“Clean Heat Streets”

A project funded under BEIS’ Heat Pump Ready Programme

Development of a methodology for high-density deployment of heat pumps in an urban area

Executive summary

As part of the BEIS funded Heat Pump Ready Programme, Samsung led a consortium to develop a methodology for optimised high-density deployment of domestic heat pumps in an urban area of the City of Oxford. Our project is called Clean Heat Streets (CHS).

Consortium partners at the feasibility stage were BOXT Limited, GenGame Limited, University of Oxford, Oxford Brookes University, Oxfordshire County Council and SMS Energy Services Ltd. Our methodology aimed to overcome three major barriers to heat pump adoption and optimal use:

- By reducing the upfront and running costs, Clean Heat Streets aimed to provide an answer to the common question: “Why should I get a heat pump if getting a new gas boiler is easier and cheaper?”;
- By working with the local Distribution Network Operator (DNO) and using both “static” and “dynamic” control strategies, we aimed to demonstrate that high densities of heat pumps can be deployed without causing problems on the low voltage electricity distribution network; and
- In the context of 80% of domestic UK heating being provided by gas central heating systems, the technology is innovative and requires different heating practices and control strategies to incumbent gas boiler heating systems to get the best out of it. Consequently, there are a range of social, cultural and behavioural barriers that stand in the way of heat pump adoption and optimal use.

Summary of our methodology

Step 1: Agree general approach and develop framework documents
Project activities must be guided by an agreed and documented approach. We do this by:

- Agreeing general approach and assembling project partners with requisite skill sets;
- Writing key project management documents including the consortium agreement;
- Writing a document setting out our ethical approach to all activity;
- Documenting the detail of the customer journey;
- Writing a communications and engagement strategy. These documents are live and amended as the project progresses; and
- Agreeing a conceptual framework to assess the technical, social and economic attributes of our chosen area and to be used in informing the design of interventions and value

propositions[1]. We have used the Capability Approach and an extended version of the Centre for Sustainable Energy's (CSE) Capability Lens[2] in this work[3].

Step 2: Understand the neighbourhood

The second step is to build a deep understanding of the social, technical and economic attributes and capabilities of our chosen area. We do this by:

- Conducting a door-to-door community survey of the neighbourhood capturing technical, attitudinal and social information about resident households. This is also the first engagement step;
- Conducting information capture and co-design sessions with residents, local groups and other embedded "middle" actors such as social housing landlords and local heating system installers; and
- Conducting social, technical and economic spatial analysis of the neighbourhood informed by proprietary datasets and primary data collection[4].

Step 3: Identify target areas within the general area

The third step is to identify areas with the highest percentage of homes that are:

- Technically suitable for a heat pump;
- Most likely to take-up the offer of a heat pump, based on economic circumstances, social and digital capabilities and attributes; and
- In areas where a high-density of heat pumps can be installed whilst minimising the need for expensive local grid upgrades.

Step 4: Develop the value proposition

This involves:

- Reducing the costs of an installation to allow an offer that is seen as at least "as attractive" as a new gas boiler;

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[1] The framework CHS proposes to use is based on approaches developed as part of Project LEO (https://project-leo.co.uk/). These involve an extension of the "Capability Lens" developed by the Centre for Sustainable Energy (See Roberts et al (2020) combined with other tools such as Strategiser's Value Proposition and Business Model Canvases.

[2] Capability assessment is based on the capability lens approach developed by the Centre for Sustainable Energy (CSE). The assessment helps to find out how likely households are to adopt different Low Carbon Technologies and those who may be left behind based on their socio-economic characteristics. It can give an idea of the technical, digital, financial as well as social propensity of the households to take up low carbon technologies.

[3] Our capability framework proposes that in order for individual, organisational or community actors to participate in and benefit from the from the energy transition a range of Capabilities are required. These fall into various domains: a) technical (e.g. possession of a smart heat pump, suitability of the house for a heat pump installation); b) economic (e.g. financial resources to invest in a heat pump; c) lifestyle/operational (e.g. ability to shift heating demand without detriment to take advantage of a ToU tariff and a heat pump optimised around the ToU tariff); d) skills and motivation (e.g. digital skills to use an app controlling the heat pump operation); e) social capital (e.g. sharable skills and insights, normative approval, the likelihood of hearing about a successful heat pump installation from a trusted local neighbour).

[4] We used the Local Area Energy Mapping tool (LEMAP) developed at Oxford Brookes University for this purpose. See Gupta et al (2021)

- Identifying a range of finance options for households in different financial circumstances and with different attitudes towards taking-on debt;
- Providing a minimum viable offer in compliance with Microgeneration Certification Scheme (MCS) requirements, whilst being open and transparent about the costs and benefits of additional measures;
- Including pricing techniques to incentivise customer referrals, for example by having a % community discount that increases the more local people sign-up;
- Ensuring that any measures that a householder can/is willing to pay for are undertaken, prior to the heat pump installation. For example, signposting and support for households to undertake ECO+/ECO measures; and
- Using smart meters, half-hourly settlement and static and/or dynamic management to provide a flat-rate electricity tariff offer that is cheaper than the energy price guarantee rate.

Step 5: Develop and implement the engagement strategy
The next step is to develop a householder engagement strategy and householder offer that will persuade enough homes to sign-up within the identified area(s). This involves:

- Close engagement with the local community to understand their needs and concerns;
- Involvement of the Local Authority through employment of a Local Coordinator to act as the trusted person coordinating activity “on-the-ground”;
- Using modelling and householder data/information to accurately forecast the expected running costs of a heat pump and compare with the running costs of a gas boiler;
- Recruitment of 2 local heat pump champions / show homes in each target area to reduce the “fear of the unknown”, create opportunities for social learning where residents can experience a heat pump installed in a home in the neighbourhood similar to their own, create a social norm for heat pump adoption and to demonstrate the benefits of the technology;
- Creating a moderated virtual space where project participants can crowd source solutions and access peer support; and
- Deploying feedback devices into participant homes to provide real time engaging feedback on the performance of their systems.

Step 6: Ensuring pre-install, install and post-install experience is a highly positive experience
A high-level of uptake depends on local trust in the offer, so all installations and post installation support need to be exemplary. This means:

- Providing installation and post installation support with enough data and information from a trusted source to demonstrate to users that the heat pump has been cheaper and provided a better heating service than a gas boiler; and
- Using remote commissioning to provide installation follow-up calls/visits and remote adjustment of settings to improve comfort and/or reduce running costs at set times post install, including whenever a householder adopts additional measures (e.g. additional insulation, other upgrades).

Step 7: Ensuring the technology is smoothly integrated into local networks
Core to the methodology is the need for interaction with the local DNO. The current method for giving permission for the connection of low-carbon technologies is based on the DNO having no

control over how the heat pump will operate. DNOs currently base connection decisions on the technical information in the product information set. Under our methodology, the DNO will have input into how the heat pump is set-up and operated. This could allow them to update their modelling techniques to allow the connection of more heat pumps in a local area before expensive grid upgrades are required. This interaction will include:

- Providing anticipated usage modelling to the DNO to support initial calculations;
- Involvement of the DNO when deciding on the initial field-setting values (FSVs) for the heat pump;
- Reviewing settings on a regular basis and applying remote updates to static settings where required; and
- Working with a Heat Pump optimiser service to dynamically control heat pumps' power usage based on data from the DNO on level of load.

Step 8: Monitoring and post install support

It is vital that participants are able to operate their systems optimally, that the DNO is able to measure impacts on local networks, and that partners and BEIS are able to capture data and learnings from the project. Actions to ensure this include:

- Installation of monitoring equipment at substations to monitor impacts on local networks;
- Installation of monitoring equipment in homes to provide feedback to occupants and project partners on system performance; and
- Post install visits by the project officer to ensure the heat pump is operating as intended and to help residents get the best out of it.

Key findings

Ensuring the project is conducted ethically

Building on learning from other community based low carbon technology trials we conclude that it is imperative that all the project’s activities adhere to the highest standards of ethical project delivery. Not only is this morally right thing to do, but also, without strong ethical standards, trust in the project will be undermined, installations will go in where they should not, and the project will quickly fail.

Understanding the community

Demand profiling

We found that using proprietary and publicly accessible datasets we can generate representative energy demand profiles for heating and hot water, both with and without a heat pump. Further, we can assign a likely demand profile to each specific postcode in our target areas using a geo-demographic classification system such as ACORN[5] or MOSAIC[6].

Intervention design

We found that demand profile modelling, producing detailed hour-by-hour modelling, is a potentially effective approach in designing interventions for specific target areas and postcodes. These interventions would aim to change the shape of the demand profile so as to achieve network management and carbon benefits as well as financial benefits to the household.

The importance of working with locally embedded sustainability and low carbon groups

We have found that the existence of a local group with a general interest in sustainability to be critical in understanding the community and in developing and targeting the value proposition.

Targeting the offer

Heat Pump suitability mapping work allowed us to identify the three most suitable secondary substations in the Rose Hill area to maximise Heat Pump adoption rates given the products that we are able to offer. In total, 394 of the 600 homes within the three selected areas were deemed suitable for our offer. The mapping approach that we have developed can be applied to any area in the UK.

Engagement

The importance of social learning

Further, we need to maximise opportunities for householders to see, hear, feel the heat pump technology operating in local homes. This means setting up show homes but also encouraging those that take the offer to talk about it to their friends and neighbours. Those that install a heat pump through the project will be our best salespeople and advocates for Clean Heat Streets.

Householder engagement and recruitment

The key finding was that the offer had to provide something that was seen as more attractive than the best current heating offer - i.e. a replacement gas boiler. To increase uptake, we will also need to

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[5] ACORN classification system website: https://acorn.caci.co.uk/

[6] MOSAIC consumer classification based on demography and socio-economic characteristics, shopping preferences, lifestyle variables, property type and location, preferred method of communication (mail, email, phone), travel patterns etc: www.experian.co.uk

overcome people's current apprehension concerning adoption of a "new technology" such as a heat pump. To do this, the methodology needs to build trust in the offer and the wider Clean Heat Streets project by working closely with the local community and other embedded "middle" actors such as the local authority, local low carbon living groups, local installers etc.

Design, install and operation

Reducing install and operational costs

Key to reducing costs is specialisation and automation. By removing the need for installers to be heat pump design and commissioning experts, and by transferring administrative tasks to a central body, local heating installers can be upskilled with minimal training to install heat pumps.

Using archetypes to simplify design process

The use of archetypes can greatly simplify the design process and reduce the risk of changes in costs between initial expression of interest stage and final quotation. The process that we have developed for our methodology provides a simple, seamless householder journey and a high level of replicability.

Implementing dynamic and static control

Currently heat pumps are installed with settings that do not take account of the fact that heat pumps need to be "good neighbours" to avoid overloading local transformers that are not all sized to cope with tens of heat pumps running at the same time. To reduce these impacts, simple "static" grid-friendly settings can be set at installation. For example, hot water and legionella cycles can be scheduled at grid friendly times (whilst still meeting householder comfort demands), rather than all being set at the same times.

Working with the DNO

Heat demand modelling focussing on maximum demand scenarios is more appropriate for heat pump design and sizing. A heat pump needs to be designed to cope with a home full of guests, and not just for an average day when only a single person is at home in a large house. Calculating electrical heating demand for a worst-case scenario is also better aligned with DNO risk assessment and load profiling methodologies used to manage new connections and to determine stress on network assets.

The importance of flexible operation of the heat pumps in achieving dense installation rates

There are also "dynamic" control strategies that can take account of the demand level on a local grid to limit real-time power usage. Static and Dynamic configuration and control strategies can be used to allow more heat pumps to be connected whilst minimising the need for expensive grid reinforcements.

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1 Introduction

This introduction describes the aims, expected outcomes and objectives of Phase 1 of our BEIS-funded Heat Pump Ready Stream 1 project, “Clean Heat Streets” (CHS). The overall aim was to develop an innovative methodology for the co-ordinated deployment of heat pumps at high-density within the Oxford area.

Samsung led the consortium which comprised: BOXT Limited, GenGame Limited, Oxford University Centre for the Environment (OUCE), Oxford Brookes University, Oxfordshire County Council and SMS Energy Services Ltd.

In developing our methodology we drew on the skills and expertise of all the partners and also took some learnings and approaches resulting from work in Project Local Energy Oxfordshire (LEO)[7], a major smart grid demonstration project sited in Oxfordshire, led by SSEN and funded under the government’s Prospering From the Energy Revolution programme. Oxfordshire County Council, Oxford University and Oxford Brookes University are all partnered on LEO and have been able to bring their collective experience of working together on LEO to development of the CHS methodology. LEO experience of working in the Rose Hill area of Oxford was also an important factor in selecting this particular area for the CHS project.

The expected outcome of our work in Phase 1 was this final report detailing:

- Our approach to the feasibility study;
- Findings from our feasibility work;
- Our methodology for high-density deployment;
- The innovations within our approach; and
- How we would approach a demonstration of our methodology.

Our methodology sought to identify and address the current barriers to high-density heat pump deployment and to detail an innovative approach to reaching 25% penetration of heat pumps in secondary substation areas. The three main barriers are:

- Heat pumps are more expensive than incumbent gas boiler technology. We tackled this by developing a methodology which reduces the upfront and running costs, thereby providing an answer to the common question: “Why should I get a heat pump if getting a new gas boiler is easier and cheaper?”;
- Heat pumps, installed at sufficient density, have the potential to cause problems on the low voltage network. Consequently, we have developed methodology which, working with the local Distribution Network Operator (DNO), can anticipate where and at what time there are likely to be problems. We have also developed “static” and “dynamic” control strategies, which will mitigate issues and create the opportunity for more heat pump connections in the area. As such, we aim to demonstrate that a higher density of heat pumps can be deployed than is currently possible with current deployment methodologies; and
- Heat pump technology is innovative and unfamiliar to British households. Supply chains to support installation and maintenance are still early in their development. Heat pumps also

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[7] https://project-leo.co.uk/

require different heating practices to get the best out of them versus incumbent gas boilers and to secure the energy and financial savings that are possible. Therefore, acquiring, maintaining and operating a heat pump is a relatively risky proposition versus the tried and tested gas boiler. Consequently, there are a range of social, cultural and behavioural barriers that stand in the way of heat pump adoption and optimal use.

Our core objective in Phase 1 was to develop a methodology that overcame each of these barriers.

2 Summary of feasibility work

Samsung Research identified the key areas of work that were needed to develop an innovative methodology and solutions for the co-ordinated deployment of heat pumps at a high-density. Given the short timescales, effective project management would be essential. Samsung Research UK has experience at managing major projects involving many consortium partners. Samsung has also worked on projects where project management was outsourced. We found that in time-critical projects, project management outsourcing increases the cost and delivery risk. We therefore took the decision to manage the project in-house.

The second identified area of work was data modelling to assess the impact on gas and electricity usage of a household switching from a gas boiler to a heat pump. This would be essential not only to develop the householder offer, but also to assess the grid impact of a high-density of installations. Samsung was aware of the work done by Project LEO on energy systems - modelling the impact of Low Carbon Technologies. We interviewed and subsequently invited the University of Oxford Environmental Change Institute to join the consortium. Oxford University uses advanced statistical techniques to identify distinct energy demand profiles.

To achieve a high level of recruitment in a small area, it would also be essential to select the secondary substation areas most likely to take up a heat pump offer. Oxford Brookes was recommended by University of Oxford Environmental Change Institute for their modelling work that could be extended to identify the most suitable areas for targeting based on technical suitability of homes, but also on other economic and social factors.

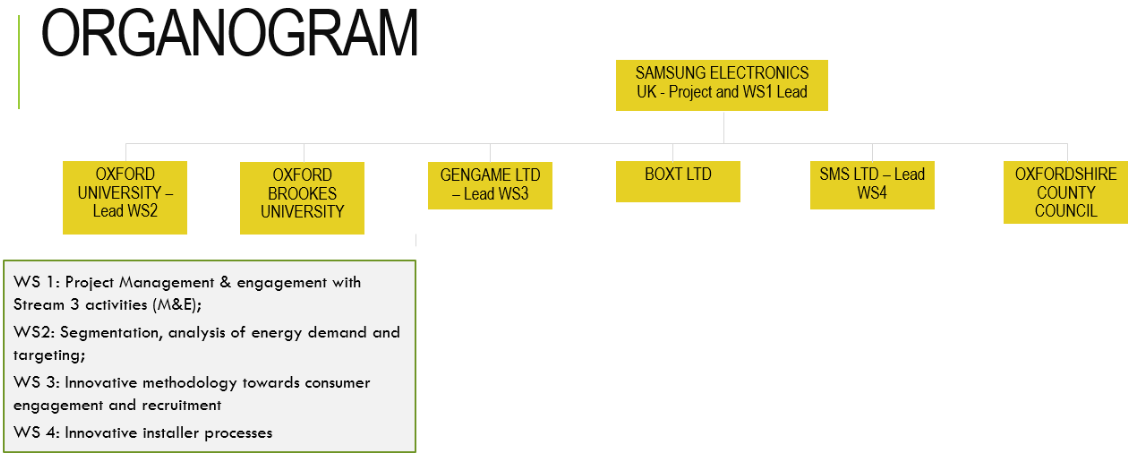
The third area of work identified was householder engagement and recruitment. Persuading households with working gas-heating systems to upgrade to (and pay for) a heat pump during a cost-of-living crisis would need a very attractive householder offer and householder engagement and marketing strategy. We interviewed a number of companies but selected Gengame to join the consortium. Gengame specialises in householder behaviour change and feedback and we decided that they would be able to develop an innovative householder offer and householder engagement and marketing strategy.

We also knew that trust would be very important in persuading people to take part, and that local authorities are more trusted than companies which are not locally-based. We therefore included Oxfordshire County Council in our consortium and included a letter of support from Oxford City Council.

The fourth area of work was innovative installer processes. Using a business-as-usual approach to installations would result in an offer that would be far too expensive and not tailored to the local community. We identified Boxt Ltd as a company with experience at disrupting the boiler installation business by using a new tech-driven approach to simplify the householder journey and invited them to join the consortium. We also identified the need for experienced consultants to develop the methodology's approach to surveying and design. We interviewed a number of companies and decided to invite SMS to join the consortium. SMS was able to provide staff with the required level of expertise of renewable heating system design and specification.

Involvement of the local DNO was identified as essential to our work on suitability mapping and to develop ways of using smart settings to limit grid-impact of a high-density deployment. We invited the local DNO Scottish and Southern Electricity Networks (SSEN) to join the consortium. SSEN was not able to join at the feasibility stage as they did not have sufficient resources to participate in all the projects which had requested their support. However, SSEN did provide a letter of support that gave us confidence that we would get the DNO loading data required to add to our mapping tool, and information on the LCN permissions process needed to develop our detailed process map.

An organogram showing the how the partners were organised according to their skill sets in delivering the feasibility study is shown below:



WS 1: Project Management & engagement with Stream 3 activities (M&E);

WS2: Segmentation, analysis of energy demand and targeting;

WS 3: Innovative methodology towards consumer engagement and recruitment

WS 4: Innovative installer processes

Figure 1: Organogram of the Phase 1 project partners showing leads

Description of how the delivery of the feasibility work was structured, outlining work packages, key activities and deliverables.

