and region using the trial numbers indicated in the full ITT gas dataset row in Table 4. However, no statistically significant effect was seen for any region so this was removed as a control variable (see regression results Annex C, Table 7).

A statistically significant reduction in gas consumption of 1.92±1.50 kWh per day (95% Confidence Interval, $p<0.05$) was seen for the intervention group compared to the control (see Table 8 in Annex C). These results correspond to an effect size of 5.0% ± 3.9% (95% Confidence Interval, $p<0.05$), calculated using the average annual gas consumption of 13923 kWh during the trial.

4.3 Treatment on the Treated (TOT) analysis

The TOT was estimated using the ITT result in the numerator and the proportion of trialists who received the intervention left in the ITT dataset (93 out of 261). The TOT analyses found a statistically significant reduction in daily gas consumption between the intervention and control group of 5.39 ± 4.21 kWh per day (95% Confidence Interval, $p<0.05$) or 14% ± 10.9% (95% Confidence Interval, $p<0.05$).

This is a large effect size and indicative of why it has been possible to obtain a result from the trial despite lower numbers than those planned for recruitment.

4.4 Sensitivity analysis

Since a large portion of the intervention group did not receive the SENS-ST smart thermostat product (341 properties), properties which did not actively opt out and did not receive the thermostat (i.e. did not refuse the intervention), or control group trialists which did receive the intervention, further regression analysis was carried out to explore potential effects from these dilutors. A sensitivity analysis was run on the ITT dataset (Section 4.2), but with an additional control variable to account for dilutors in the regression analysis.

The consumption and regional distributions were compared for the sensitivity group. The pre-trial consumption and average HDDs were comparable, however there was a larger difference in the regional distribution between treatment and control groups. However, this was not considered important since, as with the original ITT, no region showed a significant effect in the sensitivity analysis (see Table 9 in Annex C) and was therefore removed as a control variable.

The results showed a reduction in gas usage of 2.67±1.75 kWh per day (95% Confidence Interval, $p<0.05$) and is again a significant result at $p<0.05$. This indicated an effect size of 7% ± 4.6% (95% Confidence Interval, $p<0.05$). Full results for the regression models can be found in Table 10 in Annex C. As expected, the average treatment effect size has increased when accounting for dilutors. This is to be expected as the dilutors would serve to reduce the overall effect size when not accounted for. The confidence in the result is also higher when accounting for these dilutors.

4.5 Overall findings from energy consumption analysis

Overall, there was a statistically significant reduction in gas energy consumption from the SEN-ST product with the significance consistently $p<0.05$ across the ITT and sensitivity analyses. The ITT effect size was 5.0% ± 3.9% (95% Confidence Interval, $p<0.05$). The TOT estimates the effect just for those who actually received the intervention, which was estimated at 14% ± 10.9% (95% Confidence Interval, $p<0.05$).

To explore the effect of the dilutors more, exploratory analysis was carried out using a sensitivity and outlier analysis. This indicated an effect size of 7% ± 4.6% (95% Confidence Interval, $p<0.05$). It is likely that the true effect was towards the lower end of the estimate as this removes some significant outliers in the results.

4.6 Supporting evidence from the survey results

The results of the quantitative telephone survey showed that there was a change in attitudes towards understanding energy use between the intervention and control group.

When asked if they *did not* spend much time thinking about energy use, there was an increase in those disagreeing with this statement in the intervention group from the beginning to the end of the trial (64% at endline compared to 36% at baseline). At the same time, the numbers stayed fairly constant in the control group for those who answered both surveys (48% at baseline and 49% at endline). This indicates that those who received the intervention were more likely to be engaged with thinking about energy usage which would help reduce their consumption. One trialist interviewed who received the intervention found they were more interested in energy used and through this trial that they are more cautious about putting heating on and how often they put it on:

> *"…[I] thought it would be interesting to see what I was using because this was the first house I bought, so I hadn't had to think about it before."*

When asked if they had tried to reduce the amount of energy used at home, there was no evidence of any change between intervention and control groups. Both had around 80% agreeing at baseline (77% and 80% for intervention and control, respectively) and an indicative shift to 90% overall at endline (91% for intervention and 88% for control). The indicative increase across the trial period showed that there was an active aim to reduce energy usage for all trialists regardless of whether they received SENS-ST or not. This is likely to be a combination of the increased awareness of their energy consumption from the standard smart meter consumer proposition, but also driven by external factors.

Around two thirds (63%) of trialists surveyed with the intervention group said they had tried to reduce their household gas consumption since using the product, and around three quarters (74%) reporting they had tried to reduce electricity consumption. What is not clear is whether this was wholly due to SEN-ST or due to other factors (outside the scope of the survey questions). One trialist whom reported that they had their GEO IHD in a readily visible location said this helped increase energy awareness and incentivise them to lower their energy usage:

> *"My wife now uses the tumble drier less because the IHD shows how much electricity it uses. My wife got a bit of a shock when she saw how much it uses, so now she uses it less because she sees how much it costs us."*

The interviews also provided insight into how these trialists attempted to reduce their energy consumption through more efficient heating with a few trialists lowering their heating temperatures:

> *"[We] have it (room temperature) at 19C in the evening where before it was probably around 23C or 24C because we can control it."*

> *"[We have] turned the temperature down by a degree or so when heating their home. [We are] conscious about how much we're heating because bills have just increased."*

> *"I have been able to get the temperature down in the house by a few degrees and keep it comfortable."*

Other aspects were indicated as being useful such as the GEO app allowing heating to be switched on remotely and not using schedules, however, it was not clear if this reduced usage or not. The survey data suggested that at endline the trialists with the intervention tended to actively switch the temperature up or down more, with an indicative change of around 10% more (26% compared to 14%) saying they change the temperature depending on how cold or warm it is rather than using a schedule. This might indicate that homeowners are more able and motivated to adjust their temperatures with the enhanced controls offered during this project.

5 Analysis of secondary outcomes

5.1 Spill over effects on electricity usage

A similar regression framework was created for electricity usage factoring in pre-trial consumption electricity usage. This was to test for any spill-over effect into electricity consumption, either with less gas use perhaps offset by increased electricity use, or a decrease in electricity use too from increased awareness or similar reasons. As with gas consumption, properties with less than 50% of daily electricity readings were excluded from the analysis. Sample sizes are shown in Table 4. Full regression results can be found in Table 11 and Table 12 in Annex C.

No statistically significant effect was observed in either the full ITT or exploratory sensitivity analysis indicating there was no knock-on effect on electricity usage. Figure 15 and Figure 16 in Annex C show average electricity usage before and during the trial.

5.2 Subgroup analysis - index of multiple deprivation quintile

The effect of the IMD was tested to see if the intervention worked (reduced gas consumption) better for any particular social demographic. Results are presented on Table 13 in Annex C for the case with the largest treatment effect (sensitivity analysis). There was no statistically significant effect for the IMD quintile which suggests that the intervention had a similar effect (or that the effect is small and we would need a much larger sample sizes for a significant result) for all demographics and that other factors were more important to its success.

5.3 Analysis of smart thermostat data

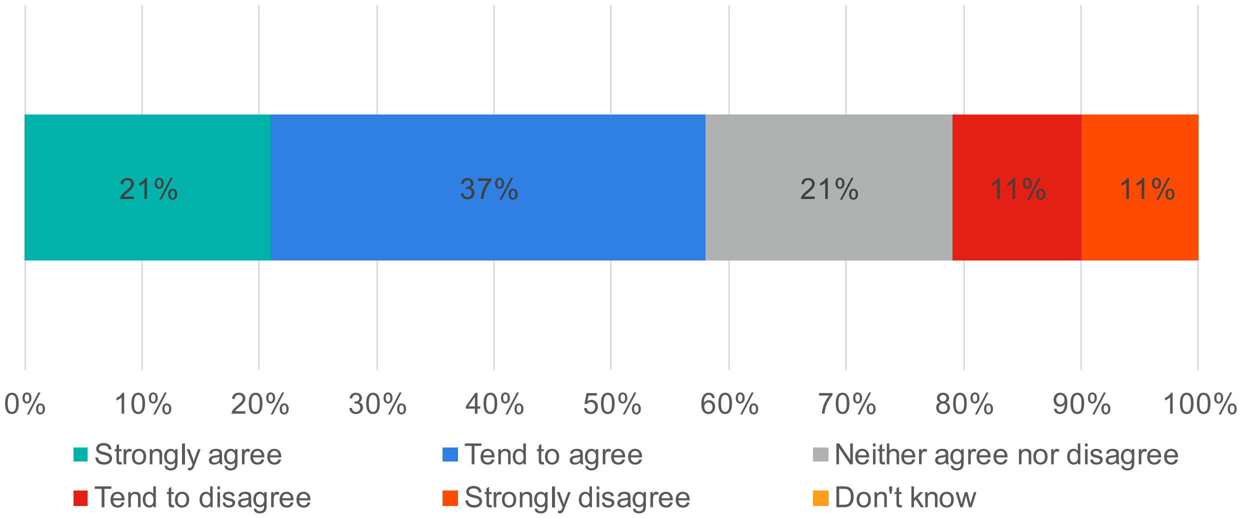
GEO Limited provided TDEL with half hourly data from the SEN-ST smart thermostat which included achieved temperatures in the home (internal temperature), heating set points and call for heat from the boiler. Simple regression models controlling for each of these variables separately were used and are detailed in Table 14 to Table 16 in Annex C. While all three showed a positive trend (as each increased, the gas usage increased), only the heating hours and set point temperature showed statistically significant results (at $p<0.01$ and $p<0.05$ respectively).