Table 1 Structure and purpose of the work streams

	Summary	**Activities**	**Outputs**
Work stream 1: Project management	Project management and meetings. Development of project management tools and processes. Planning Phase 2 and engagement with stream 3.	1. Develop and sign consortium agreement; 2. Day-to-day project management; 3. Engagement with BEIS, Monitoring Officer and Stream 3	Consortium agreement Phase 1 report Phase 2 bid
Work stream 2: Segmentation, analysis of energy demand and targeting	Segmentation of customer types and linkage to geographical reference for mapping. Linkage of customer types to demand profiles discovered with cluster analysis. Segments and demand profiles will be mapped and used in targeting heat pumps into local areas and developing strategies to mitigate any network problems caused by their operation.	1. Creation of a segmentation of end user types using information about ½ hourly gas and electricity consumption, socio-economic and technical data. 2. Analysis of electricity and gas demand profiles revealed by smart meter data. Link demand profile to postcode. 3. Use Local Area Mapping Tool (LEMAP) to: a) map capability to adopt a heat pump, and b) demand profile segments. 4. Use LEMAP to assess impacts of heat pump installations on the electricity network. 5. With SSEN use LEMAP and SSEN load analysis tools to understand the effects on the network. 6. Explore use of commercially available control and monitoring systems allowing smart heat pumps to be controlled to mitigate network constraints and provide flexibility services.	Segmentation of demand profiles. Map allowing identification of target areas. Feasibility work on shifting heat pump electricity demand
Work stream 3: Innovative methodology towards householder engagement and recruitment	Gain insights from secondary and primary research to understand the Rose Hill community social diversity. Create methodologies that will target engagement and recruitment for the segment group identified in work stream 2.	1. Conduct desk research on current state of the art propositions. 2. Carry out a householder proposition workshop to discuss desk research findings and segmentation data from work stream 2. 3. Perform user research focus groups with Rose Hill residents to test findings from the householder proposition workshop. 4. Develop a digital recruitment/engagement plan that will target the local community. 5. Develop local/community engagement plan and development of innovative engagement strategies that work with social processes including facilitating social and peer-to-peer learning.	Desk research and householder proposition workshop key findings. User research focus groups key findings. Value propositions summary of 4 distinct tenure based segments.

		6. Develop tailored value propositions for segments and communities from the outcome of the householder proposition workshop and the user research.	
Work stream 4: Innovative installer processes	Investigate the existing heat pump quotation, design, installation and hand-over processes, find areas where significant innovative implementation, simplification and automation can be worked out to reduce cost for supplier and for householder. Furthermore, find new innovative data collection and analyser, design and proposal tools which can improve the processes, and result in a seamless process for householder and supplier.	1. Investigate EPC data collection and process from government’s EPC database via API, process the valid householder assigned EPC data, feed into the process, support pre-design and quotation activities 2. Investigate adaptation of historic smart data to support pre-design activities 3. Develop reliable pre-design heat demand calculator and proposal mechanism which can estimate the necessary HP size, system components and additional works 4. Improve mechanical and electrical (M&E) survey activities, design tasks with innovative design and survey tool, and MCS compliant certificate mechanism 5. Develop the existing installer network allocation, and tasks management 6. Develop the hand-over processes and after-care for householders 7. Develop after-care householder tips and energy saving advice 8. Investigate the existing installer network’s training and development plans, improve the technical knowledge of the installers 9. Develop the existing installer QA system with centralised check of the completed works, quality assurance of the completed works, and manage householder satisfaction 10. Create high level and detailed process map about the developed process 11. The developed process includes a feedback mechanism to deliver continuous improvement	The consortium revised the complete process, and developed the data collection, process, pre-design and design tasks. The proposed process gained significant time and resource requirement reduction with the newly developed tools and automation. The proposed process is replicable and suitable for the “typical” domestic dwellings. The developed process uses more effectively the existing online databases, tools and communication channels.

3 Methodology for feasibility study

We identified the need for four work streams for the study:

1. Project management
2. Segmentation, analysis of energy demand and targeting
3. Householder engagement and recruitment
4. Installer processes

3.1 Interdependencies

Several interdependencies between and within these work streams were identified in our work plan. Main interdependencies, blockages and how blockages were removed as part of our feasibility work are shown in the table below.

Inter-dependency	Blockages and Facilitators to the inter-dependency
Task 2.1.1. involved development of a segmentation of household types and associated demand profiles. The cluster analysis, performed by Oxford University, to produce the segmentation and demand profiling was to be performed on the Smart Energy Research Lab (SERL) dataset of 13,000 households[8]. SERL data contains smart meter data, plus Energy Performance Certificate data plus "contextual" data describing the demographic characteristics of the occupants, heating settings etc. Hence, the segmentation work was dependent on timely access to this data.	Access to SERL data is safeguarded and therefore requires clearing a number of complex and time-consuming administrative hurdles including prospective users receiving training and passing an exam. In the event, the lead researcher was only able to secure access to SERL in October, which was far too late to meet project deadlines. Consequently, two alternative strategies were pursued: Rather than using SERL data for the main profiling cluster analysis, we used the Energy Demand Research Project dataset[9]. Critically, for our purpose, each case in the EDRP dataset is given an ACORN classification. Hence, clustered demand profiles can be associated with ACORN profiles. We re-designed our method and were able to use a sample of SERL data via another colleague at Oxford University who had access to it. The sample of SERL data was used to calculate clusters of COP for heat pumps which could then be linked to the clusters generated using the EDRP data. In this way, we were able to develop a clustering methodology and prove that meaningful demand profiles could be generated using smart meter data linked to socio-economic and demographic data. Now that full access to the SERL data is secured, we will

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[8] SERL is consortium of universities led by UCL. Details of SERL and how it can be accessed are found at https://serl.ac.uk/

[9] Further detail of the EDRP dataset is found here: https://www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/energy-demand-research-project-edrp

	repeat the essential steps in our methodology in this superior dataset.
Segments developed in 2.1.1 were to be mapped by Oxford Brookes University by linking the segment with postcodes. OBU and the County Council has proprietary data giving socio-economic and demographic and technical data for every postcode in the Oxford City area (MOSAIC and ACORN data)	In the event, demand profiles generated by cluster analysis were not mapped via ACORN classification to Rose Hill but the methodology to do this was established: for any postcode in the UK we can determine the ACORN classification and then link this to the demand profile with which it is most associated.
Segments developed in 2.1.1 were to be used in developing an engagement strategy in WS3	In the event, we developed a methodology that would allow this but did not work up an engagement strategy around the segments. Instead the path to do this was established and the engagement strategy was developed around other project outputs - such as the capability analysis conducted by Oxford Brookes University
Demand profiles generated by Oxford University in WS2 were to be used in determining if problems on the network might result where a concentration of heat pumps were installed at particular points.	In the event, it was decided to use a worst-case scenario approach to this. This meant that rather than relying on demand profiles driven by socio-economic and demographic characteristics of the household we should use only the technical information about the home's fabric, efficiency and built form, assuming that the whole house is heated to comfort temperatures 24/7. We can make these calculations using a thermal model developed by SMS. This approach fits better with the worst-case scenario approach to network power modelling used by the DNO.

Our methodology for each work stream is described below.

3.2 Work stream 1: Project management

Work Stream 1 was led by Samsung Electronics.

All parties signed a consortium agreement (governed under English law). In the agreement partners agreed to work together subject to the Specification (the Tender), the Proposal (our bid) and the Funding Body T&C's.

The finalised project plan was attached as a Schedule of the consortium agreement, and each partner agreed to carry out the tasks allotted to it in the Project Plan. The consortium agreement also covered:

- Project management arrangements,
- Use and exploitation of IP,
- Academic publication,
- Data Protection,
- Confidentiality,

- Liability,
- Force Majeure,
- Termination,
- Withdrawal and
- Addition of new parties.

The project was managed following PRINCE2 methods with clearly defined task-based responsibilities and outputs tracked to dependent task inputs. Management reporting lines started with named responsible individuals (as task leads) reporting to work stream leads via short custom task management templates; work stream leads then reported to the Core Team & Project Manager, adding synopsis & RAG assessments for their work stream, for the core team to review. The Project Manager then highlighted omissions, risks & mitigations, programme critical path & overall timekeeping.

In addition to work stream leads, one representative from each partner was part of the Core Team and attended a weekly call. The Project Manager kept the live risk register updated, and all members of the project team committed to immediately raise any new major risks with the Project Manager by email or phone.

The Project Manager summarised project progress and risks and issues in a monthly call with the project monitoring officer.

3.3 Work stream 2: Segmentation and analysis of energy demand and targeting

Work stream 2 was led by Oxford University and Oxford Brookes University. The purpose of work stream 2 was to develop analytic approaches which reveal the attributes, capabilities and priorities of the target communities. This allows us to:

- Develop an engagement strategy and value proposition with the best chances of interesting target communities;
- Develop interventions to mitigate potentially problematic aggregated demand profiles; and
- Identify specific streets and postcodes where the offer has the best chance of acceptance.

The team used advanced statistical analysis and spatial data analytics to develop a rich understanding of the target area. Work stream 2 outputs included a set of 6 demand profile types which could be mapped to any UK postcode and a detailed spatial analysis of the Rose Hill area providing postcode level information on a variety of socio-economic and technical variables. This information is used in a variety of ways in the methodology:

- Identifying the change in electricity consumption in households in each postcode as a result of adoption of heat pumps;
- Identifying possibly problematic aggregations of demand profile at the secondary substation level;
- Forecasting likely impacts on demand shape and volume at particular locations from various types of intervention including direct load control and Time of Use tariffs; and

- Developing engagement strategy including consideration of working with the capability profile[10] found in each part of the Rose Hill area; identifying key postcodes to initially target with the CHS offer.

Work stream 2 was divided into 3 main areas:

- Segmentation and analysis of energy demand;
- Identification and mapping of the target community; and
- Analysis of potential network constraints and technical feasibility of installation of smart control and monitoring systems.

The methodology for each component is described further below.

3.3.1 Segmentation and analysis of energy demand

We needed to estimate the expected usage profile of households following a heat pump installation for four main reasons:

- Firstly, a key part of the value proposition is the need to provide something that is as cheap to install and to run as a gas boiler. To estimate the relative energy costs of a gas boiler versus heat pump we need ways of translating gas usage to electricity usage, and of associating a profile type to a particular household in instances where we do not have access to a home's smart meter data.

- Secondly, expected usage profiles allow us to aggregate households' usage and predict the change in overall electricity usage of a secondary substation area given different levels of take-up of the heat pump offer. When combined with DNO data on network headroom this allows us to assess how many heat pumps could be accommodated in our areas without network upgrades. Also, because we can link likely demand profile to specific postcodes in our target areas we can determine which postcodes should be targeted for interventions to flatten peaks or move demand around to avoid network problems

- Thirdly, demand profiles allow us to assess whether certain profile shapes are already "off-peaky", and therefore may be able to get a cheaper electricity tariff than a standard variable tariff (which is based on the profile class 1 shape). During the feasibility stage we did not have a flexibility provider partner, but we would aim during a demonstration phase to also assess how flexibility of heating load could reduce energy tariffs further and allow more heat pumps to be connected to a local grid without increasing the risk to a DNO.

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[10] The "Capability profile" refers to the range of technical, social, economic, digital and personal capabilities possessed by an individual, a business or organisation or even a community that bear on the ability of the individual or organisation to participate, beneficially, in the energy transition. Using the Capability Approach and its simplified form developed by the Centre for Sustainable Energy, the so-called, "Capability Lens" to think about which households and communities have the potential to benefit and which are at risk of being "left behind" we arrive at questions such as, "what level of digital capability is required for a household to use an app to operate their smart heat pump"? And "how is this capability distributed across demographic, socio-economic and geographic categories"?

- Fourthly, demand profiles, where associated with particular technical, socio-economic and demographic characteristics, allow us to design highly tailored interventions (to change the demand profile) which account for the capabilities and priorities of the households. Interventions under consideration include direct control via the Passiv system and Time of Use tariffs.

The demand profiling tasks in work stream 2 used two datasets:

1. The Energy Demand Research Project (EDRP) dataset[11]. This dataset contains half-hourly electricity and gas demand of homes with gas boilers and was collected between May 2009 and July 2010 as part of the Energy Demand Research Project (EDRP). Data is captured from over 6600 single-family homes distributed across Great Britain. The dataset has a mix of gas boiler and system types and households of diverse and defined socio-economic types (ACORN categories[12]).

2. The Smart Energy Research Lab (SERL) dataset[13]. This is a dataset of half-hourly gas and electricity data readings drawn from a sample of 13,000 households. The dataset has “contextual” data on household characteristics plus technical data captured from the EPC certificate.

The outline methodology for the demand profiling work is shown below. Further detail of the cluster analysis is shown in Appendix 1: Detailed methodology for cluster analysis.

Stage 1: Data Pre-Processing
We developed an algorithm to select a sample of the EDRP households with dual fuel (gas and electricity). Only smart meter data for January was used in subsequent analysis.

Stage 2: ACORN matching
In stage 2 we linked each household in our sample with its associated ACORN classification. For instance, the ACORN classification, ‘1,B,7’ indicates:

- Category 1 (Affluent achievers),
- Group B (Affluent Greys), and
- Type 7 (Old People, Detached Homes).

Stage 3: Cluster Analysis
This clustering algorithm aims to:

- Find the 12 most typical electricity and gas profiles based on all EDRP gas and electricity data in January. Each electricity cluster is associated with its corresponding gas cluster – so there are 6 electricity clusters associated with 6 gas clusters.

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[11] The EDRP dataset can be accessed from the UK data service website here: https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=7591

[12] The file of ACORN classification for the EDRP dataset is also held by the UK data services and is downloadable separately. A guide to the ACORN classifications is found here: https://acorn.caci.co.uk/downloads/Acorn-User-guide.pdf

[13] Further information about the SERL dataset is found here: https://serl.ac.uk/

- Find the distribution of ACORN types associated with each cluster.

Stage 4: ACORN Distribution

For each cluster we then identify the associated ACORN types. An example is shown in Table 1 where the clustering has been applied to a random sample of cases from the full EDRP dataset. Histograms showing the association of ACORN types with each demand profile (i.e. cluster types 1-6) are shown in Figure 2.

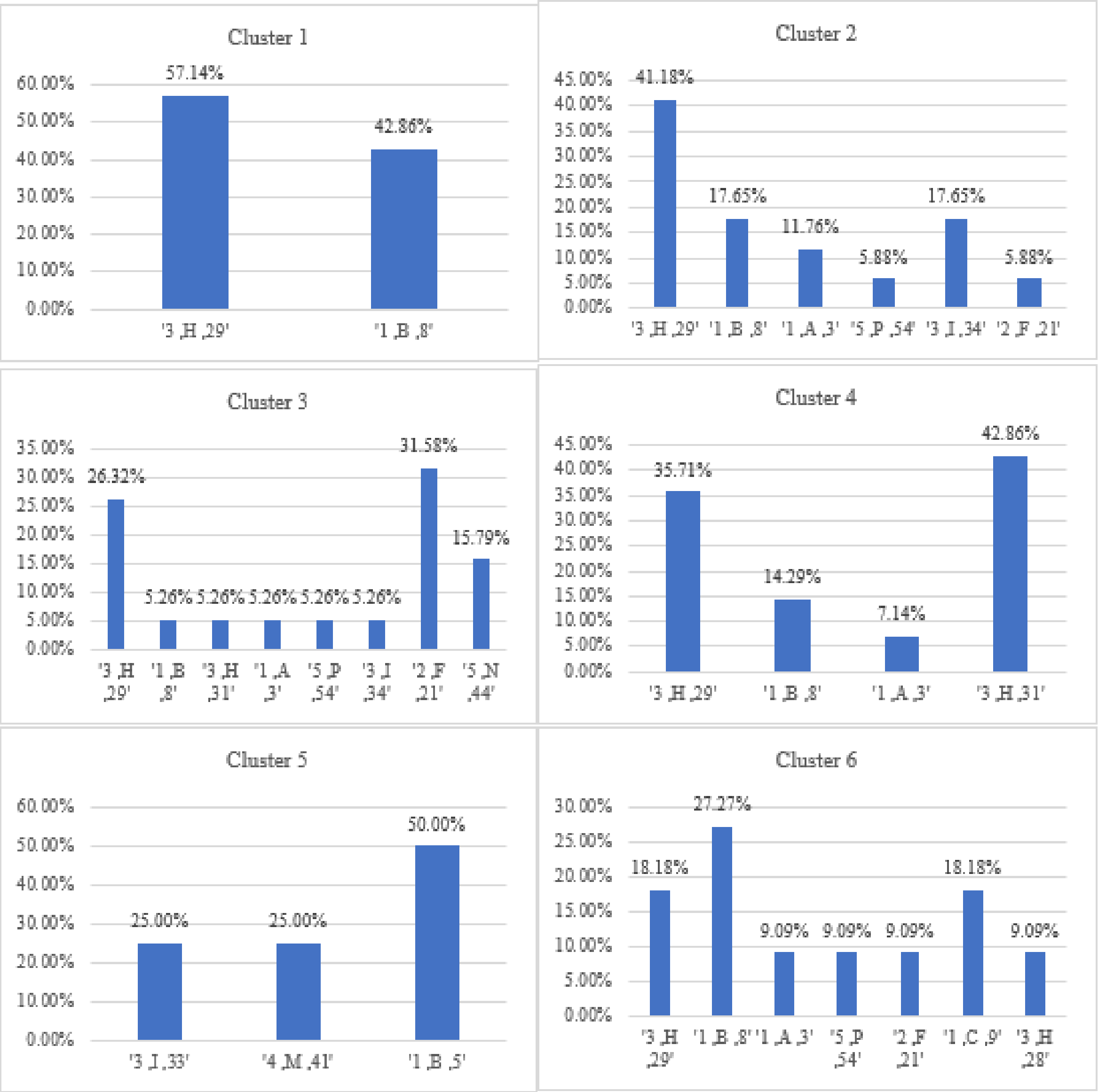

Figure 2 Allocation of ACORN types to Cluster Types 1 to 6

Stage 5: ACORN Explanation

The ACORN types associated with each cluster are reviewed to identify common factors which could explain the profile shape and therefore why the cluster exists as distinct from other clusters. In particular, we explore the demographic, socio-economic and lifestyle related information used to characterise ACORN type. This is possible because the ACORN classification contains rich information about:

- The life stage of the occupants (e.g. retired couple, working parents etc);

- Number of occupants;
- Built form of the property including indicative age of the home;
- Number of bedrooms;
- Attitudes, values, hobbies and measures of social capital[14].

An example of the socio-economic and technical detail available for each ACORN type is shown in Appendix 2: Example description of specific ACORN type for a category 1 (Affluent achievers), group B (Affluent Greys), and type 7 (Old People, Detached Homes).

Stage 6: Postcode Allocation

For every postcode in Rose Hill (see Appendix 3: Rose Hill Postcodes, socio-economic and technical characteristics and demand profiles) we have an associated ACORN classification available through a proprietary dataset supplied by Oxfordshire County Council. Therefore, we can match each of our derived demand profiles to each postcode in Rose Hill using the ACORN classification as the common index[15]. For example, OX4 4TP is designated as ACORN type 5,P,53 which, from our analysis, is in turn strongly associated with Cluster 6. Appendix 3: Rose Hill Postcodes, socio-economic and technical characteristics and demand profiles shows the allocation of Rose Hill postcodes to demand profile types.

Stage 7: Heat Pump Projection

In this stage we match our EDRP electricity consumption clusters to electricity consumption clusters in the Smart Energy Research Lab (SERL) dataset based on how similar they are. Critically, we use a sample of SERL households that have had a heat pump installed and have pre-heat pump and post heat pump install data. Thus we are able to link EDRP electricity clusters with SERL electricity clusters before and after the install of the heat pump. From this we are also able to derive a Coefficient of Performance (CoP) for the heat pump in each household in each half hour period during January and thereby derive an indication of how a gas thermal demand profile is satisfied by the heat pump and what the resulting electricity demand looks like.

Stage 8: Validation

Using EPC data, a typical home archetype for each postcode was found. The archetype was characterised by floor area, build year, and number of heated rooms. The SMS thermal model was then used to generate power profiles of the heat pump using floor area, build year, and bedroom

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[14] Many of the capabilities described above derive from the relative strength of core "social" properties of the community. Some of these social properties have been termed "social capital" which is the ability to generate or capture benefits in a community which contribute to general welfare through strong and resilient social networks, trust and willingness to share knowledge, time and goods. High levels of social capital are associated with networks imbued with trust, norms and shared values. High levels of social capital can address many problems and facilitate the spread of innovative ideas and practices. Our Capability analysis suggests that Social Capital is a key factor affecting the spread of new technologies and practices in a community

[15] Noting that there is a complication here: the ACORN types in our EDRP dataset used to generate the clusters are from 2010 whilst the ACORN types allocated to Rose Hill are from the 2020 version of the ACORN classification. Unfortunately there is no direct association between a particular 2010 ACORN type and a particular 2020 ACORN type. Consequently, we have manually assigned a 2020 type to each 2010 type based on a common sense assessment of the salient demographic, technical and socio-economic characteristics held in common. We acknowledge that this introduces unwanted noise into the analysis.

number as inputs. The power profiles created by the SMS model can then be compared with the projected profiles calculated by the EDRP method outlined above.

Stage 9: Heat Pump Potential Analysis
The potential for heat pump installation at each postcode can then be assessed based on the projected electricity demand profile once a heat pump is installed combined with information describing the household's capabilities.

3.3.2 Identification and mapping of the target community

As part of Project LEO[16], EnergyRev research and many other historical projects, Phase 1 partners and stakeholders, SSEN, OU, OBU and the City and County Council have long standing experience of working with Oxfordshire communities on energy projects including in our finally chosen target community, Rose Hill, to the south of the city. This gave the project team a good overall sense of a suitable location for CHS. However, our original intention was to deploy Oxfordshire County Council's Strategic Energy Mapping tool to get a bird's eye view of the low carbon energy potential across the County as a whole. This would reveal the most suited areas for Clean Heat Streets. We would then conduct further analysis and explore, with key local stakeholders such as the local authorities, the technical, social and economic viability of the project sites to determine the final target site. In the event, partner experience and the characteristics of the community made Rose Hill and Iffley ward, to the South of the City of Oxford, the obvious choice and so a more formal process of identification using the County Council tool was not deemed necessary.

A critical factor in selecting Rose Hill and Iffley was the fabric standards of most of the housing there. Most of the housing was constructed post war and therefore there are reasonably good fabric standards meaning extensive programmes of insulation works to enable heat pumps to operate optimally were unlikely to be needed in most cases.

The Rose Hill area of Oxford City has long been a focus of engagement thanks, in no small part, to there being a highly active low carbon living group embedded there: "Rose Hill and Iffley Low Carbon" (RHILC). Oxfordshire CIC and IPS, the Low Carbon Hub (LCH), has been working with the Rose Hill community for some time, and, as part of Project LEO, has sought to establish a "Smart and Fair Neighbourhood" in the area which aims to encourage local residents to self-consume PV generated electricity supported by an innovative electricity tariff. As part of the Smart and Fair Neighbourhood work, OBU and LCH have conducted social surveys in the area and OBU, working with the local community, has built up detailed spatial analysis of the area[17] using their LEMAP tool. Therefore, the CHS team decided to capitalise on this experience, spatial analysis and the pre-existing relationships with Rose Hill stakeholders (including RHILC) in selecting Rose Hill and Iffley Ward as the project site.

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[16] Project LEO is a major smart grid demonstration project funded under the UK Government's, "Prospering from the Energy Revolution (PFER) programme

[17] See Spatial analysis of Smart and Fair Neighbourhood in Oxfordshire at https://project-leo.co.uk/reports/spatial-analysis-of-smart-and-fair-neighbourhood-in-oxfordshire/

Like anywhere, Rose Hill and Iffley Ward is composed of a patchwork of different neighbourhoods with different attributes, priorities, resources, house types, income levels, tenure types etc[18]. Some neighbourhoods in the post war housing estate are classified as amongst the 20% most deprived in the UK whilst other areas are relatively well off. Therefore, having selected Rose Hill as the general area, the next step was to develop methodology to analyse the diversity of income levels, tenure types, "capabilities" and other attributes distributed across the Rose Hill and Iffley ward. This detailed analysis allowed the project team to select particular areas where the heat pump offer had the best chance of acceptance and gave insight into how the offer should be made.

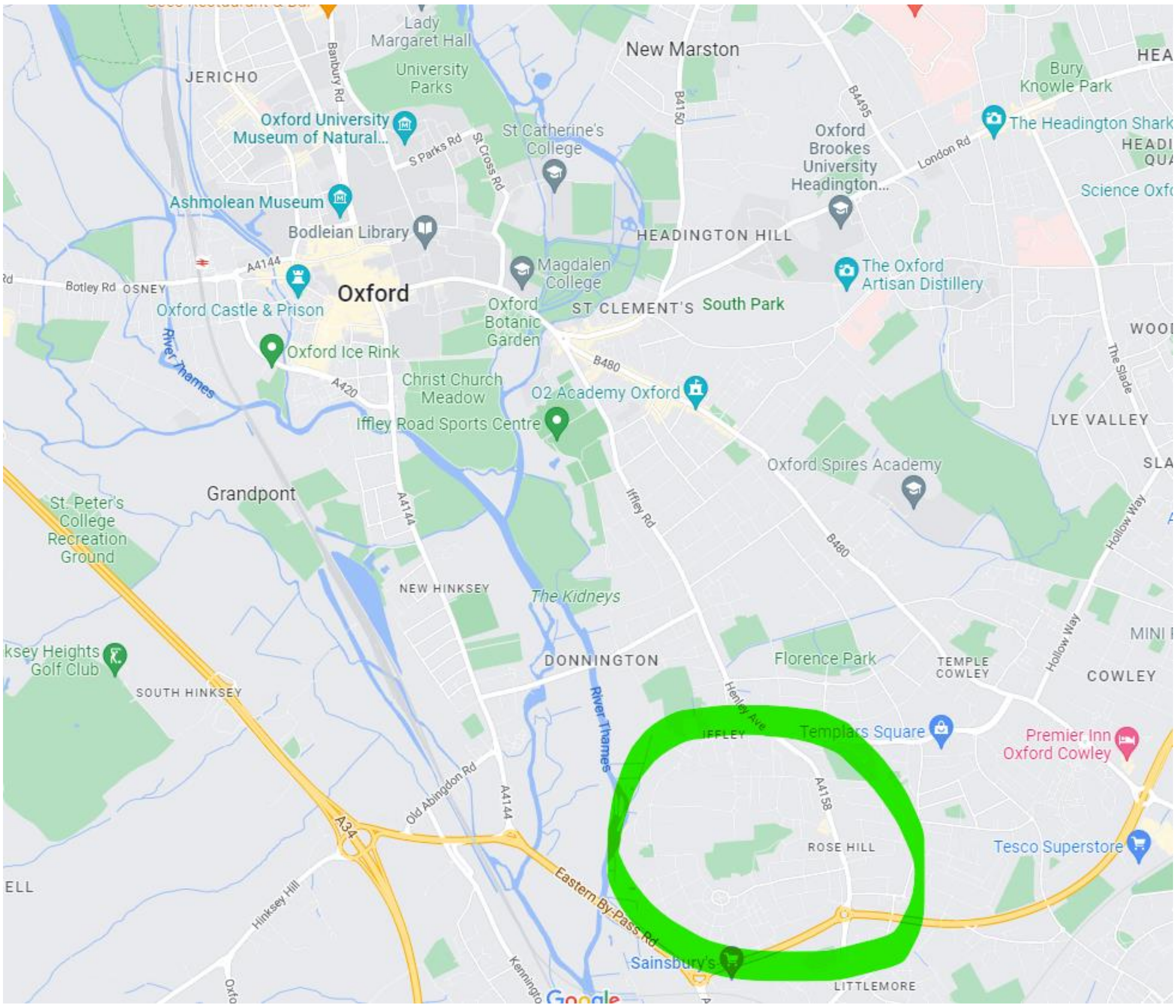

Figure 3: General location of our target area, Rose Hill and Iffley ward

To do this detailed analysis we used the LEMAP (local area energy mapping)[19] tool developed by Oxford Brooks University. This is a versatile mapping tool designed to be at the heart of a Local Area Energy Planning approach. Our methodology uses LEMAP to decide upon the locations for high-density deployment by using the tool to map, at postcode level, the capability of households to adopt a heat pump.

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[18] See detail of the socio-economic and demographic profile of the Rose Hill and Iffley ward on the Ward Profile pages of Oxford City Council's website: https://www.oxford.gov.uk/downloads/download/1228/ward_profiles_-_may_2021_onwards.

[19] Further detail on LEMAP is found in Gupta et al 2021. LEMAP is owned by Oxford Brookes and available for those interested in local area energy mapping. But it is not currently supported for anyone to use.

Our capability assessment includes consideration of technical suitability, likely economic circumstances, and social and digital characteristics of the household. Identification of suitable areas is a key part of the initial targeting phase of the methodology prior to recruitment.

Further data layers allowing targeting of the CHS offer include DNO data quantifying headroom of the secondary substation in the Rose Hill area, including household tenure. These data layers allow us to score and rank every postcode in Rose Hill on the basis of its suitability for a heat pump. The results are visualised and mapped, which allows for identification of target postcodes and even individual households. This mapping work can be replicated in any area of the country and is a way of identifying the areas where the chances of achieving a high-density deployment are higher.

Three aspects of evaluation were undertaken to identify appropriate postcodes for targeting heat pump installation. These were:

1. Dwelling suitability;
2. Socio-economic capability; and
3. Grid loading.

Dwelling suitability assessment
Each dwelling in Rose Hill was assessed for the following criteria based on EPC and Geomni[20] data:

- Wall, roof, floor energy efficiency must be above 'average' in EPC, that is not rated as very poor, poor, or average; and
- There cannot be single glazing as shown in the EPC.

After all the filters are applied, each dwelling was assessed as suitable or not suitable. Of 1457 buildings 44% (n=640 dwellings) were deemed suitable for ASHP installation.

3.3.3 Capability assessment

Capability assessment is based on the capability lens approach developed by the Centre for Sustainable Energy (CSE). The assessment helps to find out how likely households are to adopt different low carbon technologies (LCTs) and those who may be left behind based on their socioeconomic characteristics. It can give an idea of the technical, digital, financial as well as social propensity of the households to take up low carbon technologies.

The capability assessment in the LEMAP tool for Rose Hill was conducted using data from EPC, Geomni and Mosaic datasets for Rose Hill. The capability categories are described in more detail below:

Table 2: Levels of technical, digital, financial and social capability

No.	**Technical**	**Digital**	**Financial**	**Social**
1	Full potential - Fully capable of adopting multiple LCTs	High tech user - households with cutting-edge	Happy investor - households with the ability to invest in	Fully convinced - households that prioritise activities

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[20] Building age and building use data-www.geomni.co.uk

		hardware immersed in digital technology	LCTs without looking for a financial return.	towards the environment
2	Partial potential - capable of adopting some LCTs.	Tech. savvy - households composed of avid users of social media and smartphones that aspire to obtain cutting-edge hardware	Venturers - households with access to capital or funding to acquire LCTs and expect some economic payback or delay of payments	Motivated - households with some interest and knowledge on the effect of energy flexibility and LCTs on the environment
3	Need improvement - capable of adopting technologies if relevant improvements are made to the dwellings	Training required - households that only use digital technology for entertainment, shopping or practical purposes	Penny savers - households that depend on loans, grants, or programmes to implement LCTs or change life patterns towards energy flexibility	Sceptical - Households that need to be trained or guided to understand the benefits of implementing LCTs or making changes in their lifestyle to flex their patterns of energy use
4	Unsuitable - dwellings unsuitable for LCTs, such as listed buildings	Other priorities - households with limited, little or no interest in digital technology, preference given to non-digital approaches	Deprived - socially or economically deprived households with priorities beyond LCTs	Not interested - households with lifestyles that do not align with using LCTs

Each capability weight was summed for each dwelling in Rose Hill to create an overall capability grade for each dwelling. These are then summed within postcodes to order postcodes from high to low in terms of suitability.

3.3.4 Secondary substation considerations: analysis of potential network constraints

Another key element in identifying the areas that are most suitable to high-density deployment is the current level of network headroom. If there is little existing headroom then it is likely that reinforcement work would be needed before a high-density of heat pumps could be installed.

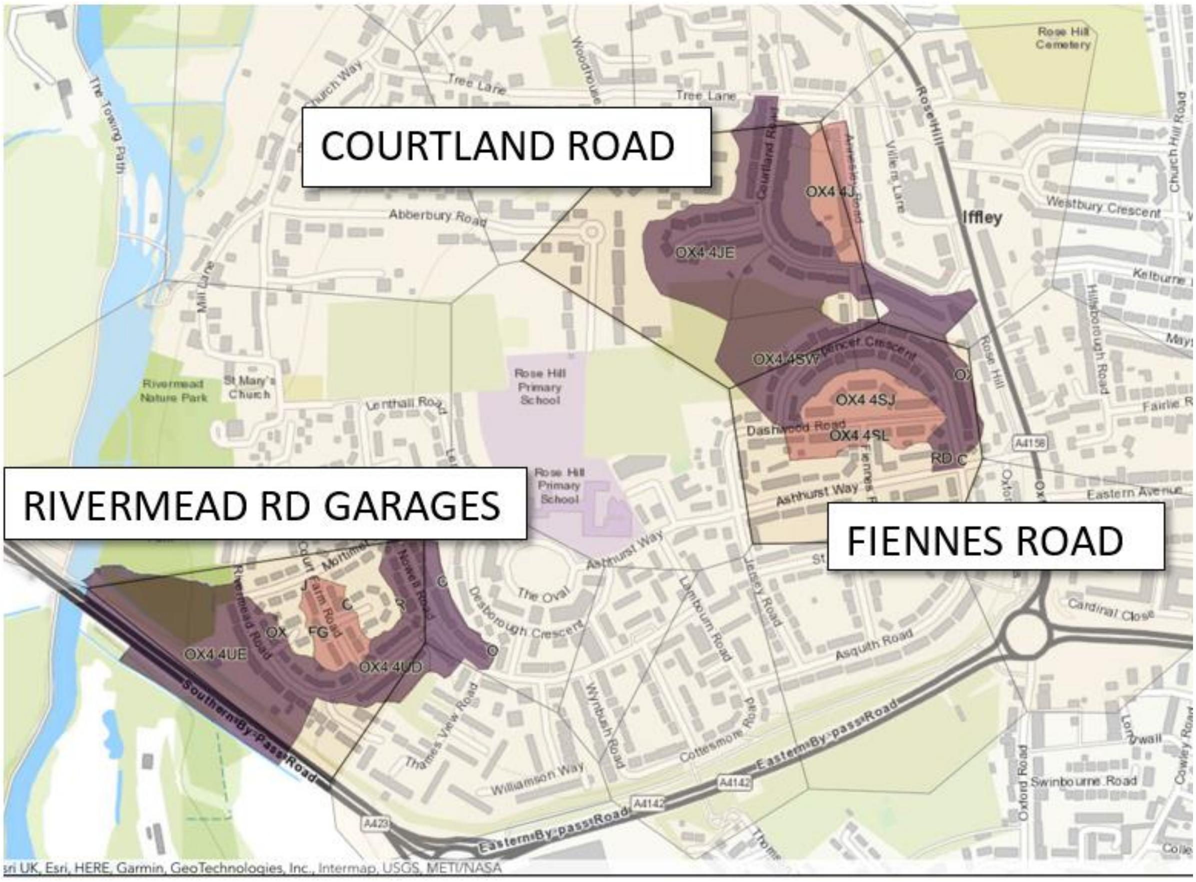
To assess this in our target area, high capability (i.e., priority) postcodes were grouped to find the secondary substations with the highest number of priority postcodes. These postcodes were also verified to have higher counts of suitable dwellings (from the capability assessment).

The following postcodes were identified across the following secondary substation areas:

1. **Courtland Road secondary substation** (postcode and total dwelling): OX4 4HZ (n=50 dwellings), OX4 4JE (n=34 dwellings), OX4 4JB (n=29 dwellings), OX4 4JH (n=20 dwellings)

2. **Fiennes Road secondary substation** (postcode and total dwelling): OX4 4SN (n=56 dwellings), OX4 4SW (n=32 dwellings), OX4 4SJ (n=25 dwellings), OX4 4SL (n=21 dwellings)

3. **Rivermead Road Garages secondary substation** (postcode and total dwelling): OX4 4TB (n=42 dwellings), OX4 4UE (n=33 dwellings), OX4 4UD (n=32 dwellings), OX4 4UL (n=19 dwellings)



sri UK, Esri, HERE, Garmin, GeoTechnologies, Inc., Intermap, USGS, METI/NASA

Figure 4 Targeted areas of Rose Hill derived from the capability analysis

These substations were then listed with relevant characteristics for engagement in the next phase of the project.

Table 3: Headline characteristics of the secondary substations

Courtland Road secondary substation	**Fiennes Road secondary substation**	**Rivermead Road Garages secondary substation**
• Level of loading: <40% • LV feeder 85-90% loaded • 162 customers total • Selected postcodes account for 80% of dwellings in secondary substation area • Dominate dwelling age band: 1920 – 1945 • Dominate tenure: owner-occupied • Mean fuel poverty 25-31% • Mean household income £44,000 – 52,000	• Level of loading: 40-60% • LV feeder not overloaded • 265 customers total • Selected postcodes account for 50% of dwellings in secondary substation area • Dominate dwelling age band: 1920 – 1945 • Dominate tenure: public rent • Mean fuel poverty 55-68% • Mean household income £19,000 – 23,000	• Level of loading: 60-80% • LV feeder not overloaded • 150 customers total • Selected postcodes account for 80% of dwellings in secondary substation area • Dominate dwelling age band: 1946-1954 • Dominate tenure: owner occupied / public rent • Mean fuel poverty 47-67% • Mean household income £22,000 – 29,000

3.4 Work stream 3: Methodology for householder engagement and recruitment

This work stream was led by Gengame. To achieve a high-density deployment we need to have an approach that will get sufficient people in a local area to sign-up-for and pay for a heat pump installation. To do this we firstly looked at current householder attitudes and barriers, and at what heat pump propositions are currently available. We then used householder journey mapping and value proposition canvases to develop householder propositions for our target area; together with a householder engagement and marketing strategy tailored for the local community.