5.4 Improved individual perceptions of home comfort

There was generally mixed evidence about the effect of the smart thermostat on households' perceptions of home comfort. Home comfort is defined as a perceived comfortable temperature within your home which is not too hot or too cold for the occupant(s). This is important for physical and mental health reasons, with medical conditions linked to extremes of temperature as well as mental wellbeing from being happy in your home.[12]

By the end of the trial, 58% of SEN-ST intervention group trialists surveyed agreed that they found it easier to heat their homes to a comfortable level since starting to engage with the product, while only 21% disagreed and 21% neither agreed nor disagreed (see Figure 4). This suggests that a large proportion of households using SENS-ST felt they became more able to heat their home to a comfortable level.

Figure 4: Agreement with the statement: "I have found it easier to heat my home to a comfortable level since I started to engage with the tool".



N intervention endline (used tool) = 19

Findings from the qualitative interview data provided insights into the reasons why households found it easier to keep their home at a comfortable temperature such as allowing households to switch the heating on when they were out of the house, so they come home to a warm house; and enabling those on a flexible working pattern to switch their heating on remotely from the app, rather than having to set schedules that would otherwise need constantly updating. Some of these activities could lead to longer heating hours than would have been used previously and therefore may increase consumption through rebound effects (where any savings are wholly or partially offset by trialist increasing their comfort).

It should be noted that there was a reduction (from 22 to 18) during the trial period in the number of trialists (who answered both baseline to endline surveys) in the intervention group who reported that they were able to heat their home to a comfortable temperature. However, the majority said they were still able to keep their home at a comfortable temperature. The small sample size is likely to be a contributing factor to this change here, although it may be that with factors such as increased energy bills, people were heating their homes less and were not able to be comfortable. The timing of the survey may be relevant too, with the endline

[12] Liddell C, Guiney C. Living in a cold and damp home: frameworks for understanding impacts on mental well-being. Public Health. 2015 Mar;129(3):191-9. doi: 10.1016/j.puhe.2014.11.007. Epub 2015 Feb 26. PMID: 25726123.

survey happening just at the end of winter and the baseline predominantly during spring. Of the 19 that had reported using the tool at the endline, 17 agreed they were able to keep their home to a comfortable temperature.

Generally, it does not appear from the survey data that the cost of energy was identified as a barrier to keeping homes warm after engaging with the product, with the vast majority of trialists not finding it too expensive to heat their homes to a comfortable level.[13] As mentioned in Section 4.7, this may be because people were already comfortable in their homes but may have been heating them more than needed to be comfortable. With the additional control provided by SEN-ST, this allowed them to heat the home to a lower temperature while remaining comfortable. This indicates that costs were a likely factor resulting in people heating more efficiently and may also explain why there were some issues with comfort levels after engagement with the intervention. If homes are heating to the minimum comfort level, any lower temperature periods may result in discomfort where the excess heating would have previously masked this.

> *"Last year (winter 2020) the house was too warm, but we didn't care much because gas and electricity costs weren't that bad at the time. But the increase in costs has made us more conscious of it. So we switch it on and off more, but no decrease in comfort because before the house was too warm a lot of the time."*

5.5 Improved household budgeting

There was a clearer indication that the intervention improved the ability for trialists to budget better and reduce their bills, whilst still retaining a good level of comfort.

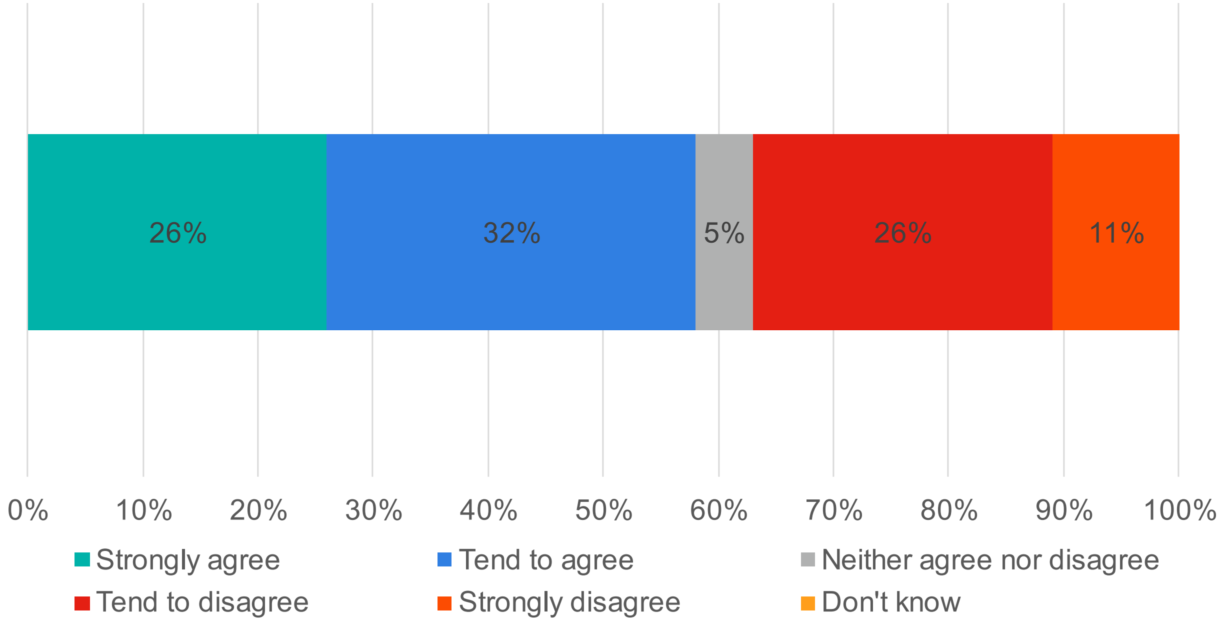
> *"I can see at a glance what the costs will be and add them up on a daily basis."*

This is supported in the survey data with 58% of responding SEN-ST users agreeing they found it easier to control how much they spent on energy since starting to engage with the product. Only five percent neither agreed nor disagreed while 37% disagreed with this statement (see Figure 5).

[13] It should be noted that the April 2022 price cap increase had not come into effect at the conclusion of this trial. However, those on variable rate tariffs had seen their costs increase up to the previous price cap rate.

Around half the respondents (47%) reported feeling either a little or much more confident in controlling how much they spend on energy, with the other half (53%) feeling the same.

Figure 5: Agreement with the question: "I have found it easier to control how much I spend on energy since I started to engage with the tool".



N intervention endline (used tool) = 19

For context, a large proportion of all the respondents (i.e. both intervention and control group trialists) who participated in the endline survey indicated that they were very conscious about the cost of their energy during the baseline survey. By the endline, they showed a higher awareness of the cost of energy, with an indicative increase from 85% at baseline indicating they were aware to 92% at endline for the control group trialists. A similar proportion of respondents that had used SEN-ST product also showed similar levels of awareness (82% at baseline to 91% at endline). This could well be due to the background context of rising energy prices over the course of the trial. The intervention itself had also helped trialists understand the cost of energy and manage their energy usage:

> *"The app has helped manage the heating – I feel better informed. I find it's easy to adjust usage slightly. [I am] a bit more aware of monthly usage which is useful with price increases."*

Over the same period, for the same group of respondents, when asked to describe how well they and their household were keeping up with their energy bills at the moment, those responding that they were managing very well or quite well dropped from 86% to 64%. This change could be due to the timing of surveys, with the endline occurring towards the end of winter.

Findings from the qualitative interviews seemed to support the possible explanations around increased awareness of the cost of energy. Most trialists interviewed highlighted the rising cost of energy as a factor in their ability to manage their bills in comparison to the previous year.

> *"I've turned the temperature down by a degree or so when heating the house; conscious about how much [the house is] heating because bills have just increased."*

In terms of usefulness of SEN-ST in helping households manage their bills, several trialists interviewed made it clear that they used the household budget function on the app and used this to monitor their energy bills. While trialists reported the function had little to no impact in terms of reducing their energy bills, several found that it was a useful function that improved their awareness of their overall energy usage:

> *"We don't do anything differently if it looks like we're going over budget. The only thing we do is we will switch it off when we go out and monitor how much we use during the day and at night."*

5.6 Use of intervention features

Around three quarters (76%) of the survey respondents were satisfied with the intervention, supporting the qualitative interview responses where around two thirds of indicated they were generally satisfied with the intervention. The qualitative interviews with trialists gave some indication on which parts of the intervention were most predominantly used and effective.