3.4.1 Desk research on current state of the art propositions

Secondary research was carried out on existing propositions from competitors and other research projects together with published analysis of barriers and challenges facing heat pump uptake for householders. This information (See Desk Research Findings (external link)) was used for discussion points during the householder proposition workshop.

3.4.2 Householder proposition workshop

Partners took part in a 2hr workshop to discuss segmentation of the Rose Hill area residents, different financial propositions and engagement propositions. During this session a customer journey was mapped (Householder journey map - awareness and discovery phases – external link) focusing on the awareness and discovery phases. The outputs of these discussions (CHS workshop discussion notes – external link) were tested in the focus groups and used to create the targeted value propositions.

3.4.3 User research

Two sessions were arranged to conduct primary research with residents of the Rose Hill area.

Session 1

Eleven participants were split into two separate face-to-face two hour focus groups (Focus group 1 Discussion guide – external link) held in the Rose Hill area. (Focus group 1 Presentation – external link) The focus groups were designed to:

- Understand any previous experiences of heat pumps, the challenges and barriers; and
- Present heat pump information together with the aid of a mobile heat pump demonstration vehicle, to understand any concerns, and the most important information required to encourage heat pump uptake.
- Present financial propositions developed in the householder proposition workshop.

Session 2

Members of the Rose Hill and Iffley Low Carbon (RHILC) group took part in a 1.5 hr online meeting. The RHILC group was invited to this session due to their wealth of experience and knowledge of the community (Focus group 2 Discussion guide – external link). The session was designed to:

- Characterise the different neighbourhoods comprising the Rose Hill community; and
- Discuss engagement and recruitment methodologies specific to the Rose Hill area and the constituent neighbourhoods.

3.4.4 Development of digital recruitment/engagement plan and value proposition work

To create a recruitment/engagement plan, market research was conducted to identify possible digital networks and platforms to target the diversity of Rose Hill residents.

To develop a local/community engagement plan and innovative engagement strategies that work with social processes including facilitating social and peer to peer learning**,** we used innovative engagement methodologies using insights gained from the second focus group session and previous academic studies of social cohesion theories and processes.

To develop tailored value propositions for segments and communities we conducted four workshops to understand different segmentation groups and define different value propositions for each segment using value propositions canvases.

3.5 Work stream 4: Installer processes

The Work stream was led by SMS with input from Boxt Ltd and Samsung Electronics. The work stream's main tasks were to analyse and improve the processes from the initial expression of interest (end of recruitment phase) to post-installation monitoring and support:

- Analysis of current heat pump data and processes;
- Design, installation, post-installation support and monitoring activities, and
- Development of an improved methodology for these tasks.

The work stream participants explored many areas in the current process where significant improvement can be carried out resulting in time, resource and cost savings for the suppliers and cost saving for the householder. These savings are essential to allow deployment of the methodology to achieve a high level of uptake.

The process has 5 main stages:

- Input stage;
- Pre-design stage;
- Design stage;
- Installation stage;
- Post-installation stage.

Methodology for these is described further below.

3.5.1 Input Stage

The Input Stage was focussed on improving the data collection and process tasks. To use existing public databases (e.g., EPC data) to extract and process householder-assigned data and collect system-specific data directly from the householder. The collected and processed data will support the next stage.

3.5.2 Pre-Design Stage

The Pre-Design stage focuses on establishing a reliable heat demand calculator where the system will be able to determine the required heat pump and component sizes from the data from the Input Stage. Furthermore, the established mechanism will be able to generate proposals to the householder based on the result of the pre-design calculation, and the collected information from the Input Stage.

3.5.3 Design Stage

This is the first place where the householder and the supplier physically meet. The first task in this stage is to arrange a mechanical and electrical (M&E) survey with the householder, carry out a property survey to complete all necessary design calculations as required by the MIS3005 standard, and cross-check the correctness of the previously collected data, and real data. Lastly the Design Stage will confirm the previously offered system is correct, or place modification requirements in the proposal, and complete the MCS-compliant certificate requirement.

3.5.4 Installation Stage

The Installation Stage is focused on achieving the highest installation and system efficiency output. Using inputs from the Design Stage to produce a configuration file for the Unit to allow pre or remote configuration. We will also organise and quality assure the installer’s work.

3.5.5 Post installation Stage

Using in-situ monitoring data and customer feedback post-installation we will refine the configuration of the unit (using remote configuration capability) to improve efficiency and performance.

3.5.6 Technical feasibility of installation of smart control and monitoring systems

If there is existing headroom, an area might be currently suitable for high-density deployment, but network readiness can change quickly with today’s rapid uptake of other LCTs such as Electric

Vehicles and Solar PV. This piece of work assessed how heat pumps could be controlled to reduce the network impact of a high-density of heat pumps in a small area.

Samsung Heat Pumps can be installed with Wi-fi connectivity; and we identified two levels of remote control as part of our methodology:

1. The “static” control (with input from the DNO) will remotely configure the initial field-setting values (FSVs) as part of the commissioning process. Further FSV refinement (including but not limited to the weather compensation curve) occurs at two points post-installation:

   - Firstly, to check the hot water heating performance 1 month post installation;
   - Secondly, to check the space heating performance either 1 month post installation if during the heating season, or 1 month after the start of the heating season.

This check will comprise:

- Performance check using performance data retrieved from the heat pump via SmartThings APIs;
- User comfort check via call with the end user to discuss their heating and hot water experience;
- Remote changes to FSVs to improve performance and comfort.

This is a highly innovative approach as there is currently little innovation in FSV configuration to “keep things simple” for installers who currently configure settings manually.

2. Real time control of FSVs, including the water leaving flow temperature via a Samsung SmartThings cloud API. This allows advanced weather compensation and management to avoid network constraints.

4 Findings from Work Streams

4.1 Work stream 1: Project management

Principal finding from WS1 are as follows:

4.1.1 Need for a very broad range of partners and skill sets

We found that a very broad range of partners were required to deliver this challenging methodology and to minimise project risk. This is because the project aims to transform an entire supply chain and to work with actors representing all niches of the energy system – including universities, technology companies, landlords, local groups etc. We minimise risk in the project by making all these disparate actors, project partners – working towards a common goal.

4.1.2 Need for enterprise software to coordinate complex customer journeys

A second key finding was the need for enterprise software capable of managing the complex information and data flows (an Information and Data Management System (IDMS)). The technology partner should set-up the IDMS using an information and data management tool such as Amazon Web Services. The IDMS should include front-end allowing partners to log-on with different user roles to input and access information and data.

The IDMS should also support recruitment, including a data repository with details of each householder to manage the customer journey and to make data available to relevant parties that they need to carry out their tasks. Given that some of the data held within the IDMS will be personal data, the IDMS will need to include terms and conditions and a Privacy Policy, and the IDMS should follow current industry best-practice with regards to platform security[21].

4.1.3 The benefit of the 'Capability Lens' for targeting households

We have found that the "Capability Lens" developed by the Centre for Sustainable Energy and then elaborated in Project LEO offers a valuable conceptual framework to organise project activity. It has been particularly useful for understanding implications for disadvantaged, low income, vulnerable households.

The basic premise is that in order for households, businesses and organisations to participate in, and benefit from, the energy transition, certain capabilities are required. But these capabilities are unevenly distributed with the strong likelihood that disadvantaged communities and those on lower incomes and in vulnerable situations do not have requisite capabilities and are therefore at risk of being "left behind". Capabilities for participation by individual, organisational or community actors fall into the following domains:

- Technical (e.g. possession of a generation asset);
- Economic (e.g. financial resources to invest in assets);
- Lifestyle/operational (e.g. ability to shift demand without detriment);
- Skills and motivation (e.g. digital skills);
- Social capital (e.g. sharable skills and insights, normative approval)[22].

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[21] https://docs.aws.amazon.com/wellarchitected/latest/security-pillar/welcome.html

[22] See Banks and Darby (2021)

4.2 Work stream 2: Segmentation and analysis of energy demand

Work stream 2 had three main components:

1. Demand profiling and segmentation;
2. Mapping target areas; and
3. Understanding technical and social capability to flex demand from heat pumps.

Findings from each of these work areas are summarised below.

4.2.1 Demand profiling and segmentation

The aim of this work was to:

- Produce a "translation algorithm" which will allow us to convert half-hourly gas data to the expected half-hourly additional electricity usage which will result from that home getting a heat pump;
- Produce an "expected demand profile algorithm" that is able to take a home's estimated heat demand (from our heat demand modelling work) to produce an estimate for the expected half-hourly additional electricity usage from a heat pump; and
- Link distinct demand profiles to explanatory socio-economic and demographic data in the form of the ACORN classification.

These algorithms allow us to estimate what the half-hourly electricity demand will be following installation of a heat pump, which then allows us to:

- Map demand profile to postcode via the ACORN classification which is known for every postcode in the target areas;
- Work with suppliers to see whether a cheaper flat rate tariff can be offered (where half-hourly profiles are less "peaky" than an existing profile class (e.g. Profile class 1[23]);
- Provide an estimate to the householder of the running costs of a heat pump and how they compare to the alternatives;
- Work with the DNO to see how many heat pumps can be accommodated on the local grid with and without flexibility (static and dynamic flex described in work stream 3);
- Design interventions to change the shape of a demand profile if aggregations of a particular demand profile could prove problematic for network management;
- Interventions can be informed by the socio-economic and demographic data shaping the profile (via the ACORN and MOSAIC classification of each postcode in the area), alongside using the spatial maps of technical, digital, social and economic capability generated by Oxford Brookes University.

Our methodology to derive energy demand profiles and link these to household "segments" produced a number of findings:

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[23] Profile classes are what is currently used to allocate consumption to half-hour settlement periods for customers who are not half-hourly settled. If a supplier chooses to settle a customer based on their actual half-hourly usage, the supplier can save costs (and therefore offer a cheaper rate) if the actual profile comprises less usage during more expensive periods than would have been the case had the usage been allocated using the profile class shape - https://www.elexon.co.uk/knowledgebase/profile-classes/

1. We have demonstrated that demand profile segmentation of gas / electricity consumption and calculation of changes to an energy demand profile resulting from adoption of a heat pump is possible - although computationally onerous[24] if large samples are used. However, larger samples are highly desirable in creating more accurate and robust analysis. In a demonstration phase we recommend using larger samples and running the analysis on super-computers.
2. Our methodology allows us to match a demand profile to any postcode in the UK so long as we have an ACORN classification for the postcode. Consequently, we have been able to match a likely demand profile to each of the Rose Hill postcodes.
3. Using regression analysis, we can identify the relative influence of key demographic / socio-economic variables (e.g. presence of children) on membership of our 6 demand profile types. This will be done as part of the demonstration of the methodology.
4. Scrutiny of the demand profile and associated CoP allows us to identify appropriate interventions which could change the shape of the demand profile so as to achieve network management and carbon benefits as well as financial benefits to the household. For example:

    - Low CoP is indicative of poor insulation standards. The property could be targeted for insulation works.
    - A period of high demand can be identified as beneficially shifted to another time period to reduce carbon emissions and/or take advantage of cheaper electricity and/or assist with management of the network and mitigation of network constraints (especially when the particular demand profile is common to multiple postcodes connected to a particular constrained part of the network).
    - Peaks during periods of high carbon intensity and cost can be identified and interventions developed to reduce the peak size.

5. Because we can combine information about the demand profile with data on the digital, social, and technical "capabilities" of the household and its geographical location, we can design interventions which have the best chance of shifting or changing demand. For example, a bespoke Time of Use (ToU) tariff could be developed to facilitate a shift of high demand to another period. When combined with information about the likely technical and digital capabilities of the household the ToU offer can be tuned to match those capabilities - for example the ToU offer can be bundled with the offer of insulation to allow a preheating strategy and therefore a heating demand shift which does not impact comfort and could also save the household money.

6. Our methodology allows the mapping of demand profiles to postcode where postcode also indexes other data including ACORN and MOSAIC classifications, capabilities, income levels and other socio-technical information. Thus value propositions can be intelligently developed and targeted at specific postcodes allowing a hyperlocal energy plan and strategy to be developed. This will be done as part of the demonstration of the methodology.

7. We can project electricity consumption once a heat pump is installed for a postcode or for percentage of the buildings in that postcode using the segmentation method described above. However, we think a potentially less computationally onerous method would be to use the thermal model developed by SMS. The SMS model calculates electricity demand for a heat pump

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[24] Sample sizes of several thousand cases could take up to two weeks to process using a conventional desktop computer.

to heat a defined house type with known floor area and efficiency levels but assumes that the entire space is heated to the comfort temperatures 24/7: a demand profile is not assumed by the model.

Whilst this is not how an actual home would be heated, the approach does have the advantage of calculating electrical heating demand for a worst-case scenario i.e. where the heating is run continuously. This worst-case scenario approach is better aligned with DNO risk assessment and load profiling methodologies used to manage new connections and to determine stress on network assets. However, the approach has the disadvantage that without a demand profile underpinning the calculations and information about the capabilities and demography of the household it is more difficult to design effective smart interventions facilitating demand shifts, peak shaving etc.

4.2.2 Mapping and targeting findings

In the feasibility stage we used the LEMAP tool for mapping and targeting suitable homes for heat pump deployment in the Rose Hill area in Oxford. We have found that the LEMAP tool allows us to map, at postcode level, the capability of households to adopt a heat pump through the CHS programme.

Our capability assessment included consideration of technical suitability, likely economic circumstances, and social and digital characteristics of the household. Further data layers allowing targeting of the CHS offer include DNO data quantifying headroom of the secondary substation in the Rose Hill area and also household tenure. These data allowed us to score and rank every postcode in Rose Hill on the basis of its suitability for a heat pump.

The results were visualised and mapped allowing identification of target postcodes and even individual households. Because we have data identifying both capabilities and wider priorities of the householder our approach allowed us to develop value propositions which can be targeted at individual postcodes and clusters of postcodes sharing the same attributes.

Based on the analysis, we identified three secondary substation catchment areas in our general target area. Each of the substations have different levels of loading with a mixture of owner-occupier, social housing and privately-rented dwellings.

4.2.3 Analysis of potential network constraints and technical feasibility of installation of smart control and monitoring systems

This task was addressed in three ways:

- Data identifying network constraints in our target areas was requested from SSEN and mapped;
- Various systems capable of flexing heat pump demand were researched and recommendations made for deployment in Phase 2;
- A brief evidence review was conducted to consider the technical, digital and social capabilities that are required by households to flex their heat pump demand.

These findings are discussed below:

Provision of data identifying distribution of network constraints. Mapping of Network Constraints
During the formation of our consortium to bid for the project we invited the local DNO SSEN to join the consortium. At the time they had been asked to join a number of consortia and therefore said: "As you can see we have decided not to partner with any specific proposal at this stage but will provide letters to all bidders that approach us allowing us to support all our stakeholders equally."

Oxford University and Oxford Brookes had existing contacts at SSEN from their work on Project LEO which was led by SSEN. Through these contacts we set up initial meetings, but it was only following the Carbon Trust workshop in August that we found the right contact within SSEN who was able to provide initial loading data. Following that, SSEN provided initial data on the loading of the secondary substations in the entire Rosehill and Iffley area[25]. We used this data as part of our suitability mapping approach described in more detail later in the report. This data gave us an initial level of assurance that we can achieve the 25% identity deployment in the three selected areas.

However, the data provided is not completely up-to-date, and it only includes data on overall loading, and not on voltage drop or harmonics. We are very pleased that SSEN has decided to join our consortium for Phase 2. If we are successful in our application, SSEN will immediately redeploy existing LV network monitoring devices to the transformers being targeted to provide visibility to all parties of network demand impacts.

Another issue identified towards the end of the feasibility stage was that older networks are very complex as over the years the connections of homes to secondary substations have been switched to support balance loading or to power other parts following faults. As a result, immediate neighbours on a street are often connected to different secondary substations. This will make recruitment more difficult if the methodology does not allow some flexibility to accept homes which are connected to a non-targeted secondary substation.

It is often difficult to know who to contact at a DNO when working on an innovation project. It would therefore be useful if DNOs could provide a page on their website with contact details for different kinds of innovation project. Alternatively, there could be an innovation mailbox, which could direct queries to the correct contact at the DNO.

Technical, digital, economic and social capability to deliver flexibility from heat pumps
As part of our feasibility work in work stream 2 we conducted an evidence review to assess the technical, digital, social and economic capabilities that may be required to deliver flexibility from heat pumps. The full evidence review is provided in Appendix 4: Evidence review: delivering flexibility from heat pumps. Principal findings and how these findings were used in the development of the methodology are reported here:

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[25] SSEN have enthusiastically engaged in the project and have signalled their wish to become a partner in any subsequent implementation of the methodology. We speculate that this is because engagement with projects of this type allows SSEN to develop the protocols and operational systems needed as they transition from DNO to DSO. This transition entails fostering new working relationships with end users of the network. In the context of dense deployment of heat pumps this means actively assisting with the development of solutions to network issues caused as a result of multiple new connections being sought in a constrained area. This is shift from previous practice where active involvement in solution development using, for example technologies to flex demand, would not usually have been part of their operational practice.

1. There is a clear need for heat pumps to be operated flexibly if government decarbonisation targets are to be met. Flexible operation of heat pumps could shift electricity demand away from peak periods and could also provide other useful services as part of a decarbonising energy system, such as response and reserve services and load shifting to support increased penetrations of variable renewables (Turvey, Clarke and Calder, 2018; Rosenow et al., 2020; Vaillant and geo, 2022).

2. The need for flexible operation of heat pumps therefore originates with the needs of the electricity system, but it has the potential to impact on households in multiple ways. As such, it will depend on successfully engaging households to be both technically effective, and just or fair. To aid our understanding of how to engage households with the "offer" of flexible heat pump operation we have reviewed the range of social, technical, digital and economic "Capabilities" that can support the flexible operation of heat pumps in homes[26]. Findings on Capability were used to develop the evidence base for the approach and provide rationale for the spatial Capability analysis of our target areas produced by Oxford Brookes University.

3. Technical capability
   Greater levels of building insulation and thermal mass can support the flexible operation of heat pumps by helping to maintain indoor temperatures despite reduced electricity supply to heat pumps (Vaillant and geo, 2022). Retrofitting building fabric insulation can therefore increase the potential for heat pump flexible operation, as well as reducing heat pump peak demand and impact on the low voltage network.

   Our recommended pre-install survey will pick up details of the building fabric. The associated analysis will explicitly address the technical ability of the home to store heat and have detail on appropriate insulation measures. The findings of the technical survey will be communicated face to face with the householder in jargon free language and all options discussed allowing an informed decision on whether to install the heat pump.

4. Digital capability
   Households will need access to appropriate smart meters and home broadband to engage with Demand Side Response (DSR). It is recognised that the reliability of home broadband connections can also limit DSR reliability (Frontier Economics, 2015; NEDO, 2017; Sweetnam et al., 2019). Capabilities to engage with different types of user-facing controls are also key to households actively engaging with DSR. For example, low engagement with Direct Load Control events occur where systems are controlled via an app, and many households report low desire or ability to engage with apps (Calver, Mander and Abi Ghanem, 2022).