Many trialists mentioned that SEN-ST gave them a very clear idea of their overall energy use, and for many, this increased their understanding of energy use in the home and which appliances used more or less energy. However, whilst this finding is useful, not all trialists were able to use this information to reduce energy usage any further as they were already using relatively little. Others did manage to report reduced usage and change their behaviours such as using the tumble drier less often.

The ability to reduce energy consumption through better understanding of a comfortable temperature has already been covered earlier but is a key area in reducing energy consumption. Other users found the ability to easily switch on/ off the heating as needed very beneficial to reduce the number of hours the heating was switched on. As discussed in the smart thermostat analysis (Section 5.3), there is a clear trend between reduced heating hours and lower energy consumption.

Although not a stated feature of the device, some trialists also found the ability to be able to move the smart thermostat to different rooms very useful as the heating system would then target the temperature in that specific room.[14]

[14] It should be noted that there is a risk that depending on the control system in place (e.g. TRVs) that this method could result in increased consumption through incorrect control of the heating system.

6 Conclusions

This section discusses the results of the SENS SEN-ST trial and highlights the implications of its findings, along with considerations about its limitations, lesson learnt and future opportunities.

The results showed that the SEN-ST product successfully achieved its primary aim of a reduction in gas energy consumption. The ITT analyses showed a statistically significant reduction in gas usage of 5.0% ± 3.9% (95% Confidence Interval, $p<0.05$) between the intervention and control groups. The TOT estimated the effect for just those who received the full intervention, which was estimated at 14% ± 10.9% (95% Confidence Interval, $p<0.05$). Further exploratory sensitivity analysis was carried out to examine the effect of the dilutors (included in the main body of the report).

Overall, despite the trial not achieving the number of successful SEN-ST installations as initially planned (with an effective sample size achieved that was 25% that of initial recruitment targets - the expected sample size required to detect the expected impact), a significant effect upon consumption was still detected. The product made a consistent and significant impact for the trialists who received it, also demonstrated by the high TOT values and supported by the survey and interview evidence.

The trial assumptions were tested, assessing the randomised nature of the trial and the heating season over which data was captured. There were similar distributions of previous consumption (both gas and electricity), average HDDs and period of the intervention. This allowed the analyses to be carried out with confidence in their results.

Through the survey and interview data, it was possible to understand some of the mechanisms which helped trialists to reduce their gas consumption. The majority of SEN-ST trialists indicated they were satisfied with the intervention, and believed it made it easier for them to understand their usage and lower it accordingly. They also found the convenience of a smart thermostat (being able to switch it on and off remotely) useful, allowing them to only use the heating when they needed to. This reduced the number of hours their homes were heated, which supported evidence from analysis of the smart thermostat data that homes with fewer heating hours had lower energy bills. Interview evidence suggested that one of the main methods for reducing gas consumption was the lowering of the internal set point temperature whilst remaining comfortable. This reduced excessive heating of the property, with further supporting evidence of the smart thermostat data which showed a reduction in energy use for homes with a lower set point temperature. Overall, the combination of easier heating controls, linked with direct feedback on how much energy the heating system was using, provided trialists with the confidence and tools to make a sizeable reduction in their heating consumption.

There was mixed evidence on the effectiveness of the SEN-ST product helping households keep their home at a comfortable temperature. Prior to the trial, households perceived/ reported that they were generally able to keep their homes at comfortable temperatures, although there were some examples of excess heating. The SEN-ST product was found to make it easier for some trialists to keep their home warm (for example providing the ability to switch it on remotely so the home is warm upon arrival) and also allowed users to heat to a lower temperature while remaining comfortable. However, some trialists found it more difficult to keep their home warm after they received intervention, which may to be due to other external factors, such as reducing the amount they heat their home in light of increased fuel bills.

Trialists generally found it easier to see how much they spent on energy since using SEN-ST, though due to rising energy prices, their ability to use this information to manage their heating bills was reduced.

Overall, we can conclude that the SEN-ST product achieved the outcomes it intended to in terms of a reduction in gas consumption. There was robust evidence of a reduction in energy use 5.0% ± 3.9% (95% Confidence Interval, $p<0.05$) for ITT analyses as well as an increased awareness of energy usage and expenditure on energy. There was no spill-over effect on electricity consumption, with no statistical difference between the two groups for this variable. The majority of the gas consumption savings came through the reduction in heating energy, although for some trialists there was anecdotal evidence that they were using less energy elsewhere through behavioural change from increased energy awareness. The innovative nature of the product combining heating controls with smart meter energy consumption data showed a clear means to reduce consumption while educating end users on energy use more generally.

Glossary

ANCOVA	Analysis of Covariance
AQ	Annual Quantity (gas)
ATE	Average Treatment Effect
BAU	Business as Usual
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEIS	Department for Business, Energy and Industrial Strategy
BIT	Behavioural Insights Team
BST	British Summer Time
CA	Contribution Analysis
CAD	Consumer Access Device
CHP	Combined heat and power
CIC	Community Interest Company
CMO	Context-Mechanism-Outcome
CO2e	Carbon dioxide equivalent
COVID-19	Coronavirus Pandemic
CP	Competition Partner
CRL	Commercial Readiness Level
DCC	Data Communications Company
DESNZ	Department for Energy Security and Net Zero (formerly BEIS)
EAC	Estimated Annual (energy) Consumption
ECA	Energy Consumption Analysis
EL	Energy Local
ELC	(SENS) Energy Local Club

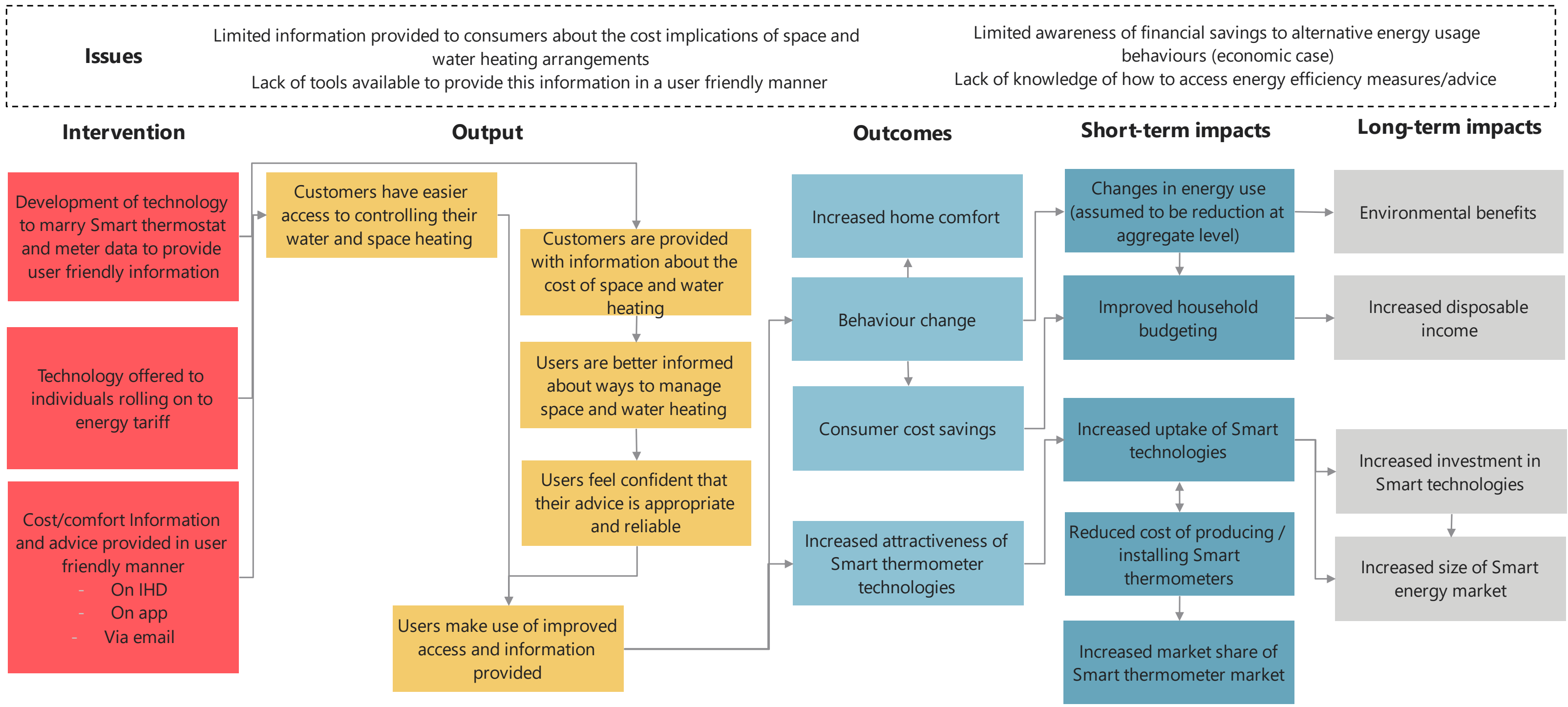
EPC	Energy Performance Certificate
GDPR	General Data Protection Regulation
GEO	Green Energy Options Ltd.
HAN	Home Area Network
HDD	Heating Degree Day
ICE	Igloo Customer Engine
IDEAS	Intelligent Digital Energy Advisory (SENS project)
IHD	In-Home Display
IMD	Index of Multiple Deprivation
ITT	Intention to Treat
KW	Kilowatts
kWh	Kilowatt-hour
M&MH	Me & My Home profile
MDE	Minimum Detectable Effect
MEETS	More Effective and Efficient Thermal comfort with Smart meter data (SENS project)
MI	Monitoring Information
MOP	Meter Operator
MPAN	Meter Point Administration Number
OLS	Ordinary Least Squares
OWL	A brand of electricity monitor used to monitor consumption in Roupell Park
PSM	Propensity Score Matching
RCT	Randomised Controlled Trial
SEC	Smart Energy Code
SECAS	Smart Energy Code Administrator and Secretariat

SENS	Smart Energy Savings Competition
SENS GenGame	SENS GenGame Energy Saver app (SENS project)
SEN-ST	Smart Energy-Smart Thermostat (SENS project)
SERL	Smart Energy Research Laboratory, based at University College London
SM	Smart Meter
SMETER	Smart Meter Enabled Thermal Energy Ratings
SMETS	Smart Metering Equipment Technical Specifications
SMETS1	Smart Metering Equipment Technical Specifications - First Generation
SMETS2	Smart Metering Equipment Technical Specifications - Second Generation
SMS	Smart Metering Services
SoLR	Supplier of Last Resort
TDEL	Trial Design and Evaluation Lead
TOT	Treatment on the Treated
TOU	Time of use
TOUT	Time of Use Tariff
TP	Trial Protocol
TRL	Technology Readiness Level
UCL	University College London
WAN	Wide Area Network

Annex A: Theory of Change

This section presents the SENS SEN-ST Theory of Change, which sets out the issues the intervention was trying to address, the core components of the intervention itself, the outputs it was expected to deliver, the outcomes to achieve, and ultimately, the impacts of the intervention.

Figure 6: SEN-ST Theory of Change



Assumptions & Risks:

A1. User is comfortable providing household information, e.g. type and number of appliances in the home
A2. Users trust advice, are not overburdened with information and feel able to take action
A3 Users effectively engage with the tool
A4. Advice is sensitive to household context, i.e. not encouraging users whom are fuel poor to reduce their consumption further
A5: Demonstration of effectiveness leads to increased demand

R1. Customers understand the information that is being provided to them
R2: Data provided is accurate e.g. weather data
R3: The communication mechanisms (app, email, IHD) are intuitive enough for customers to use
R4: Competitors create similar technologies, reducing competitive advantage and potentially market share
R5: Smart Thermostat/IHD may not be in accessible location resulting in less use
R6: A significant change in gas consumption (e.g. removal of gas oven/fire) will give inaccurate pre - consumption estimates and skew results

Annex B: SENS SEN-ST Trial Overview

Table 5: SEN-ST trial overview

Milestone / stage / sample		Number / count (households)	Date (where applicable, and including start and end date as needed)
Number of households / customers contacted to participate in trial (total)		75,804 dual-fuel customers (not previous SM2 customers)	August 2020 – November 2020
Number of households / customers that agreed to participate	**Treatment**	1292	
	Control	1275	
Number of households / customers providing consents to be contacted for TDEL research	**Treatment**	1292	
	Control	1275	
Number of households / customers providing consents for collection/ provision of energy consumption data via SERL	**Treatment**	1292	
	Control	1275	
	Treatment	492	

Milestone / stage / sample		**Number / count (households)**	**Date (where applicable, and including start and end date as needed)**
Number of households onboarded to SERL[15]	**Control**	513	August 2020 – November 2020
Number of households / trialists **who went on to have a successful smart thermostat installation and smart meter (Treatment Group)**, **and smart meter installation (Control Group)**	**Treatment**	151	September 2020 – February 2021
	Control	429	
Number of withdrawals (overall) over trial period (up to end March 2022)	**Change of tenancy**	40	September 2020 – March 2022
	Withdrawal of consent	179	
	Other (On Hold – not onboarded into SERL)	35	
Final achieved sample	Treatment	394	N/A
	Control	396	N/A
	Treatment	375	N/A

[15] Onboarded is the term used where property details are securely connected to the SERL environment to give access to smart meter and other data.

Milestone / stage / sample		**Number / count (households)**	**Date (where applicable, and including start and end date as needed)**
Final achieved sample retained in SERL **(Sample at the end of the trial period, accounting for churn of trialists)**	**Control**	376	N/A
Final achieved sample for quantitative analysis (i.e. less records excluded for e.g. missing or implausible data)	**Treatment**	261	N/A
	Control	254	N/A
Number of households excluded from gas consumption analysis **and reasons:**	**Missing pre-trial consumption data**	69	N/A
	No gas data in SERL	152	N/A
	Less than 50% daily readings	15	N/A
Baseline survey issued / response rate (treatment group)	**No. of contacts available to be contacted**	151[16]	March 2021 – July 2021
	No. of completed interviews	66	

[16] Only trialists whom went on to have a successful smart thermostat installation and smart meter were made available for survey contact.

Milestone / stage / sample		Number / count (households)	Date (where applicable, and including start and end date as needed)
	Completion rate	44%	
Baseline survey issued / response rate (control group)	No. of contacts available to be contacted	490	March 2021 – July 2021
	No. of completed interviews	187	
	Completion rate	38%	
Endline survey issued / response rate (treatment group)	No. of contacts available to be contacted	60	March 2022
	No. of completed interviews	22	
	Completion rate	37%	
Endline survey issued / response rate (control group)	No. of contacts available to be contacted	164	March 2022

Milestone / stage / sample		**Number / count (households)**	**Date (where applicable, and including start and end date as needed)**
	No. of completed interviews	73	
	Completion rate	45%	
Qualitative interviews completed with treatment group trialists		15	February 2022 – March 2022