   This finding suggests that the flexibly operated heat pump value proposition and the design of application interfaces should account for poor digital capabilities among residents. Consequently, we have recommended in our methodology a community survey of the area which will measure and map digital capability of residents amongst other community attributes. This will allow the offer to be developed and framed in accessible language. Solutions for working with poor digital capability including interface design should also be developed in follow up focus groups/ workshops.

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[26] Our study draws on the "Capability Lens" developed by the Centre for Sustainable Energy and then elaborated in Project LEO. See Banks and Darby (2021).

5. Financial capability to bear financial risk
   If DSR signals involve time varying pricing there is a risk that households may pay more for electricity if they do not sufficiently flex the operation of heat pumps (and potentially other electrical loads). Some households will have greater capability to bear this risk than others because of their financial situation. There is also a risk that households with less financial capability feel compelled to flex electricity use in response to time varying pricing, even though this may have negative impacts in other ways (Crawley et al., 2021).

   Bill calculators can also be used to offer households an idea of whether they will save money on time varying pricing, but their effectiveness depends on households being able to predict the extent to which they will be able to flex demand, which may not be possible for novel loads like heat pumps.

   These findings emphasize the importance of taking an ethical approach in the development and implementation of our methodology. For this reason, we have recommended, as part of our methodology, that a document setting out the ethical principles that guide project activities should be produced. The document should describe how ethical principles translate into practices on the ground. For example, households that are judged vulnerable or incapable of shifting demand will be referred, with the householders consent, to the Better Homes Better Health advisory service provided by Oxfordshire County Council and the in-home visits to talk through options will be sensitive to these kinds of issues.

   Other implications from these findings are that the survey processes and bill calculation tools we have developed in our methodology should become sensitive to the demand profile of the occupants and their capability to shift demand if incentivised to do so through adoption of e.g. a Time of Use tariff.

6. Personal/social capability
   This form of capability describes the knowledge and understanding of DSR and low carbon technologies and ability to shift energy demand without detriment. Flexible operation of heat pumps was automated in some way in all studies reviewed. Nonetheless, these studies indicate that the technical effectiveness of heat pump flexible operation can be limited if household members are not effectively made aware of or do not fully understand direct load control of their heat pumps or automated responses to time varying pricing. Equally importantly, this can risk fairness to households and their trust in DSR over the longer term.

   This finding suggests that an in-home visit by the project officer several weeks after installation to build knowledge of the optimal operation of the system should be recommended as part of our methodology.

7. It also suggests that very clear guidance on use of the heat pump should be left with the household as a reference. Other support and information should be made available too. For this reason we have recommended that a moderated on-line user group be set up where Clean Heat Street participants can crowd source solutions to any problems they may have and also gain social and normative support from other project participants.

8. Social capability: Trust in DSR and low carbon technology/innovation offers

In general, trust in DSR offers may be reduced when households have concerns around privacy and autonomy connected to direct load control and suppliers' motivations for pursuing it (AECOM, 2011; Bartusch et al., 2011; Wiekens, van Grootel and Steinmeijer, 2014; Lopes et al., 2016). Trust may be promoted through transparency around the timing and purpose of direct load control (DLC) or automation (Lopes et al., 2016) (Buchanan et al., 2016; Lebosse, 2016) (Carmichael et al., 2014; Wiekens, van Grootel and Steinmeijer, 2014), as well as through providing information on DSR from independent sources (Hall, Jeanneret and Rai, 2016) and involving trusted actors in recruitment (Bird, 2015; Western Power Distribution, 2016).

For these reasons, we have recommended in our methodology that a dedicated officer should be appointed by the Local Authority to be the first point of engagement with the project. Local Authorities are embedded, familiar and have no commercial incentives in their work. Therefore they are more trusted than commercial entities and many of the engagement barriers associated with an unknown or untrusted messenger do not arise. Findings on this topic also highlight the need to engage with other trusted middle actors such as housing associations and local community groups. Recommendations for this have also been incorporated into our methodology.

4.3 Work stream 3: Engagement key findings

4.3.1 Desk research and householder proposition workshop key findings

Prior to primary research, desk research was conducted to understand the existing information barriers for heat pump up-take from previous published reports to test these findings with participants in focus groups from the target and inform questioning. Full details can be found in the Desk research document (external link). Key findings for barriers to heat pump up-take from desk research were:

- Insufficient knowledge of heat pumps and how they work;
- Upfront costs of installation heat pump;
- Hidden costs for any property alterations;
- Energy bill may not be lowered;
- Property suitability, if the home is poorly insulated for space restrictions;
- Performance and efficiency, the heat pump performance will be lower compared to gas boiler; and
- Inconsistent and lack of trustworthy advice

These findings were consistent with insights gained from the focus groups and with the finding from Ipsos Mori in Stream 3 (HPR Deliberative Workshop Evidence Summary Report – external link). During the householder proposition workshop, the partners discussed findings from the desk research and created a householder journey map to understand "Touchpoints and Pain points" customers may go through when thinking about potential heat pump installation. (Customer journey - awareness and discovery phases – external link).

Different parts of the journey were analysed taking into consideration a variety of different user cases with ranging circumstances, including tenure types (social housing tenants, private renting, and homeowners) and socioeconomic status. From this analysis potential opportunities and solutions were formed and used to develop value propositions. The segments we defined for the different value propositions were:

1. Owner occupiers;
2. Social Housing Landlords;
3. Private landlords; and
4. Tenants.

The results of the value proposition work are shown in Appendix 4: Evidence review: delivering flexibility from heat pumps

Below we provide the evidence review underpinning our findings on the behavioural and technical bases for delivering heat pump flexibility. The review was conducted by Dr Bryony Parrish at the Energy Group, Environmental Change Institute, University of Oxford.

Technical, economic and social capability to deliver flexibility from heat pumps
The deployment of electric heat pumps in UK households is expected to increase dramatically as part of heat decarbonisation (HM Government, 2021). As most UK home heating is currently provided by burning natural gas in individual boilers, the associated increase in peak electricity demand will pose challenges for electricity system operation by increasing the requirement for electricity generation and network capacity (Turvey, Clarke and Calder, 2018; Wilson, Taylor and Rowley, 2018). Flexible operation of heat pumps could reduce this requirement by shifting electricity demand away from peak periods; it could also provide other useful services as part of a decarbonising energy system, such as response and reserve services and load shifting to support increased penetrations of variable renewables (Turvey, Clarke and Calder, 2018; Rosenow *et al.*, 2020; Vaillant and geo, 2022). This short review focusses on evidence relating to shifting heat pump electricity demand away from peak periods because this is likely to be of more relevance at the distribution network level, and it is also the focus of the majority of evidence identified.

The need for flexible operation of heat pumps therefore originates with the needs of the electricity system, but it has the potential to impact on households in multiple ways; as such, it will depend on successfully engaging households to be both technically effective, and just or fair. To aid our understanding of household engagement, this work stream documents a range of capabilities that can support the flexible operation of heat pumps in homes. The capabilities approach is useful because it helps us to consider the influence of a holistic range of factors influencing the potential for heat pump flexibility at the household level: from technical and material, to financial, personal, and social (Roberts et al., 2020). It also helps us to consider how relevant capabilities may be distributed between households as users of heat pumps, and providers of flexibility services via the ways in which their offers may be designed and delivered (Banks, 2021). For brevity, this document refers to these two categories as ‘household-side capabilities’ and ‘supplier-side capabilities’ respectively.

The discussion is structured in two parts. The first part relates to capabilities that can support engagement with different forms of demand side response (DSR) – in other words, the mechanisms (such as time varying pricing, automation, or direct load control) that may be used to signal the timing of heat pump operation and respond to these signals. Such capabilities include, for example, access to enabling technologies and the ability to bear financial risk. This first section focuses on evidence related to household engagement with DSR in general, as well as evidence on DSR involving heat pumps. The second part relates to capabilities that can support changing the timing of heat pump operation in response to electricity system needs. These include, for example, the level of thermal storage provided by building fabric insulation. Reflecting the evidence identified, this relates only to flexing the timing of space heating, not domestic hot water provision

Capabilities for engaging with demand side response (DSR)
In general, DSR can involve manual demand shifting (in response to time varying pricing, or more rarely, information provision), direct control of household appliances or 'loads' by external parties (often known as direct load control or DLC), or automated response to time varying pricing (Parrish et al., 2020). None of the studies reviewed here involve manual demand shifting, which may reflect that heating is already largely automated via for example timers and thermostats, as well as that flexible operation of heat pumps may involve smart automation such as pre-heating. In BAU applications of DLC (many with AC in the US) households have typically been financially rewarded for participation (though this seems not to be the case in the trials reported here). The characteristics of different forms of DSR will influence the capabilities that are relevant to engaging with them, which are discussed further below.

Digital/technical: Access to, and capabilities to engage with, different types of digital technologies
Households will need access to appropriate smart meters and home broadband to engage with DSR. It is recognised that the reliability of home broadband connections can also limit DSR reliability (Frontier Economics, 2015; NEDO, 2017; Sweetnam et al., 2019).

Capabilities to engage with different types of user-facing controls are also key to households actively engaging with DSR. For example, within NEDO low engagement with pre-opt out of DLC events occurred because this function could only be performed via an app, and many households reported low desire or ability to engage with the tablet provided as part of the trial (Calver, Mander and Abi Ghanem, 2022). On the supplier-side, the design of user-facing controls can therefore strongly influence households' capability to engage with DSR in the intended ways. It can also influence perceived control, with potential implications for acceptance of DSR. For example, the EcoGrid EU (2016) evaluation found that participants with more control options felt more positive about DLC, although they did not override control any more frequently than other groups. Conversely, Sweetnam et al. (2019) describes participants feeling a lack of control because their user interface did not provide any feedback on the timing of temperature changes when they make adjustments to heating schedules; similarly, Calver, Mander and Abi Ghanem (2022) found some households preferred their previous analogue temperature controllers (such as pin controllers) that clearly showed the heating schedule.

Financial: Capability to bear financial risk
If DSR signals involve time varying pricing there is a risk that households may pay more for electricity if they do not sufficiently flex the operation of heat pumps (and potentially other electrical loads). Some households will have greater capability to bear this risk than others because of their financial situation. There is also a risk that households with less financial capability feel compelled to flex electricity use in response to time varying pricing, even though this may have negative impacts in other ways (Crawley et al., 2021).

DSR providers can support the capability to bear financial risk by offering shadow billing/bill guarantees. In this arrangement, households are able to trial time varying pricing for a defined

period of time with the guarantee that they will not be charged more than they would have been charged on a flat rate (Parrish et al., 2020). Bill calculators can also be used to offer households an idea of whether they will save money on time varying pricing, but their effectiveness depends on households being able to predict the extent to which they will be able to flex demand, which may not be possible for novel loads like heat pumps.
Financial risk can also be reduced through developing household-side and supplier-side capabilities that support flexible heat pump operation, as described above, and through DSR offers do not involve time varying pricing. Financial incentives or rewards for DSR can still be offered through, for example, payments for participating in DLC for reducing demand below a calculated baseline during defined peak periods.

Personal/social: Knowledge and understanding of DSR
Flexible operation of heat pumps was automated in some way in all studies reviewed. Nonetheless, these studies indicate that the technical effectiveness of heat pump flexible operation can be limited if household members are not effectively made aware of or do not fully understand direct load control of their heat pumps or automated responses to time varying pricing. Equally importantly, this can risk fairness to households and their trust in DSR over the longer term.

Frontier Economics (2015) and Calver, Mander and Abi Ghanem (2022) suggest that low awareness of when DLC is happening – and, in the case of Calver, Mander and Abi Ghanem (2022), what DLC actually entails – can lead to households unintentionally overriding DLC events by interacting with thermostat controls. Similarly, Sweetnam et al., (2019) reported households overriding automated responses to time varying pricing. It is not clear whether this resulted from a lack of understanding or knowledge of DSR, issues with thermal comfort, or both. However, Sweetnam et al., (2019) also note that night-time operation can cause confusion about whether system was operating incorrectly or wasting electricity, which does indicate a lack of understanding of pre-heating.

Overriding by households has the potential to limit the effectiveness of heat pump flexibility from the electricity system perspective, and in the case of automated response to time varying pricing, risks households paying higher bills. Low knowledge and understanding of DSR is also a risk to achieving fairness and justice in the implementation of heat pump flexibility (Calver, Mander and Abi Ghanem, 2022); to households' trust in DSR over the longer term (Parrish et al., 2020); and to the extent to which we can conclude, based on trial data, that households would be accepting of DLC as part of a wider roll out (NEDO, 2017; Parrish, Hielscher and Foxon, 2021).

In CLNR, participants were unaware of the timing of DLC because the controls/user interface were not designed to notify participants of when events was happening (Frontier Economics, 2015). In the NEDO trial, households had low awareness of DLC overall, which resulted from a combination of factors (Calver, Mander and Abi Ghanem, 2022). DLC was implemented by default when households accepted heat pumps as part of the trial. At the start of the trial, households often felt overwhelmed by information, and although written information about DLC was provided in a booklet along with information about heat pumps and other aspects of the trial, this may have been too lengthy and unclear to be useful. Households were unable to opt-out from DLC altogether, and although they were notified of and able to pre-opt-out from individual DLC events, as discussed above these functions were only available via an app that few participants actually engaged with. Participants could also opt-out from DLC by adjusting the thermostat while DLC events were taking place, but as in CLNR, the absence of effective notification means they may have been unaware that this is what they were doing.

On the supplier-side, households' knowledge and understanding of DSR could therefore be supported through more effective design of user interfaces (considering what information is provided, and through what means) and through more effective provision of information (which could helpfully include follow up information provision over the course of the trial, as well as clearer signposting of relevant information in written brochures or other materials). More generally, evidence from these studies indicates that it is important for households to have some knowledge and understanding of heat pump flexibility even when this is mediated by automation or DLC (i.e. does not require manual demand shifting). This will likely need to be combined with other capabilities that support flexible heat pump operation, as described above.

Social: Trust in DSR offers

In general, trust in DSR offers may be reduced when households have concerns around privacy and autonomy connected to direct load control and suppliers' motivations for pursuing it (AECOM, 2011; Bartusch et al., 2011; Wiekens, van Grootel and Steinmeijer, 2014; Lopes et al., 2016). Trust may be promoted through transparency around the timing and purpose of DLC or automation (Lopes et al., 2016) (Buchanan et al., 2016; Lebosse, 2016) (Carmichael et al., 2014; Wiekens, van Grootel and Steinmeijer, 2014), as well as through providing information on DSR from independent sources (Hall, Jeanneret and Rai, 2016) and involving trusted actors in recruitment (Bird, 2015; Western Power Distribution, 2016).

When considering trust in flexible operation of heat pumps specifically, it is worth noting that many of the studies reviewed were conducted in the context of social housing. Engagement with DSR is therefore likely to be based on existing trusted relationships with social housing providers, and as described above, may involve low awareness of DSR amongst households; in turn, this may contribute to relatively low levels of reported concern about loss of control, data privacy and similar issues (Calver, Mander and Abi Ghanem, 2022). However, it should be noted that not implementing DSR in a transparent way risks damaging trust in the longer term, both within households and through reputational effects (Parrish et al., 2020).

Capabilities for flexing the operation of heat pumps

In contrast to the previous section, which related to capabilities for engaging with different forms of demand side response (DSR), this section discusses capabilities relevant to engaging with actually shifting heat pump electricity demand in time. It first considers capabilities on the household-side: that in some way increase thermal storage, thus decoupling changes in electricity demand from changes in heat provision in the home, and that support living with changes in home heating resulting from heat pump flexibility. It then discusses how the design of heat pump flexibility offers might support household engagement with heat pump flexibility, and supplier-side capabilities that may be required to manage heat pumps' impact on the low voltage network as a result of such changes in heat pump flexibility offers.

Household-side capabilities that may increase potential for flexible operation of heat pumps

Technical/material and financial: access to thermal storage

Greater levels of building insulation and thermal mass can support the flexible operation of heat pumps by helping to maintain indoor temperatures despite reduced electricity supply to heat pumps (Vaillant and geo, 2022). Retrofitting building fabric insulation can therefore increase the potential for heat pump flexible operation, as well as reducing heat pump peak demand and impact on the low voltage network. Dedicated thermal storage, in the form of hot water buffer tanks or heat batteries utilising phase-change materials, can also support heat pump flexibility (Rosenow et al., 2020; Vaillant and geo, 2022). Some homes will have existing hot water buffer tanks that can be used for this purpose, but many homes in the UK have removed hot water tanks after installing combi-boilers (Sweetnam et al., 2019). Additional thermal storage could be added alongside heat pump installation, but requires sufficient space; this suggests a possible link between the size of homes and the affluence of households, and their capabilities for heat pump flexibility (Crawley et al., 2021). Phase-change material heat batteries are both smaller and lighter per unit of heat stored, which can make them easier to fit into homes (Energy Saving Trust, 2022).

Technical/material, personal and social: capabilities that support living with changing heating patterns

Flexible operation of heat pumps has the potential to change the indoor temperatures experienced by households, as well as the noise of heating system operation at different times. Amongst the studies reviewed, pre-heating is a notable control strategy in this regard. This involves increasing indoor temperatures in advance of DSR events, in order to limit any drop in temperature below users' settings during DSR periods (Turvey, Clarke and Calder, 2018; Sweetnam et al., 2019). While the emphasis is on maintaining minimum indoor temperatures during peak demand periods, pre-heating can also have the effect of increasing indoor temperatures during night-time and daytime periods, as well as creating noise from heating system operation at those times (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021). This control strategy may therefore require capabilities that enable households to avoid, tolerate or appreciate higher room temperatures and any noise from heating system operation at these times. More constant operation can also improve the efficiency of heat pump operation independently of demand shifting, so such capabilities can also support more efficient heat pump operation in general.

Day-time heating: Although many UK households typically do not heat homes during the day time, even if they are at home (Hanmer et al., 2019), more constant daytime heating may be appreciated by households who spend time at home during the day or enjoy warmer temperatures when returning home in the evening (Parrish, Hielscher and Foxon, 2021; Calver, Mander and Abi Ghanem, 2022). Households who already heat homes during the daytime can also benefit because the technical characteristics of heat pumps may allow this heating schedule to be provided at lower cost than alternatives such as gas boilers. Understanding that, in contrast with gas boilers, more constant operation of heat pumps can reduce running costs may help households to appreciate daytime heating (Sweetnam et al., 2019).

Night-time heating: households often find sleeping in warmer temperatures uncomfortable; pre-heating during night-time can therefore be supported by capabilities that allow households to avoid experiencing warmer temperatures within bedrooms, including the presence and use of thermostatic radiator valves on bedroom radiators, as well as sufficient thermal insulation between rooms (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021). These capabilities could be enhanced through installing thermostatic radiator valves and supporting households to use them effectively. It may also be helpful to assess levels of internal thermal insulation and, where appropriate, discuss the possibility that households may experience higher night-time temperatures, whether this is something they are willing to try, and what strategies they might use to respond. For example, opening bedroom windows can help to avoid the experience of night-time heating

(Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021) but will reduce heating system efficiency and would preferably be avoided.

Capabilities to avoid or tolerate noise from night-time heating operation can also support this form of pre-heating (Parrish, Hielscher and Foxon, 2021). Different people have different sensitivities to noise while sleeping, but these capabilities could potentially be enhanced if it is possible to locate heating equipment – including heat pump units, but also central heating pumps – at a greater distance from bedrooms.