Annex C: Additional analysis data and graphs

Trial Assumptions

Figure 7: Pre-trial consumption average daily gas readings

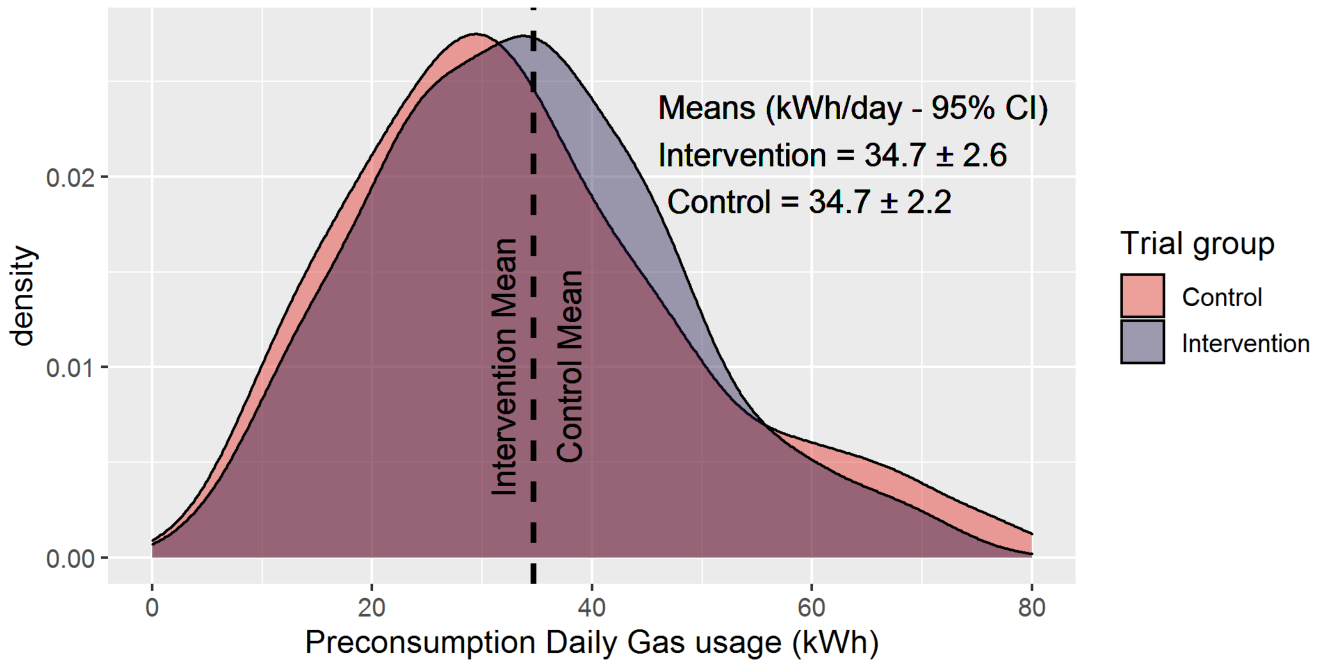


Figure 8: Pre-trial consumption average daily electricity readings

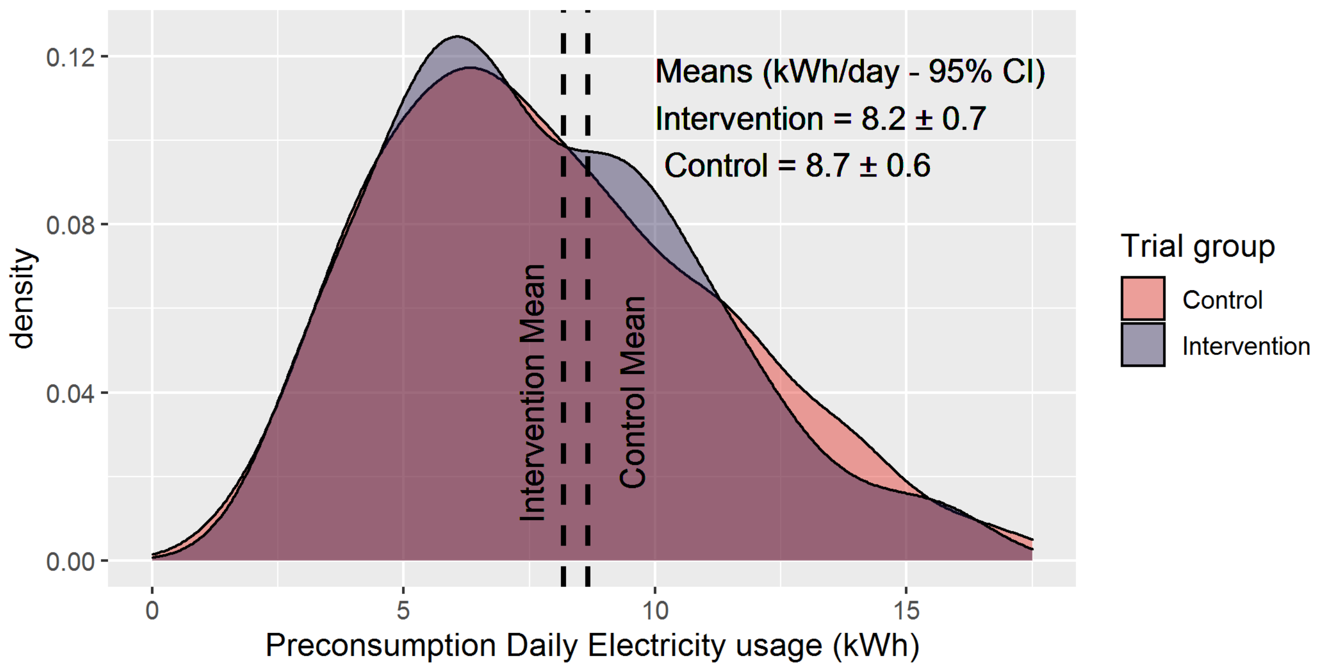


Figure 9: Regional distribution of trialists between treatment and control groups

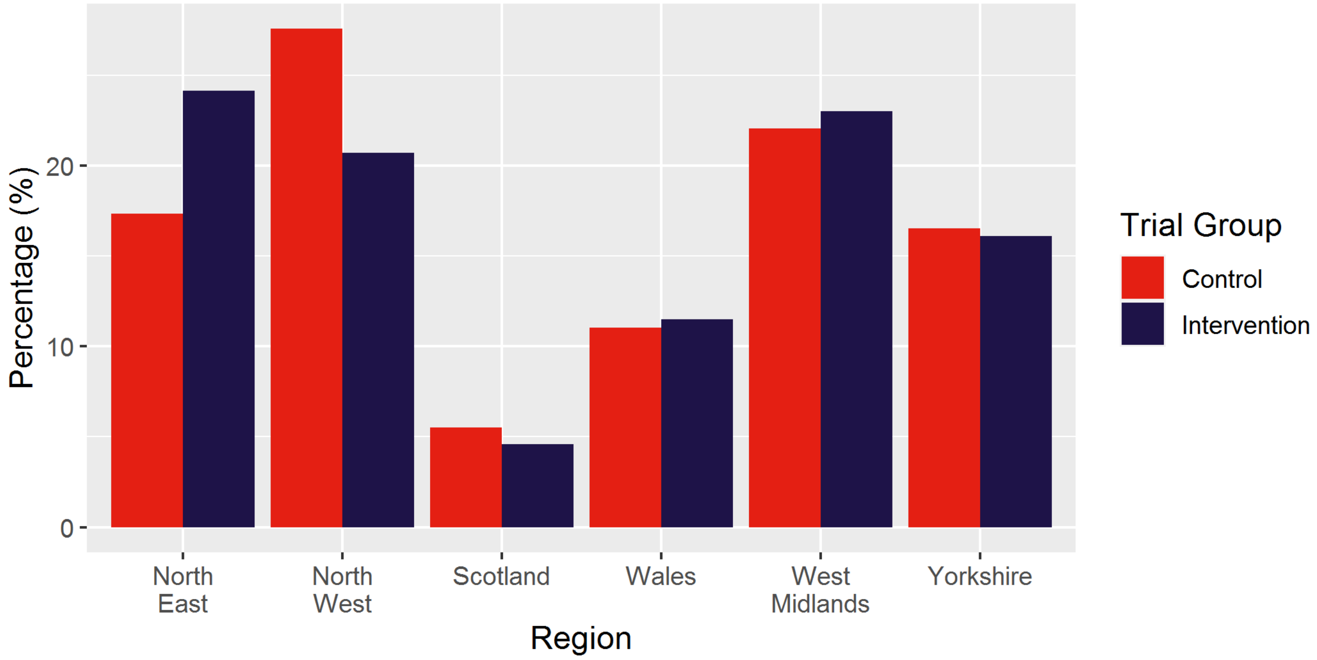


Figure 10: Distribution of number of days of gas data for the trialists

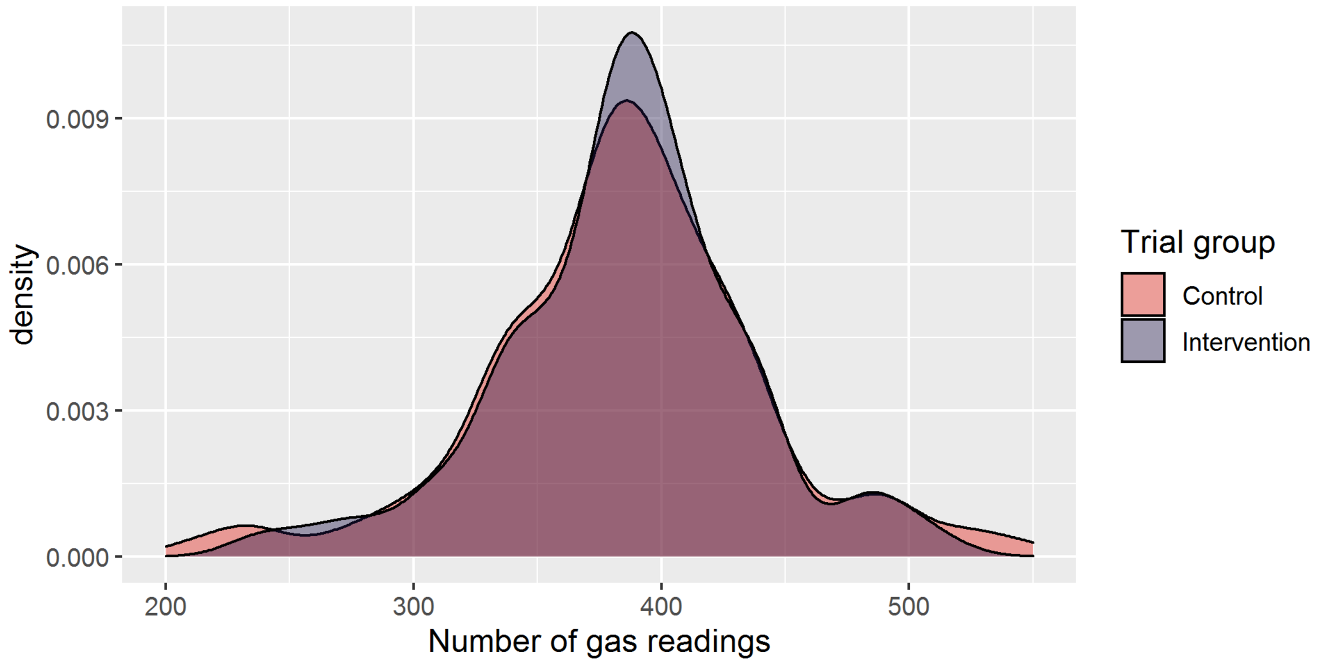


Figure 11: Distribution of average daily heating degree days between intervention and control groups