While the logic of pre-heating is to limit decreases in internal temperature, if there are unavoidable impacts on household comfort it may be useful to consider changing the offer by reducing the extent of pre-heating and allowing indoor temperatures to drop to some extent (Sweetnam et al., 2019). Even when pre-heating was not applied, control strategies applied in the reviewed studies were limited: for example, in the NEDO trial DLC automatically ended if room temperatures fell below 18°C or more than 2°C below thermostat set temperature (NEDO, 2017). However, as noted by Crawley et al., (2021), while this function is designed to protect customers it also has the effect of reducing their agency to choose when and how flexibility is provided. Thus, it may also be useful to consider which capabilities may enable households to tolerate decreases in room temperature in peak demand periods, during, for example, a limited number of critical periods each year.

Evidence related to DSR more generally suggests that capabilities to support this may include the availability of alternative sources of heating such as fireplaces (VTT, 2004; Lebosse, 2016) or the ability to spend time outside the home during DSR events (Strengers, 2010; Carmichael et al., 2014). More broadly, Strengers (2010) observed that flexible operation of AC in Australia was supported when households had maintained knowledge and skills in traditional ways to keep cool at home, which provided alternatives to AC use. In the context of heating, this might include, for example, access to and willingness to use warm indoor clothing and slippers. However, any such approach would need to ensure avoidance of any negative impacts on households – including the possibility that less affluent households may feel pressure to participate in DSR despite possible negative impacts (Crawley et al., 2021) and the potential for detrimental health impacts, particularly for household members such as young children, older people or people with limited mobility or existing health conditions.

Supplier-side capabilities relevant to flexing the operation of heat pumps

Suppliers of heat pump flexibility products and services could support the development of the household-side capabilities outlined above in various ways, which also require relevant capabilities on the supplier-side. For example, installer interactions with households could provide an opportunity to develop capabilities related to living with changed patterns of heating – but installers may lack the social capabilities to engage in this type of work (Parrish, Hielscher and Foxon, 2021). In addition, designing DSR offers to enable household engagement with heat pump flexibility may affect the potential for electricity system services provision, and require actors such as distribution system operators to possess capabilities to manage the electricity system in other ways. This is the topic of this sub-section.

Limiting the duration of DSR events can limit reductions in indoor temperatures, even in homes with limited technical capabilities to enable thermal storage. For example, in the CLNR and NEDO trials direct load control was limited to between 30 minutes and 1 hour (Frontier Economics, 2015; NEDO, 2017). However, relatively short duration DSR will obviously tend to reduce the time over which flexible heat pump operation can reduce peak electricity driven network congestion; some trials have tested staggering DSR across different populations of heat pumps to extend the total period of demand reduction, but secondary demand peaks limit the effectiveness of this approach (Frontier Economics, 2015; NEDO, 2017), although they could potentially be addressed through more sophisticated control strategies (Frontier Economics, 2015). Lowering heat pump flow temperatures (rather than curtailing electricity supply) may provide an alternative approach to limit decreases in indoor temperature while maintaining DSR for longer periods within individual households.

The timing of DSR events may also be designed to limit impact on households: in the NEDO trial, DSR design avoided night-time operation of heat pumps, at the request of social housing managers who were concerned this may be disturbing to tenants (NEDO, 2017). Limiting the timing of DSR events will obviously limit the times at which DSR can provide electricity system services, implying that capabilities for alternative/additional forms of electricity system management may also be required. However, supporting the development of household-side capabilities that enable heat pump flexibility could reduce the need for such supplier-side capabilities, demonstrating their interrelationship and the value of the capabilities approach.
Appendix 5: Value propositions for four tenure segments and outlined in section 5.

4.3.2 Focus group session 1 key findings

Following the desk research and householder proposition workshop tasks, participants recruited from the Rose Hill and Iffley area took part in focus group sessions. The sessions were used to gain first hand insights from the householders within the target area and create an engagement and recruitment strategy that will be relevant and meet their requirements for the process of heat pump installation.

To achieve this aim, we firstly needed to understand their current knowledge and experience of heat pumps and identify more details regarding any barriers. Key findings for participants' knowledge and experience of heat pumps:

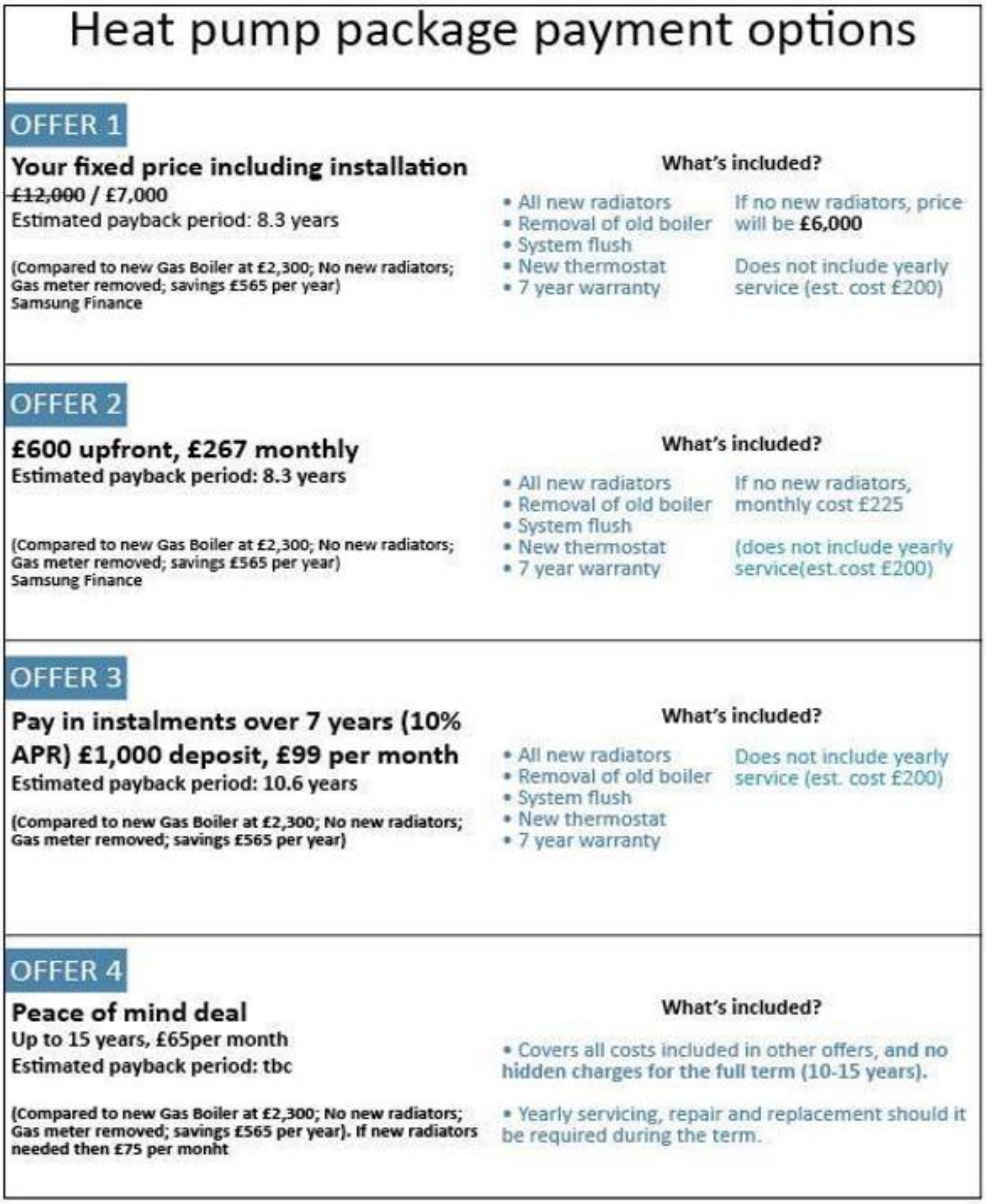
- There was a lack of knowledge about the reliability of heat pumps.
- Majority of participants think heat pumps are expensive to install.
- The participants have had different indirect experiences of heat pumps; with the most positive from a family/ friend experience.
- The interest in heat pumps has been prompted by the need for boiler replacement and the need for renovation work on their home.

The participants were asked what information would be needed to consider installing a heat pump. Insights gained here will help inform construction of 'information touch points' during the engagement and recruitment process. The priorities for heat pump information (apart from costs of the unit) were:

- What home alterations were required for efficient performance, the cost of these alterations and how could find out options for their home;
- What would be the temperature output be compared to a gas boiler and the operation control, including control of heating setpoints in different rooms of the home;
- The physical size of the unit and water tank and any spatial restrictions; and

- There was a lack of understanding of smart technologies and agile tariffs and how they were related, but after receiving information the participants could see the benefits and became more interested.

In the final part of the focus group participants were shown a variety of financial propositions developed from the desk research and householder workshop to test different types of options for tariffs and costs of the heat pump packages.



Heat pump package payment options

OFFER 1

Your fixed price including installation

~~£12,000~~ / £7,000

Estimated payback period: 8.3 years

(Compared to new Gas Boiler at £2,300; No new radiators; Gas meter removed; savings £565 per year)
Samsung Finance

What's included?

- All new radiators
- Removal of old boiler
- System flush
- New thermostat
- 7 year warranty

If no new radiators, price will be **£6,000**

Does not include yearly service (est. cost £200)

OFFER 2

£600 upfront, £267 monthly

Estimated payback period: 8.3 years

(Compared to new Gas Boiler at £2,300; No new radiators; Gas meter removed; savings £565 per year)
Samsung Finance

What's included?

- All new radiators
- Removal of old boiler
- System flush
- New thermostat
- 7 year warranty

If no new radiators, monthly cost £225

(does not include yearly service(est.cost £200)

OFFER 3

Pay in instalments over 7 years (10% APR) £1,000 deposit, £99 per month

Estimated payback period: 10.6 years

(Compared to new Gas Boiler at £2,300; No new radiators; Gas meter removed; savings £565 per year)

What's included?

- All new radiators
- Removal of old boiler
- System flush
- New thermostat
- 7 year warranty

Does not include yearly service (est. cost £200)

OFFER 4

Peace of mind deal

Up to 15 years, £65per month

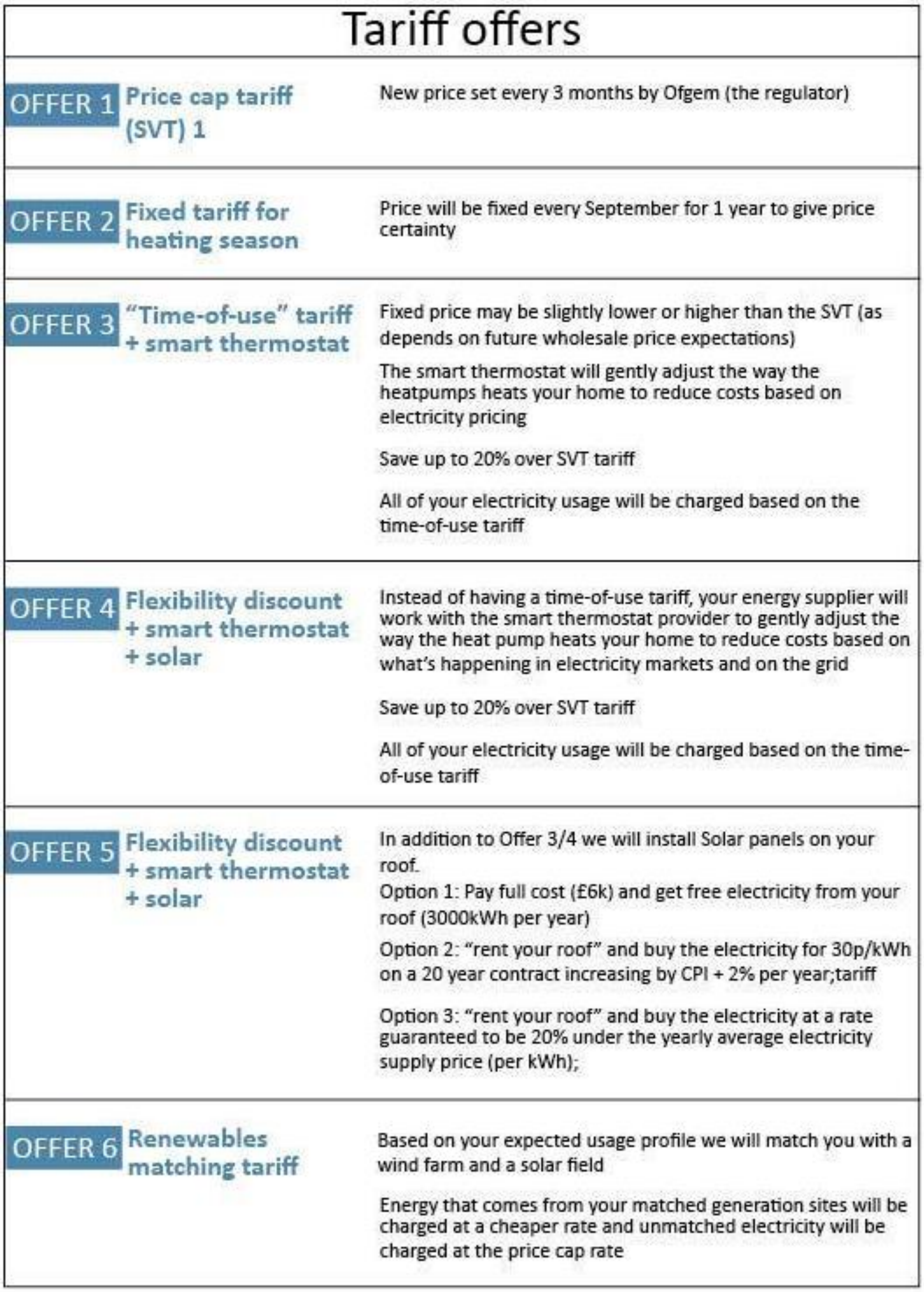
Estimated payback period: tbc

(Compared to new Gas Boiler at £2,300; No new radiators; Gas meter removed; savings £565 per year). If new radiators needed then £75 per monht

What's included?

- Covers all costs included in other offers, and no hidden charges for the full term (10-15 years).
- Yearly servicing, repair and replacement should it be required during the term.

Figure 5: Finance offers tested



Tariff offers

OFFER 1	**Price cap tariff (SVT) 1**	New price set every 3 months by Ofgem (the regulator)
OFFER 2	**Fixed tariff for heating season**	Price will be fixed every September for 1 year to give price certainty
OFFER 3	**"Time-of-use" tariff + smart thermostat**	Fixed price may be slightly lower or higher than the SVT (as depends on future wholesale price expectations) The smart thermostat will gently adjust the way the heatpumps heats your home to reduce costs based on electricity pricing Save up to 20% over SVT tariff All of your electricity usage will be charged based on the time-of-use tariff
OFFER 4	**Flexibility discount + smart thermostat + solar**	Instead of having a time-of-use tariff, your energy supplier will work with the smart thermostat provider to gently adjust the way the heat pump heats your home to reduce costs based on what's happening in electricity markets and on the grid Save up to 20% over SVT tariff All of your electricity usage will be charged based on the time-of-use tariff
OFFER 5	**Flexibility discount + smart thermostat + solar**	In addition to Offer 3/4 we will install Solar panels on your roof. Option 1: Pay full cost (£6k) and get free electricity from your roof (3000kWh per year) Option 2: "rent your roof" and buy the electricity for 30p/kWh on a 20 year contract increasing by CPI + 2% per year;tariff Option 3: "rent your roof" and buy the electricity at a rate guaranteed to be 20% under the yearly average electricity supply price (per kWh);
OFFER 6	**Renewables matching tariff**	Based on your expected usage profile we will match you with a wind farm and a solar field Energy that comes from your matched generation sites will be charged at a cheaper rate and unmatched electricity will be charged at the price cap rate

Figure 6: Tariff offer tested

The participants were asked for their level of interest and opinions of these options. The key responses were:

- The tariffs including flexibility and renewable energy sources were the most popular propositions, but participants would like clarity on these renewable sources;
- Participants priorities for choosing an energy tariff was firstly cost, also reliability, flexibility and integrating with solar; and

- For the fixed priced and peace of mind offer (leasing) heat pump packages were popular. There were concerns of how the leasing package would work if the property was sold and if the price would be guaranteed over time.

The full report is detailed in Focus group 1 Analysis – external link.

4.3.3 Focus group session 2 key findings

In the second focus group members of the RHILC group, a group highly integrated into the community, were invited to discuss the social demographics of the community and relevant forms of engagement. Key findings for this session:

Non-digital engagement

Many community members will not be digitally engaged. Face-to-face interaction is important to building trust. Therefore the methodology includes a programme of events, leaflet and letter drops, place ads in local printed publications, conduct talks about the project etc as part of our non-digital engagement strategy.

Meetings / public events

Initially, to cover the whole of the Rose Hill area, but lots of smaller communities within the area, who have their own interest and priorities and own demographics. Therefore, hold separate meetings for the different sections of the community, (e.g. Nepali group, Sisters group and Asian women's group, within the Rose Hill area). They may feel more comfortable communicating within their own group rather than in wider public meetings.

School assembly

Previously the group ran an assembly in the local primary school about insulation. A similar assembly could be repeated for heat pumps. Then children could be given literature to take home to parents, including information about heat pumps, the project and any future meetings / events.

Heat pump champions

A heat pump owner within the community could open their home so residents can get first-hand experience of the heat pump ownership process. This would work well for the middle-class estates, as there are similar demographics, and everyone knows each other. In contrast, for residents in social housing, who don’t have the same social cohesion and may feel nervous going into someone's house. In this case, the demo trailer could be placed outside the community centre on the day of e.g. the youth club.

Social Media

The RHILC group uses Facebook and found energy related posts are not as popular as general posts that are more entertaining. Other social media methods have not been tried by the group due to lack of resources. Other social media platforms were identified from conducting digital marketing research. See Digital recruitment engagement plan – external link.

Face-to-face

This would have two impacts:

1. Build goodwill and trust from events like picnics, litter picking, etc. then introduce the environment, and then energy and low carbon technology.

2. Ensure there are tangible benefits for the community

Promotion methods
These methods included, Rose Hill newsletter, part and online, leafleting (door-to-door, school, community centre, clubs etc.), posters (shops, community centre, school, Church, community board etc.)

Trust
This was found to be key requirement as to build trust it's important to get to know people, reassure them there is not an ulterior motive. To get over any mistrust, the solution would be the involving key people and groups. The full report is available here: Focus group 2 Analysis – external link.

4.4 Work stream 4: Findings

To achieve 25% deployment of heat pumps in our local area will need a completely new approach to the householder proposition and the installation processes. Business-as-usual will not be good enough. The work stream was led by an SMS Ltd, an expert in solutions development and renewable systems design, working with Boxt Ltd and the Samsung Heat pump team.

The first stage of work was to investigate the existing heat pump quotation, design, installation and hand-over processes. We then identified areas where significant innovative implementation, simplification and automation could be used to reduce cost for the solution supplier and the householder. We also looked at how innovative data collection and analysis, design and proposal tools could be used to improve the processes. This fed into the design of a detailed process map.

Our process found several elements in the current process where significant simplification and automation can be developed to improve the householder journey, and result in cost saving for supplier and householder. A simplified map of the process is shown in Figure 7, and a full version is shown in Appendix 6: Detailed process map.

The key high-level finding was that revision of the MIS3005-D standards in 2021 (MIS 3005-D – external link) allows for the separation of design and installation activities and allows up to 60 days to provide the design calculation after the contract is awarded.

Our methodology takes advantage of this specialisation to increase up-take. Due to the constraints placed on the methodology by the BEIS competition rules[27], householders will not pay prior to the detailed design, but in a commercial deployment, we recommend taking payment at the pre-design stage to reduce drop-out.

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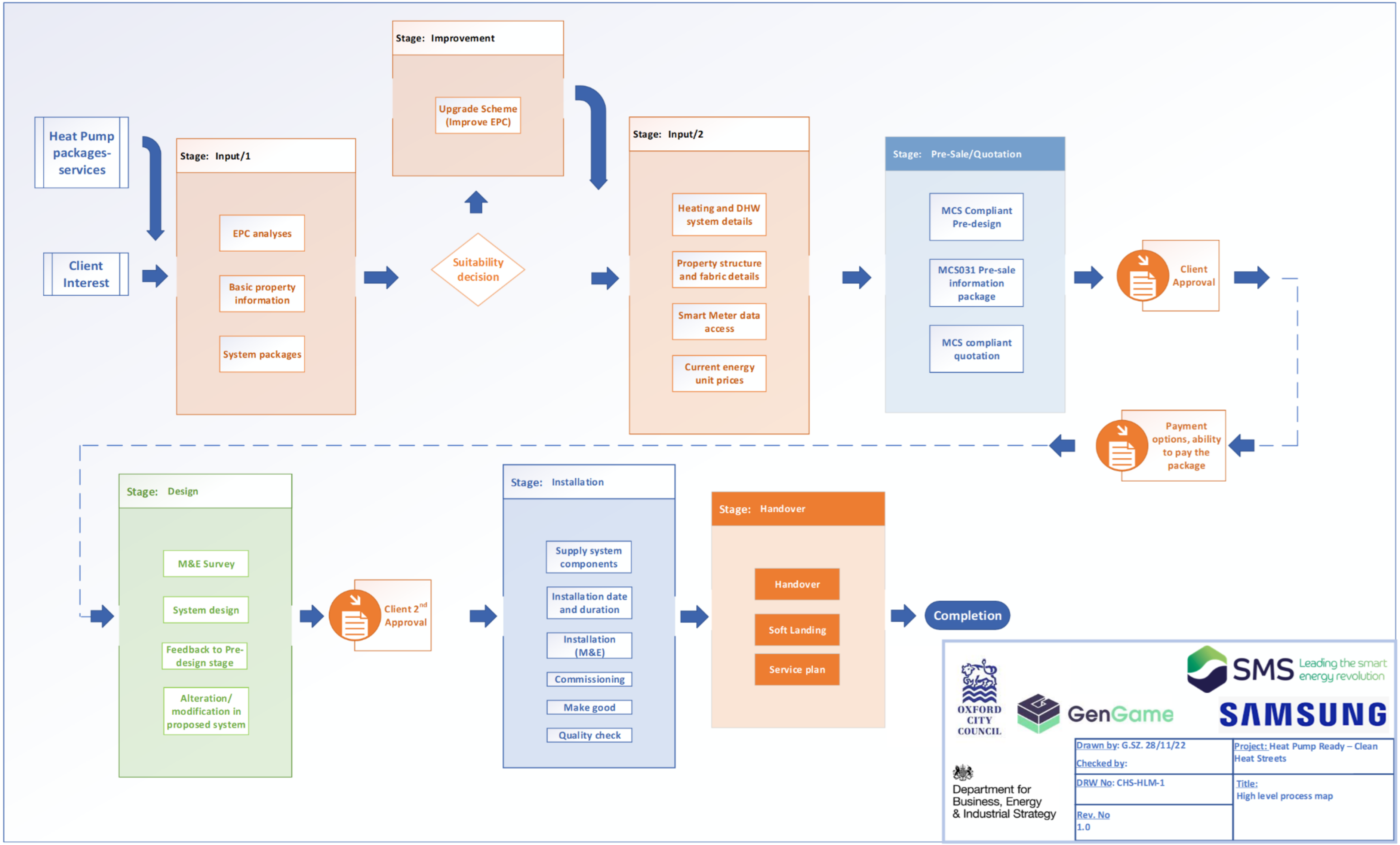
[27] The BEIS Heat Pump Ready project for deployment of the methodology (Phase 2) includes a requirement for a set level of recruited households to be reached (at a stage gate) before deployment can move onto the installation phase.



Drawn by: G.SZ. 28/11/22
Checked by:
DRW No: CHS-HLM-1
Rev. No 1.0
Project: Heat Pump Ready – Clean Heat Streets
Title: High level process map

Figure 7 High-level map of the customer journey

4.4.1 Input stage

The Input Stage is the crucial section of the process. The Input Stage is focused on collecting all available and relevant data about the property details, including its historic energy consumption. The collected information shall be processed and fed into the pre-design proposal. This information collection needs to be as accurate as possible to support the Pre-design task and offer the best possible renewable energy system to the client.

The UK government's Energy Performance Certificate (EPC) assessment was launched 1st of August 2007 as part of Home Information Packs for domestic properties. The UK Government launched the Application Programming Interface (API) feature to the domestic EPC database on 26th February 2018. With this feature, the domestic EPC database became accessible to extract domestic properties' energy efficiency data in higher volume, analyse the data, and use it for other commercial aspects. This feature provides process optimisation in the installer process described below.

The client will give the property's postcode and address, and the system shall complete the following tasks:

1. The system checks the EPC assessment database for a valid EPC record. If the client does not have a valid EPC, the system can offer to direct an Energy Assessor to carry out the EPC assessment and continue the process when the EPC shall be available. If the client has a valid EPC, the API extracts and processes the predetermined data from the valid EPC.

2. If the client has a valid EPC, but the EPC does not contain all of the pre-determined data, the client can answer questions regarding the existing building fabric. If the client is unable to provide the missing fabric details, they can then choose a fixed cost survey. In this case, the supplier shall arrange a survey date with the client and carry out the full M&E survey.

3. If the full M&E survey is completed and the Suitability Decision is positive, the process shall skip the Pre-Design stage, and shall continue with the Design task.

4.4.2 Property suitability decision

Based on the processed EPC data and the client's provided data the system shall decide the suitability of the property. The evaluation shall focus on the Energy rating and fabric details:

- If the Energy Rating is between A-D, and the property has Cavity Wall Insulation (CWI) or External Wall Insulation (EWI), and/or has at minimum double-glazed windows and doors, the client's property can be suitable for the ASHP system upgrade;

- If the Energy Rating is between E-G, also the property has no Cavity Wall Insulation (CWI) or External Wall Insulation (EWI), has no minimum double-glazed windows and doors, the client's property cannot be suitable for the ASHP system upgrade, therefore the process shall offer to show the relevant building fabric improvement options to the client.

4.4.3 Heating system specific section

The client will be asked specific questions regarding the current heating and DHW system. The answers shall support a better understanding of the existing system, and also support the quotation task based on required modifications, and additional connection packages.

The process shall recognise if the client has an incompatible heating system (e.g., storage heater, panel heater) and the proposal shall be able to offer a completely new heating system with heat emitters, and control options. In this case, the client will also be warned about the additional works in the property including possible floor lifting and laying pipework. The client will also be informed about duration of installation and any additional cost of the distribution system.

4.4.4 Smart meter data – energy unit prices

The process shall ask permission from the client to access smart data (if applicable). A smart meter data analysis tool will be used to access smart meter data, process historic energy data and carry out property-specific thermal analyses to support pre-design activities.

The algorithm shall carry out an HTC-lite calculation, as the Internal Air Temperature (IAT) is not recorded and unknown. The result of HTC-lite shall be compared with benchmark properties, EPC, and score the property energy consumption.

The HTC-lite calculation assesses energy usage for a property across a range of weather conditions in order to distinguish how sensitive the energy usage of property is to changes in temperature and other weather effects. Properties that are highly sensitive to changes in weather are deduced to be less well insulated and have worse thermal performance overall, and as such would be recommended a range of improvement measures ahead of installation of a heat pump. The method is limited by lack of IAT data which enables the full Heat Transfer Coefficient (HTC) to be determined.

4.4.5 Pre-Design stage

The collected information in the input stage supports the Pre-Design tasks. The data shall feed into the pre-design calculations and support the pre-sale information package.

Under our methodology, the installation company will use the MCS umbrella scheme. The installation service provider shall carry out all design tasks and provide MCS compliant certificates. Also, the installation service provider shall use their installer database to carry out the installation and will be responsible for checking and confirming all installations are completed according to the MIS3005I standard.

The Building Research Establishment (BRE) group published average historic heat losses data for the typical dwellings, according to the years that dwellings were built[28]. Table *4* shows the dataset.

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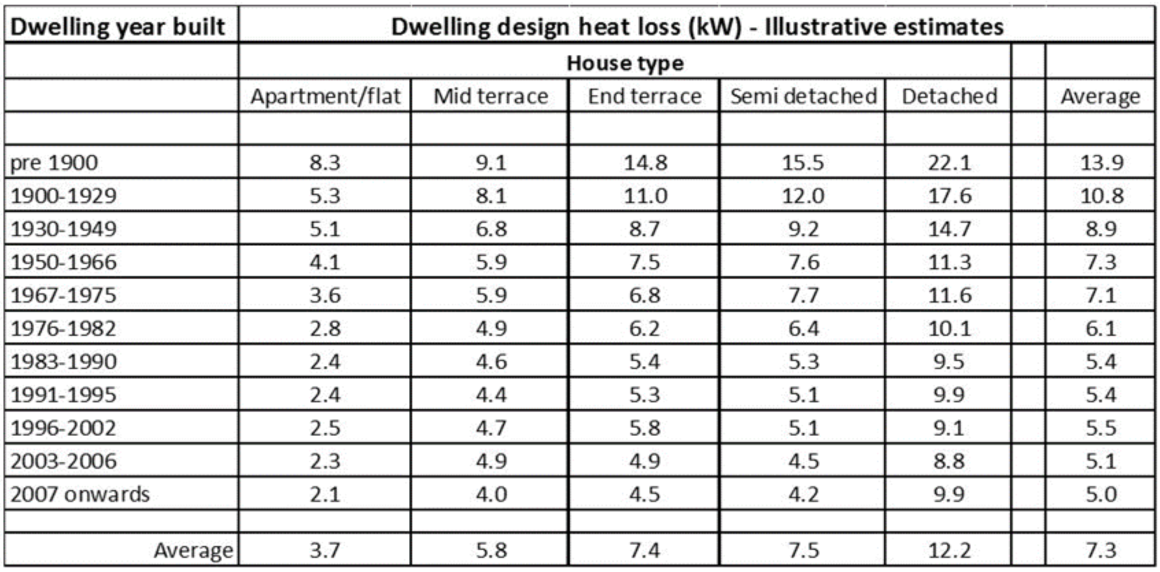
[28] The publication can be found at: https://tools.bregroup.com/heatpumpefficiency/dwelling-heat-loss

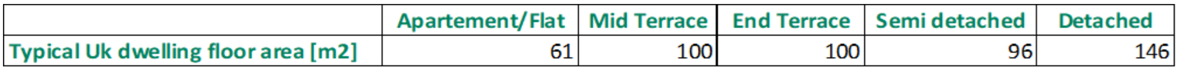
Table 4 Heat loss from different house types and vintages



Dwelling year built	Dwelling design heat loss (kW) - Illustrative estimates						
	House type						
	Apartment/flat	Mid terrace	End terrace	Semi detached	Detached		Average
pre 1900	8.3	9.1	14.8	15.5	22.1		13.9
1900-1929	5.3	8.1	11.0	12.0	17.6		10.8
1930-1949	5.1	6.8	8.7	9.2	14.7		8.9
1950-1966	4.1	5.9	7.5	7.6	11.3		7.3
1967-1975	3.6	5.9	6.8	7.7	11.6		7.1
1976-1982	2.8	4.9	6.2	6.4	10.1		6.1
1983-1990	2.4	4.6	5.4	5.3	9.5		5.4
1991-1995	2.4	4.4	5.3	5.1	9.9		5.4
1996-2002	2.5	4.7	5.8	5.1	9.1		5.5
2003-2006	2.3	4.9	4.9	4.5	8.8		5.1
2007 onwards	2.1	4.0	4.5	4.2	9.9		5.0
Average	3.7	5.8	7.4	7.5	12.2		7.3

Furthermore, the following figure shows the typical dwelling's average floor areas[29].

Table 5 Typical dwellings' average floor area



	Apartement/Flat	Mid Terrace	End Terrace	Semi detached	Detached
Typical Uk dwelling floor area [m2]	61	100	100	96	146

The pre-design matrix includes the following inputs:

- Built at (from pre-1900 to post 2006)
- Type of Property
- Total Floor area

The Pre-Design Estimator Matrix example is shown below:

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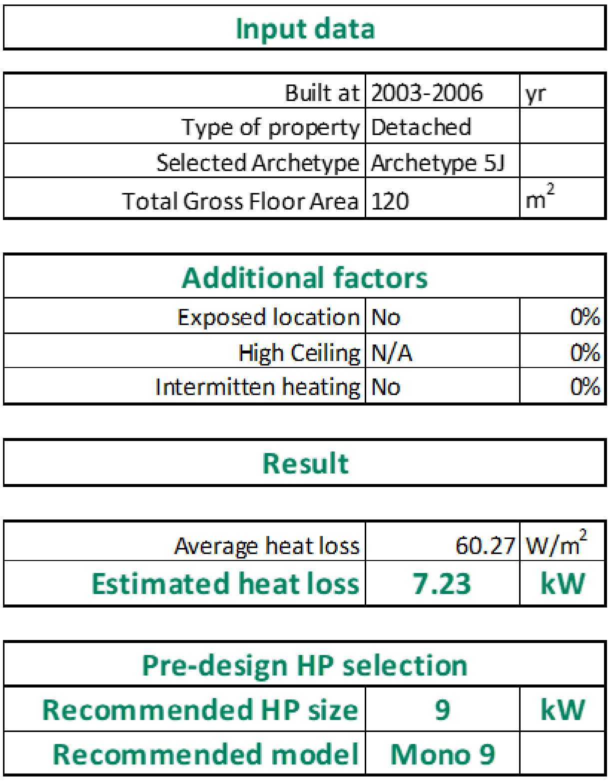
[29] The dataset can be found at: https://www.dwh.co.uk/advice-and-inspiration/average-house-sizes-uk/

Table 6: Pre-design estimator



Input data

Built at	2003-2006	yr
Type of property	Detached	
Selected Archetype	Archetype 5J	
Total Gross Floor Area	120	m^2

Additional factors		
Exposed location	No	0%
High Ceiling	N/A	0%
Intermitten heating	No	0%

Result

Average heat loss	60.27	W/m^2
Estimated heat loss	**7.23**	**kW**

Pre-design HP selection		
Recommended HP size	**9**	**kW**
Recommended model	**Mono 9**	

This Pre-Design Estimator matrix has been crosschecked with example properties where MCS-compliant heat loss calculations were as carried out, the accuracy was ±10% which gives a confident estimation to support pre-design calculations. Also, the Pre-Design Estimator tool can use the available Samsung heat pump range.

If the client has and allows historic smart meter data to be used, a bespoke algorithm can be used to support the Pre-Design Estimator matrix, which will result in a more accurate system size estimation.

The cost of providing the HTC-lite service is expected to be low, consisting mainly of cloud computing overhead costs and occasional customer support where there are issues in validating a user or collecting their smart meter data. The marginal per-user, per-assessment cost is minimal (pence).

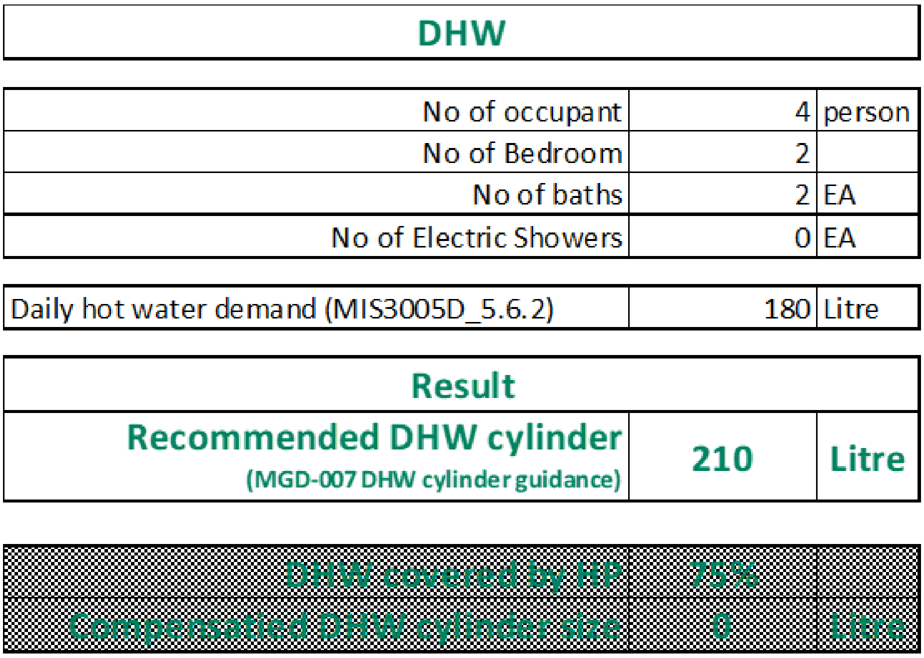
The proposed Pre-Design Estimator matrix has a DHW selection part. This part shall be a complete adaptation of MIS 3005-D 5.6.2, MGD-007 heat pump reference information, and tools Section 2 DHW Cylinder Selection Guide.

The Pre-Design Estimator can simulate two scenarios:

Scenario 1: No instantaneous electric shower in the property

In Scenario 1 the tool will need to calculate the minimum DHW cylinder size based on the number of occupants, number of baths and bedrooms. The recommended DHW cylinder shall be selected as a closest bigger volume tank. As the Rose Hill area contains "typical" dwellings, the presented DHW cylinder sizing tool shall provide a confident estimation to complete the Pre-Design and Pre-Sales requirements.

Table 7 DHW cylinder sizing tool Scenario 1



DHW

No of occupant	4	person
No of Bedroom	2	
No of baths	2	EA
No of Electric Showers	0	EA

Daily hot water demand (MIS3005D_5.6.2)	180	Litre

Result

Recommended DHW cylinder (MGD-007 DHW cylinder guidance)	**210**	**Litre**

DHW covered by HP	75%	
Compensatied DHW cylinder size	0	Litre

If a potential future client has a non-typical property (e.g. 4 or more bedrooms, 3 or more bathrooms, swimming pool and spa facilities in the property, or any other significant DHW householders in the property) it is even more important that the DHW sizing is verified after the M&E survey.