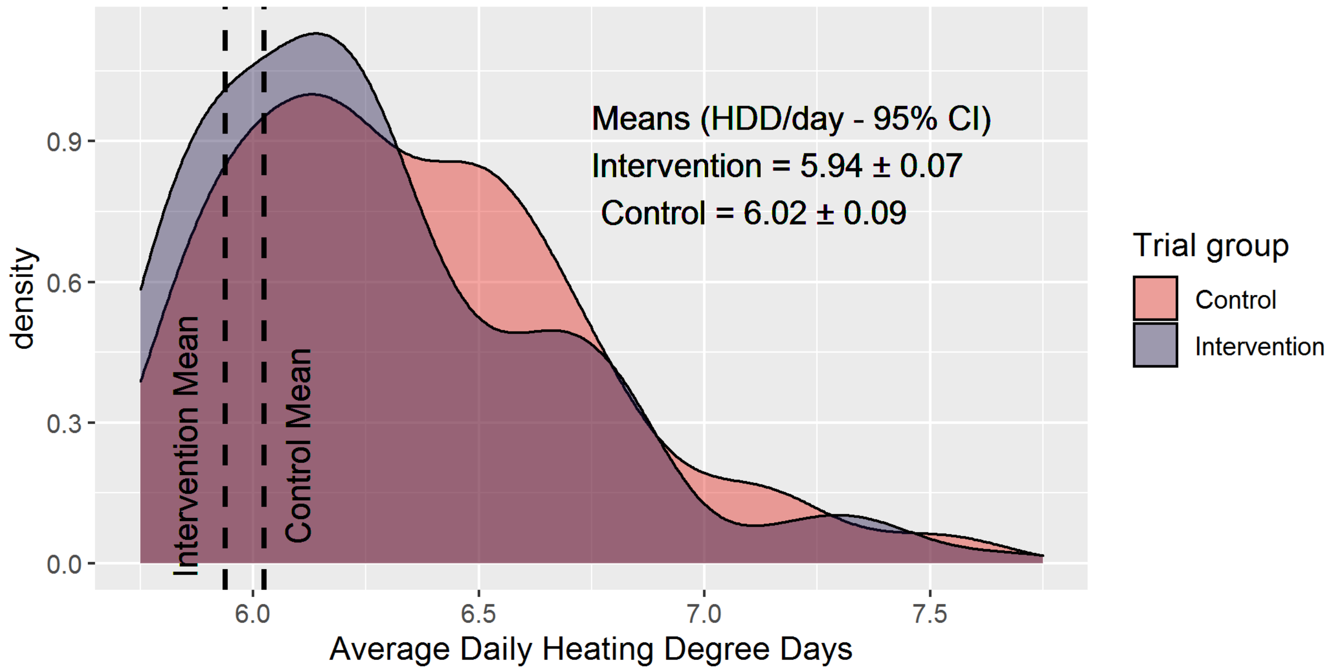
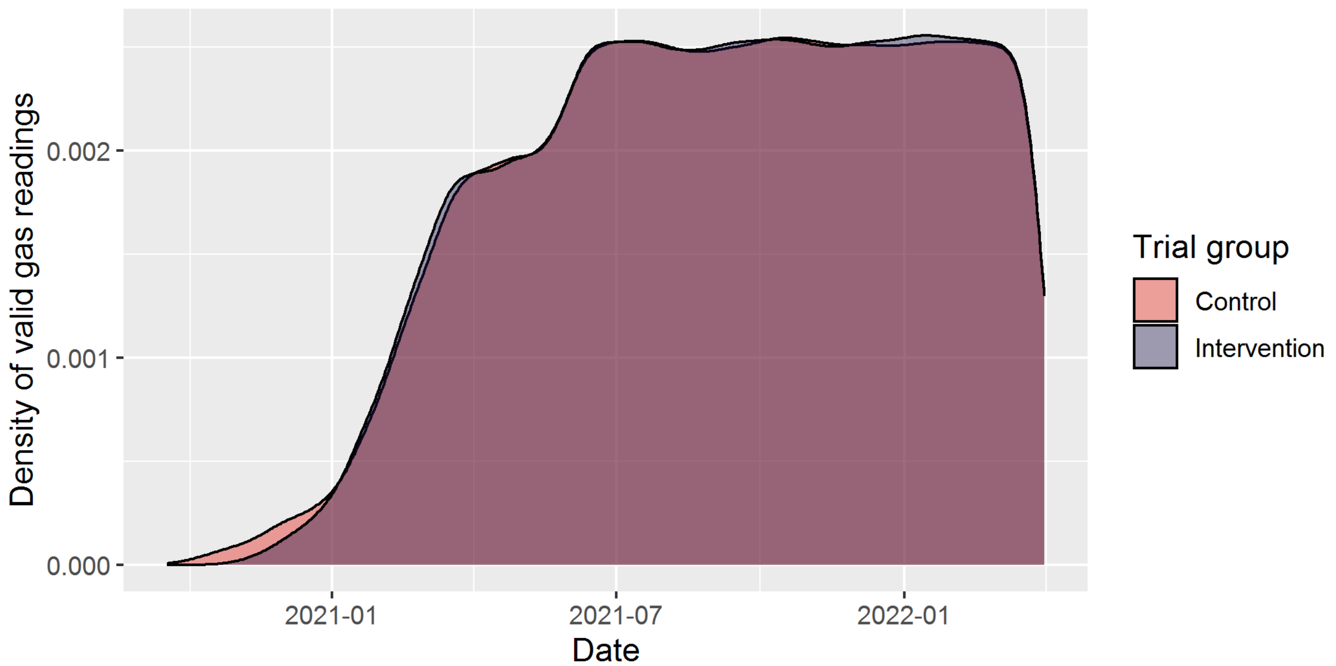


Figure 12: Distribution of proportion of daily gas readings between intervention and control groups



Gas Usage

Figure 13: Comparison of gas consumption between treatment and control groups

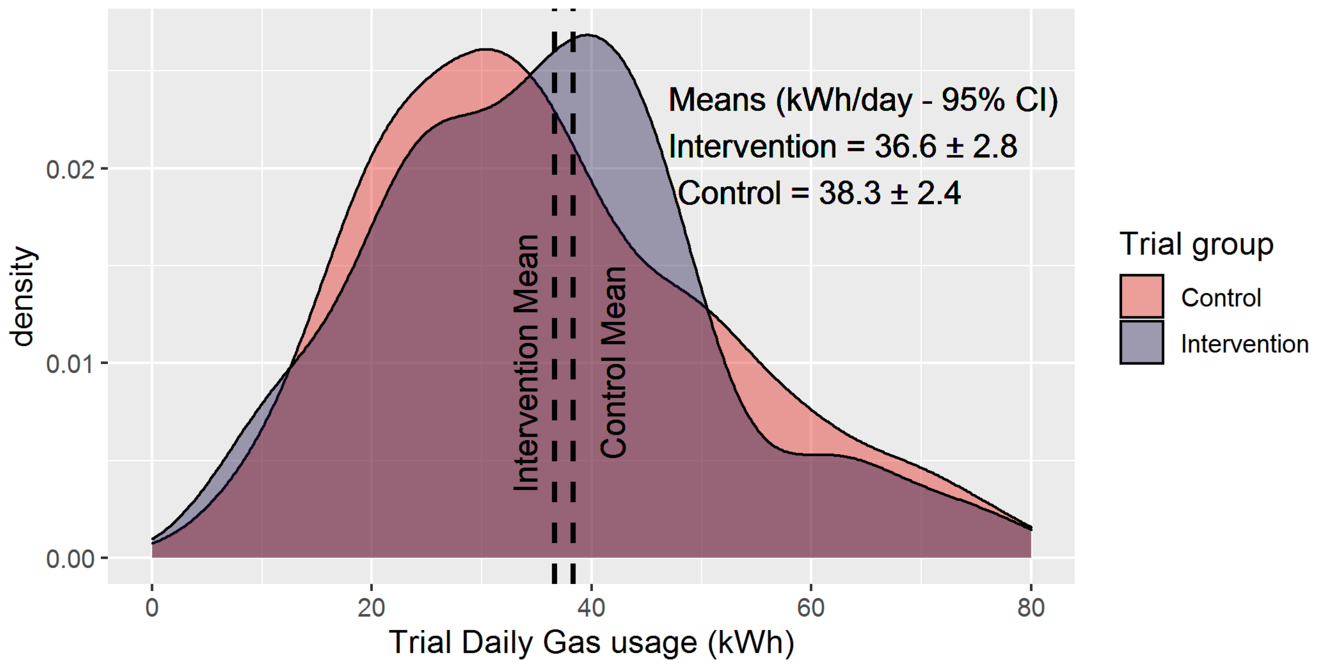
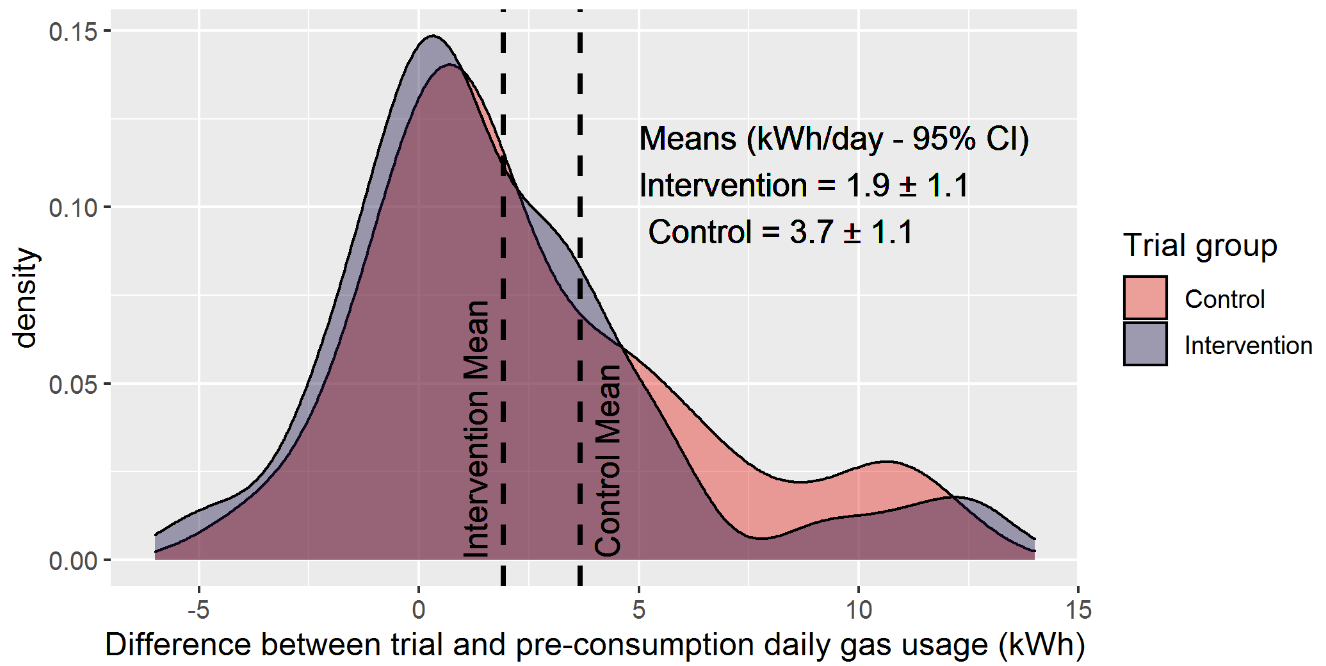


Figure 14: Difference in gas consumption before and during the trial



Gas full ITT regression analysis

Table 6: Regression results – gas full ITT with region. Dependent variable: average daily gas readings. Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group), region (Region)

term	estimate	std.error	statistic	p.value	ci_95%
(Intercept)	3.47	1.22	2.86	0.00	2.38
EAC_gas_daily	0.99	0.02	43.62	0.00	0.04
Trial_groupIntervention	-1.79	0.77	-2.32	0.02	1.51
RegionNORTH WEST	1.53	1.15	1.33	0.19	2.26
RegionSCOTLAND	3.22	1.91	1.69	0.09	3.75
RegionWALES	-0.42	1.42	-0.30	0.77	2.78
RegionWEST MIDLANDS	1.20	1.17	1.02	0.31	2.30
RegionYORKSHIRE	0.85	1.27	0.67	0.51	2.49

r.squared	0.80		logLik	-1840.92
adj.r.squared	0.79		AIC	3699.84
sigma	8.70		BIC	3738.04
statistic	281.28		deviance	38387.61
p.value	0.00		df.residual	507.00
df	7.00		nobs	515.00

Table 7: Regression results – gas full ITT without region. Dependent variable: average daily gas readings. Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group)

term	estimate	std.error	statistic	p.value	ci_95%
(Intercept)	4.31	0.95	4.55	0.00	1.85
EAC_gas_daily	0.99	0.02	44.30	0.00	0.04
Trial_ groupIntervention	-1.92	0.77	-2.51	0.01	1.50

r.squared	0.79		logLik	-1843.48
adj.r.squared	0.79		AIC	3694.96
sigma	8.70		BIC	3711.94
statistic	981.81		deviance	38771.64
p.value	0.00		df.residual	512.00
df	2.00		nobs	515.00

Gas sensitivity regression analysis

Table 8: Regression results – gas sensitivity with region. Dependent variable: average daily gas readings. Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group), region (Region), sensitivity group (AnalysisType)

term	estimate	std.error	statistic	p.value	ci_95%
(Intercept)	3.55	1.22	2.92	0.00	2.38
EAC_gas_daily	0.99	0.02	43.58	0.00	0.04
Trial_groupIntervention	-2.49	0.90	-2.75	0.01	1.77
AnalysisTypeRemoveSensitivity	1.56	1.05	1.48	0.14	2.06
RegionNORTH WEST	1.42	1.16	1.23	0.22	2.26
RegionSCOTLAND	2.98	1.92	1.56	0.12	3.75
RegionWALES	-0.47	1.42	-0.33	0.74	2.78
RegionWEST MIDLANDS	1.25	1.17	1.07	0.29	2.30
RegionYORKSHIRE	0.68	1.27	0.53	0.59	2.50

r.squared	0.80		logLik	-1839.81
adj.r.squared	0.79		AIC	3699.62
sigma	8.69		BIC	3742.06
statistic	246.97		deviance	38222.27
p.value	0.00		df.residual	506.00
df	8.00		nobs	515.00

Table 9: Regression results – gas sensitivity without region. Dependent variable: average daily gas readings. Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group), sensitivity group (AnalysisType)

term	estimate	std.error	statistic	p.value	ci_95%
(Intercept)	4.31	0.94	4.56	0.00	1.85
EAC_gas_daily	0.99	0.02	44.31	0.00	0.04
Trial_groupIntervention	-2.67	0.89	-2.98	0.00	1.75
AnalysisTypeRemoveSensitivity	1.68	1.04	1.61	0.11	2.04

r.squared	0.79		logLik	-1842.18
adj.r.squared	0.79		AIC	3694.35
sigma	8.69		BIC	3715.57
statistic	657.45		deviance	38575.36
p.value	0.00		df.residual	511.00
df	3.00		nobs	515.00

Secondary electricity consumption

Figure 15: Comparison between intervention and control group in-trial average daily electricity consumption

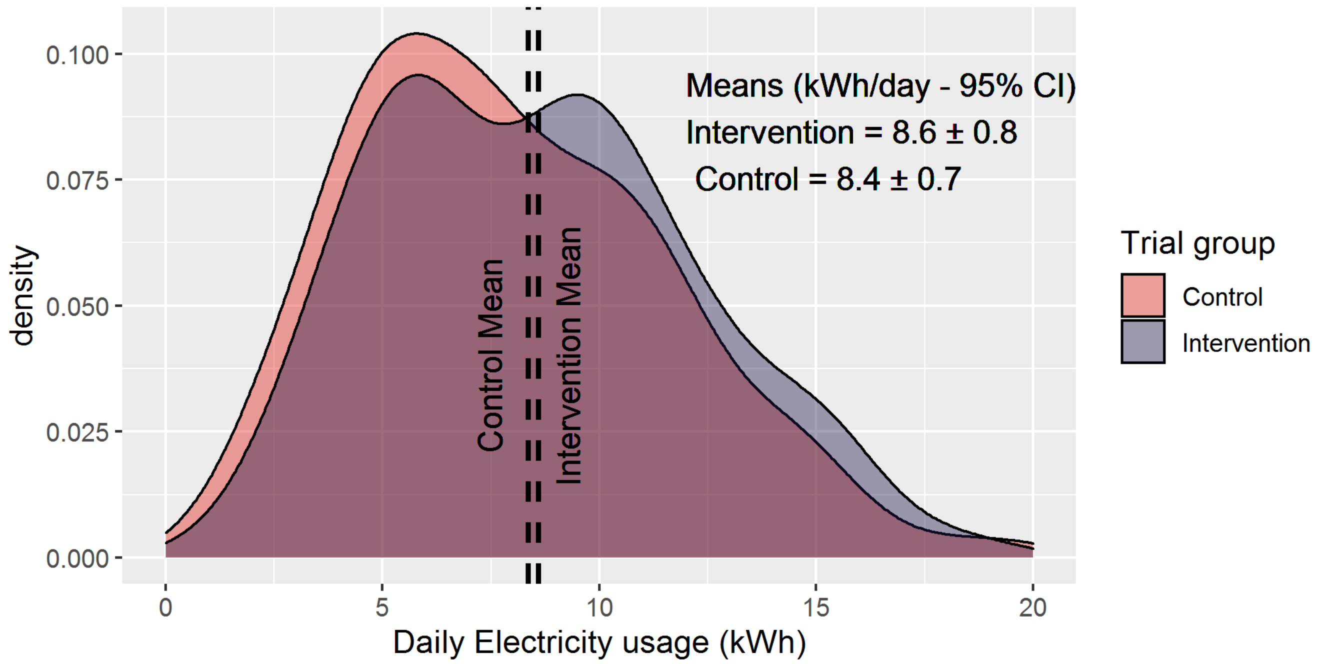


Figure 16: Comparison between average daily electricity usage before and during the trial

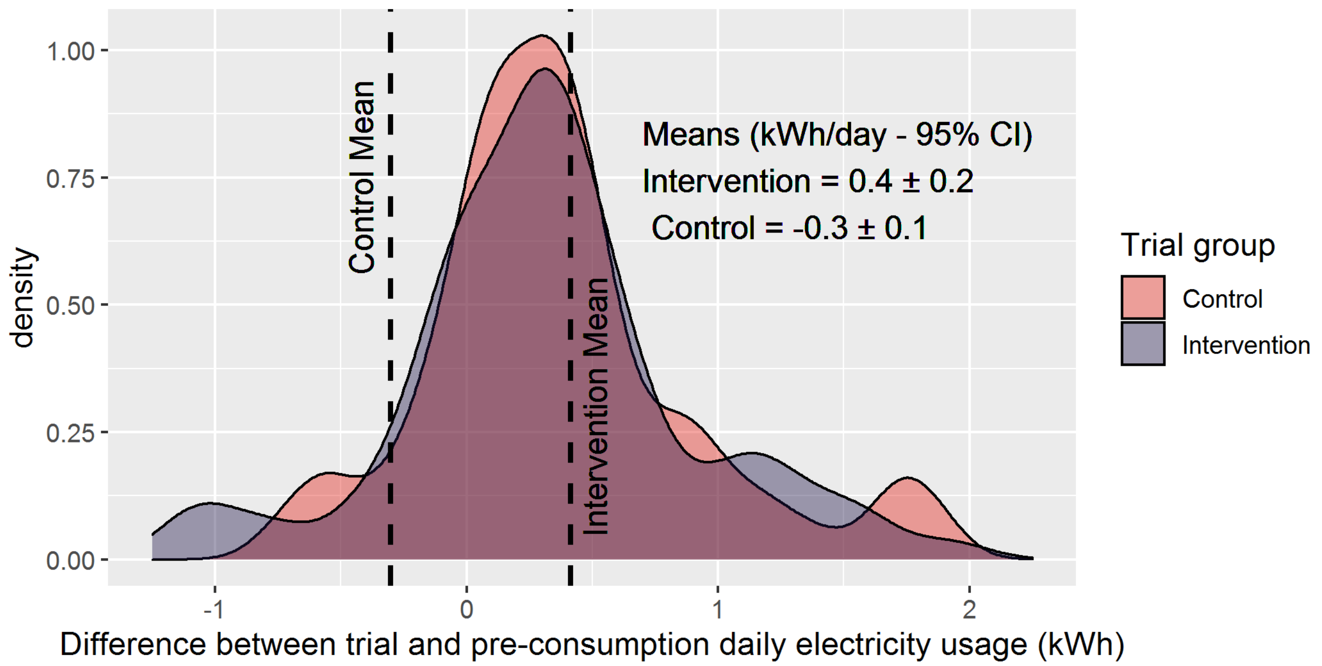


Table 10: Regression results - electricity full ITT. Dependent variable: average daily electricity readings. Independent variables: average daily pre-consumption electricity readings (EAC_elec_daily), trial group (Trial_group)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	0.00	0.18	-0.02	0.98	0.36
EAC_elec_daily	1.01	0.02	57.56	0.00	0.03
Trial_groupIntervention	0.05	0.15	0.30	0.76	0.30

r.squared	0.88		logLik	-824.61
adj.r.squared	0.88		AIC	1657.23
sigma	1.58		BIC	1673.57
statistic	1656.31		deviance	1093.50
p.value	0.00		df.residual	437.00
df	2.00		nobs	440.00

Table 11: Regression results - electricity sensitivity ITT. Dependent variable: average daily electricity readings. Independent variables: average daily pre-consumption electricity readings (EAC_elec_daily), trial group (Trial_group)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	-0.06	0.21	-0.28	0.78	0.42
EAC_elec_daily	1.02	0.02	48.06	0.00	0.04
Trial_groupIntervention	0.07	0.20	0.33	0.74	0.39

r.squared	0.88		logLik	-603.84
adj.r.squared	0.88		AIC	1215.67
sigma	1.63		BIC	1230.71
statistic	1154.98		deviance	837.75
p.value	0.00		df.residual	314.00
df	2.00		nobs	317.00

IMD regression analysis

Table 12: Regression results – IMD analysis. Dependent variable: average daily gas readings. Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group), sensitivity group (AnalysisType), index of multiple deprivation (IMD_quintile)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	4.37	1.17	3.73	0.00	2.30
EAC_gas_daily	0.99	0.02	43.60	0.00	0.04
Trial_groupIntervention	-2.67	0.90	-2.98	0.00	1.76
AnalysisTypeRemoveSensitivity	1.68	1.04	1.61	0.10	2.04
IMD_quintile	-0.02	0.28	-0.08	0.93	0.55

r.squared	0.79		logLik	-1842.172
adj.r.squared	0.79		AIC	3696.34
sigma	8.70		BIC	3721.81
statistic	492.1313		deviance	38574.82
p.value	0.00		df.residual	510.00
df	4.00		nobs	515.00

Smart thermostat regression analysis

Table 13: Smart thermostat regression - mean internal temperature. Dependent variable: average daily gas consumption. Independent variables: mean internal temperature (temp Heating_mean)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	23.73	23.33	1.02	0.31	45.74
`temp Heating_mean`	0.56	1.22	0.46	0.65	2.39

r.squared	0.00		logLik	-304.91	
adj.r.squared	-0.01		AIC	615.82	
sigma	15.11		BIC	622.73	
statistic	0.21		deviance	16431.48	
p.value	0.65		df.residual	72.00	
df	1.00		nobs	74.00	

Table 14: Smart thermostat regression - heating hours. Dependent variable: average daily gas consumption. Independent variables: heating hours on (heat_sw Heating_hours_on)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	25.91	3.11	8.32	0.00	6.10
`heat_sw Heating_hours_on`	0.01	0.00	3.14	0.00	0.00

r.squared	0.12		logLik	-296.29	
adj.r.squared	0.11		AIC	598.58	
sigma	14.21		BIC	605.46	
statistic	9.83		deviance	14330.90	
p.value	0.00		df.residual	71.00	
df	1.00		nobs	73.00	

Table 15: Smart thermostat regression - mean set point temperature. Dependent variable: average daily gas consumption. Independent variables: mean set point temperature (heat_sp Heating_mean)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	13.53	10.26	1.32	0.19	20.12
`heat_sp Heating_mean`	1.58	0.77	2.06	0.04	1.50

r.squared	0.06		logLik	-302.90	
adj.r.squared	0.04		AIC	611.81	
sigma	14.70		BIC	618.72	
statistic	4.23		deviance	15564.87	
p.value	0.04		df.residual	72.00	
df	1.00		nobs	74.00	

HDD regression models

Table 16: HDD regression ITT no region. Dependent variable: mean gas per HDD; Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	0.68	0.16	4.37	0.00	0.31
EAC_gas_daily	0.17	0.00	45.01	0.00	0.01
Trial_groupIntervention	-0.25	0.13	-1.94	0.05	0.25

r.squared	0.80		logLik	-916.68	
adj.r.squared	0.80		AIC	1841.36	
sigma	1.44		BIC	1858.34	
statistic	1013.22		deviance	1060.2	
p.value	0.00		df.residual	512	
df	2.00		nobs	515	

Table 17: HDD regression sensitivity no region. Dependent variable: mean gas per HDD; Independent variables: average daily pre-consumption gas readings (EAC_gas_daily), trial group (Trial_group), analysis type (AnalysisType)

term	estimate	std.error	statistic	p.value	ci_95
(Intercept)	0.68	0.16	4.38	0.00	0.31
EAC_gas_daily	0.17	0.00	45.00	0.00	0.01
Trial_groupIntervention	-0.35	0.15	-2.38	0.02	0.29
AnalysisTypeRemoveSensitivity	0.24	0.17	1.39	0.16	0.34

r.squared	0.80		logLik	-915.7	
adj.r.squared	0.80		AIC	1841.41	

sigma	1.44	BIC	1862.63
statistic	677.37	deviance	1056.18
p.value	0.00	df.residual	511
df	3.00	nobs	515

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