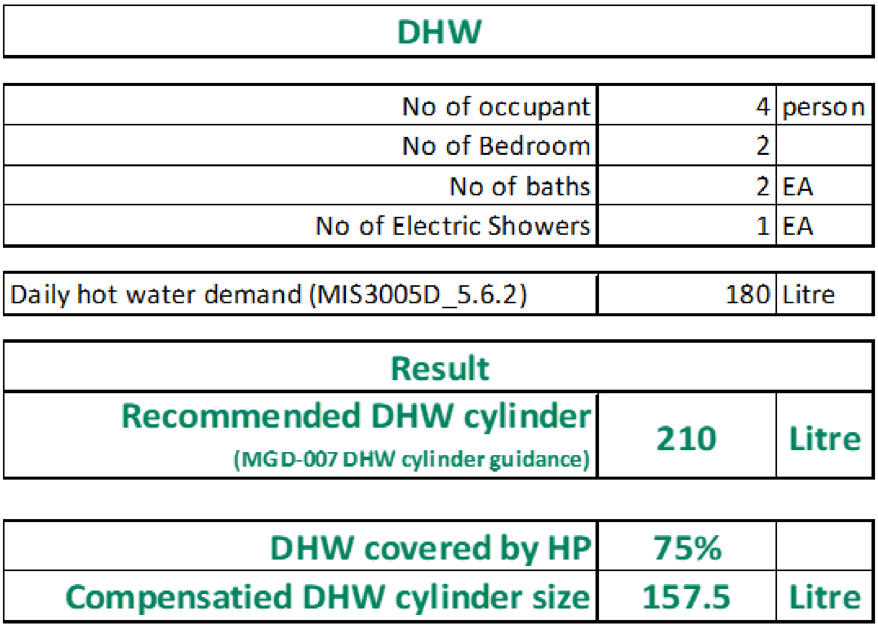
In Scenario 2 the property has a minimum 1 instantaneous electric shower.

In this case, the DHW shall be provided from two different sources. There shall be a DHW cylinder coverage and an instantaneous electric shower coverage.

As a significant portion of DHW shall be generated by the instantaneous electric shower, we recommend using a reduced DHW cylinder size. The estimation method still follows the spirit of the MIS 3005-D, MGD-007 standards, but provides a more efficient solution as the heat pump system shall need to maintain the temperature of a lower volume of DHW, thereby the renewable energy system shall be more efficient.

Furthermore, the reduced DHW cylinder size reduces the legionella disease possibility and reduces pasteurisation energy demand in the weekly cycles.

Table 8 DHW cylinder sizing tool Scenario 2



DHW		
No of occupant	4	person
No of Bedroom	2	
No of baths	2	EA
No of Electric Showers	1	EA
Daily hot water demand (MIS3005D_5.6.2)	180	Litre
Result		
Recommended DHW cylinder **(MGD-007 DHW cylinder guidance)**	**210**	**Litre**
DHW covered by HP	**75%**	
Compensatied DHW cylinder size	**157.5**	**Litre**

4.4.6 Pre-Sale Information pack – Quotation

The installation service provider will create an MIS 3005-D, Section 4 – Pre-Sale Information compliant package. The following minimum technical shall be communicated with the Client in writing:

- Result of MCS031 performance estimation[30];
- Manufacturer’s datasheet for the proposed heat pump;
- Manufacturer’s datasheet for the proposed DHW cylinder (if applicable);
- Any other requirements stipulated by the Consumer Code (if applicable); and
- Details of any subcontractors proposed to undertake the installation.

4.4.7 Quotation

To comply with MCS requirements, the Quotation shall need to include the main proposed components (ASHP, DHW cylinder, control equipment, and additional works).

Based on the collected information, the proposed system shall need to estimate:

- ASHP location;
- Wiring distance;
- F&R pipework distances;
- ASHP foundation estimation;
- Existing F&R, CW and DHW pipework’s modification/relocation costs;
- General making good builder works; and
- Gas boiler decommissioning and gas connection decommissioning (if applicable).

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[30] The template can be found on the MCS website here.

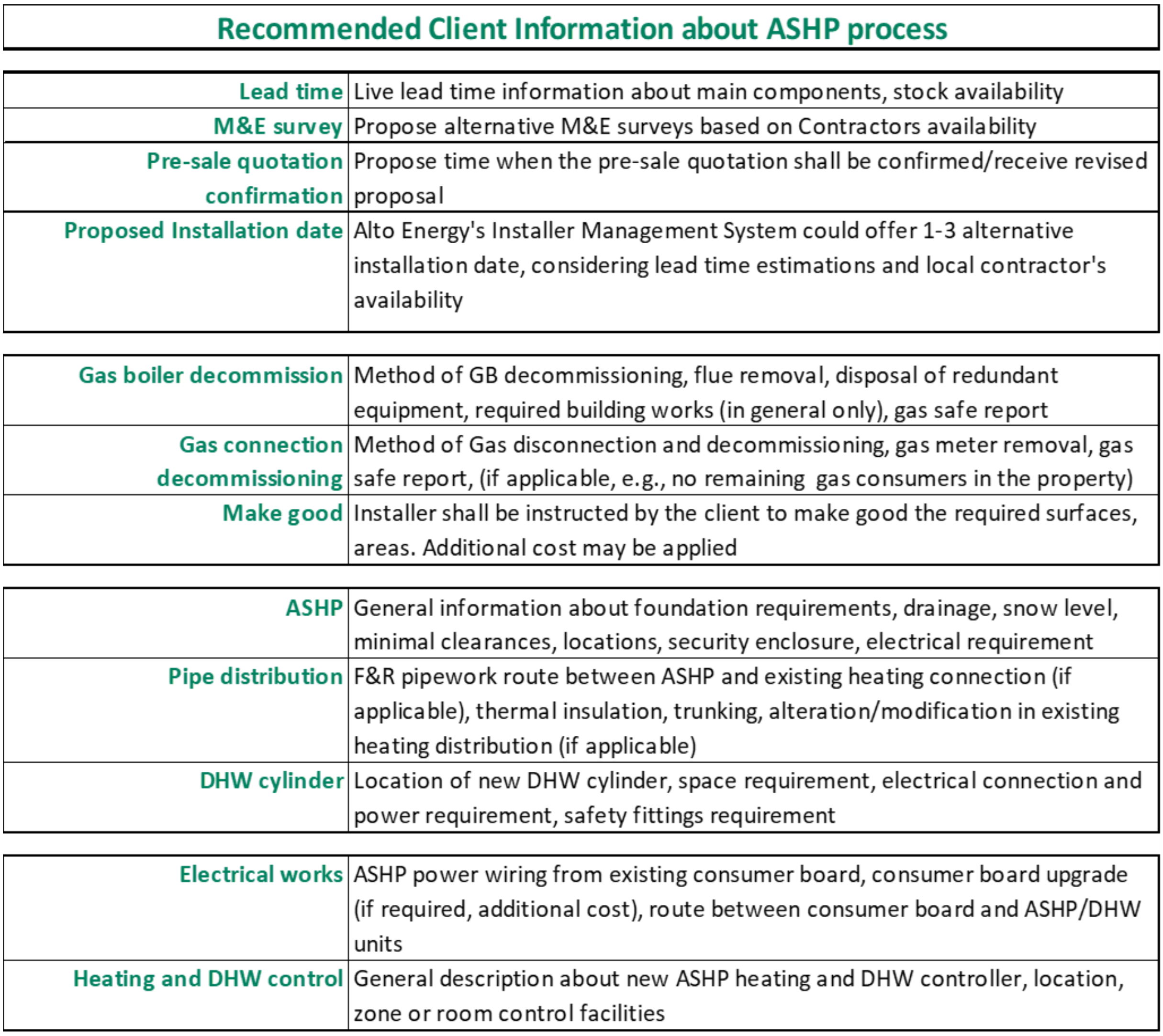
This gives confidence to the supplier and the client that the proposed price may not change after the M&E survey.

The quotation shall also include a method statement about:

- The system installation;
- Adaptation to the existing wet heating system (if applicable); and
- Step-by-step explanation of the major stages of the process.

Recommended Client Information Installation package can be seen below.

Table 9: Client information



Recommended Client Information about ASHP process

Lead time	Live lead time information about main components, stock availability
M&E survey	Propose alternative M&E surveys based on Contractors availability
Pre-sale quotation confirmation	Propose time when the pre-sale quotation shall be confirmed/receive revised proposal
Proposed Installation date	Alto Energy's Installer Management System could offer 1-3 alternative installation date, considering lead time estimations and local contractor's availability
Gas boiler decommission	Method of GB decommissioning, flue removal, disposal of redundant equipment, required building works (in general only), gas safe report
Gas connection decommissioning	Method of Gas disconnection and decommissioning, gas meter removal, gas safe report, (if applicable, e.g., no remaining gas consumers in the property)
Make good	Installer shall be instructed by the client to make good the required surfaces, areas. Additional cost may be applied
ASHP	General information about foundation requirements, drainage, snow level, minimal clearances, locations, security enclosure, electrical requirement
Pipe distribution	F&R pipework route between ASHP and existing heating connection (if applicable), thermal insulation, trunking, alteration/modification in existing heating distribution (if applicable)
DHW cylinder	Location of new DHW cylinder, space requirement, electrical connection and power requirement, safety fittings requirement
Electrical works	ASHP power wiring from existing consumer board, consumer board upgrade (if required, additional cost), route between consumer board and ASHP/DHW units
Heating and DHW control	General description about new ASHP heating and DHW controller, location, zone or room control facilities

4.4.8 Payment options

Under the methodology, 2 alternative payment options will be offered:

- <u>Fixed price:</u> One off payment, GB removal, system flush, new thermostat, 7-year warranty.

- 1-to-5-year instalments: Configurable payment terms. Householder can choose upfront payment amount and length of payback period (1-to-5-years).

Annual service and maintenance are not included in the price but will be offered to the client as a recommended extra cost.

4.4.9 Design Stage

M&E survey
The selected installer shall carry out an M&E survey, which shall check and record the following details:

- Room by room measurement (floor, windows, doors, etc.);
- Room by room heat emitter measurement, type, make and model (if applicable);
- Electrical householder board details (spare ways, suitability, flag upgrade if necessary);
- ASHP location, foundation requirement;
- DHW cylinder location, power supply to immersion heater (if applicable);
- Existing boiler location, required modification/alteration;
- Wiring route between ASHP and consumer board;
- Pipe distribution pipework between ASHP and DHW cylinder and heating F&R; and
- Pre-determined list of photographs shall be taken by the surveyor.

Design tool choice
There are available newly developed software and design tools available. The minimum criteria with this software were that it must result in:

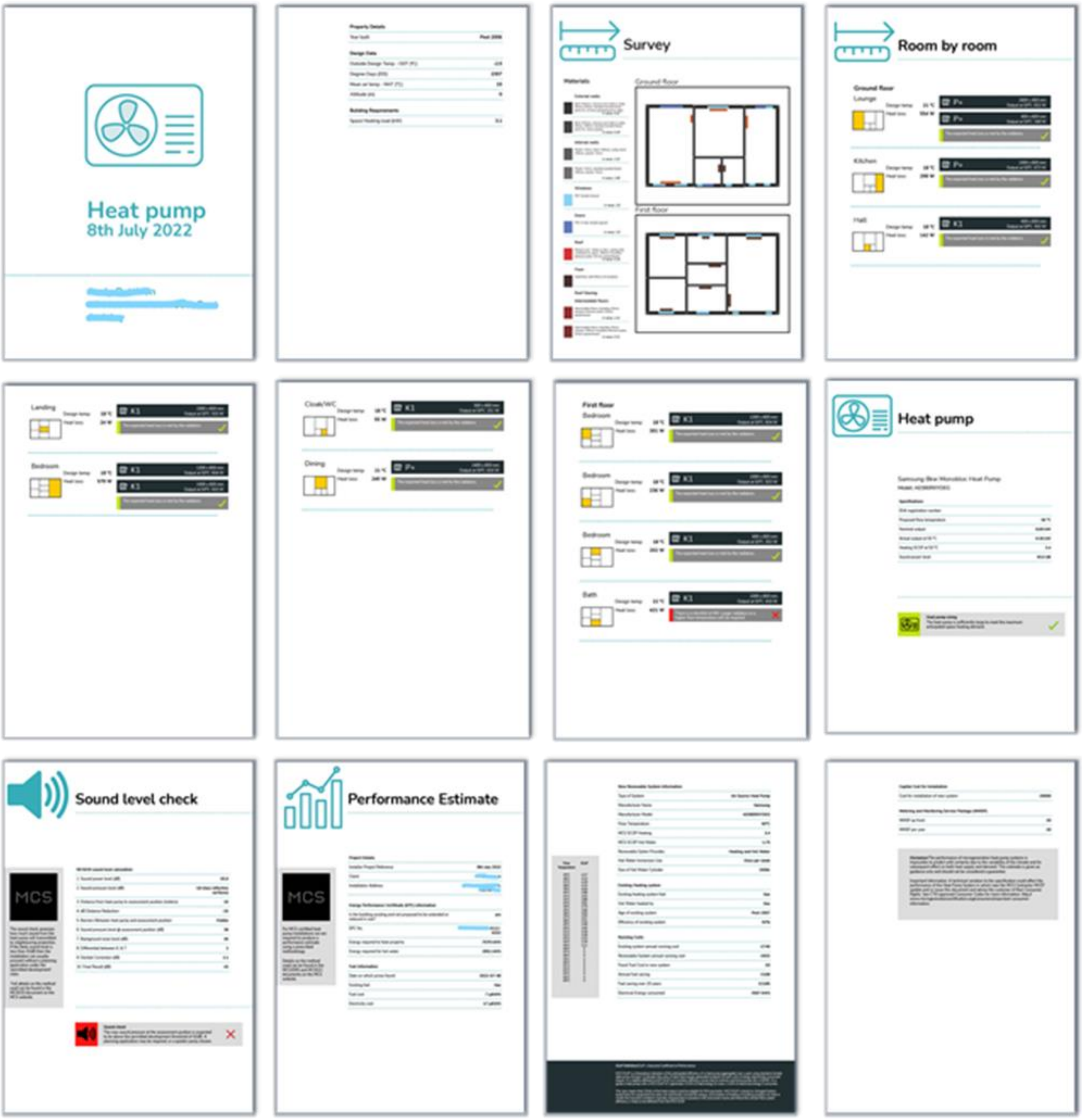
- MCS compliant heat loss,
- Heat emitter and other relevant design calculations,
- Provide client-friendly reports and be able to develop to specialized demands/needs.

Following review of the available design software we recommend using the Heat Punk tool.

The HeatPunk tool
Heatpunk was developed by Midsummer Energy. The HeatPunk is a modern adaptation of the MCS heat pump design standard. The tool can deliver:

- MCS compliant room by room heat loss calculation;
- Heat pump selection;
- Carry out heat emitter designs and check existing heat emitters' suitability;
- MCS020 Sound level calculation;
- MCS031 Performance Estimation;
- DHW system design;
- Selected system proposal;
- MCS heat pump Compliance Certificate Completion;
- DNO commissioning form completion; and
- Deliver design results in a visual form (floor plan).

Figure 8 includes an example of a HeatPunk Design report.



Heat pump
8th July 2022

Survey

Room by room

Heat pump

Sound level check

Performance Estimate

Figure 8 HeatPunk Example Design Report

The HeatPunk tool can generate an MCS Compliance report, and DNO commissioning report when the installation is completed, and the system commissioned. The existing tool covers all MCS design requirements. However, the tool can be upgraded with purpose-specific features, which can improve the survey, design, and other relevant technical aspects.

4.4.10 Installation

We have developed a detailed process map (see Appendix 6: Detailed process map). Many costs associated with heat pump quotes today are attributable to small installation company overheads driven by the “boutique” nature of heat pump design and installation jobs.

Through our methodology we will drive down these costs through onsite and offsite specialisation across survey, heat loss calculations, design, logistics, administrative processes, installation, commissioning and customer journey management.

4.4.11 Financing and handover

The methodology uses a "group-on" style discount approach under which the more people sign-up in a secondary substation area, the higher the percentage discount we will offer. Householders will be able to see the current number of local sign-ups, and the current level of discount via the Information Data Management System (IDMS).

Our analysis in the feasibility phase has shown that given the current energy price guarantee rate, a heat pump becomes cheaper than an existing gas boiler at a Seasonal Coefficient of Performance (SCoP) of around 3 for heating (using the very low required MSC CoP of 1.75 for hot water; using our field-setting-values innovations we will achieve a significantly higher CoP for hot water).

Using our methodology, we will have a basic offer of £3,000 for a heat pump installation which will allow the homeowner to switch to a heat pump and give them cheaper heat (subject to gas prices not reducing relative to electricity prices).

£3,000 may be affordable to a homeowner today, whilst an extra £1,000 for additional measures to get a SCoP improvement of 0.5 may not be affordable at the time of installation. If a homeowner decides to take a basic package, we will monitor the performance post-install, and if the homeowner takes on our service package, upgrades will be offered at each yearly service, with updated data on potential savings based on the household's data.

4.4.12 Commissioning

Given that most currently available heat pumps are not internet-enabled, and installers need to manually set up initial "Field-setting values" during installation, they are frequently installed with very basic and common settings. Many are also installed with third-party thermostats which limit the efficiency of the heating system.

The more settings that are configured at installation, the more efficiently a system can run, but also the greater the risk of installer errors. A key part of our methodology is to take the system configuration out of the hands of installers.

All our heat pumps will be installed with WiFi connectivity. From Q1 next year, Samsung heat pumps with WiFi connectivity can be configured remotely. Our methodology will see technical experts at Samsung, Passiv UK, an installation service provider, SMS, SSEN and local heat pump champions work together to develop initial set-up configurations for different groups of customers.

Flexible demand can be provided at two levels:

1. **Static settings to accurately configure weather compensation to ensure efficient heat delivery in terms of cost to householder and impact on the local grid;**
   Whilst additional efficiency and savings can be achieved through "real time" control, static control and intelligent setting of "field values" can provide significant benefits to householders and to the Grid. Our methodology will work with Samsung engineers, the local community and SSEN to optimally configure the Field-setting values to optimise static control

to increase efficiency and to reduce the impact on the local grid. For example, we will randomise the start times of the weekly legionella heating cycles to avoid unnecessary peaks.

2. **"Real-time" control in response to tariffs and DSR requests;**
   Samsung Units also allow more "real time" control. Partners who use this control method use a Modbus connection to control the target flow temperature which is directly correlated to the power usage (if the actual flow temperature is known).

   Given an existing non-project work ongoing between Samsung and Passiv systems, we hope that in 2023, Passiv UK will be able to control the FSVs, including the water leaving flow temperature in real time via a SmartThings API.

   Passiv/SmartThings integration will allow the user to opt-in to Smart Control via the SmartThings App, and then Passiv will be able to control the flow temperature based on advanced weather compensation, smart tariffs and DSR. As a back-up we will be able to use the Modbus route which is commercially available today.

5 Methodology for high-density heat pump deployment

5.1 Agree general approach and develop framework documents

The first step is to find partners in a local area who can carry out the key tasks in delivering the methodology.

5.1.1 Convene partners capable of carrying out the methodology

Our methodology requires a very broad range of industry and community actors for successful implementation. Requisite partner types and skill sets are detailed in Appendix 7: Requisite partners and skills for dense heat pump deployment.

5.1.2 Managing interaction of the partners through the customer journey

Central to the information and data flows is the Information and Data Management System (IDMS). The technology partner should set-up the IDMS using an information and data management tool such as Amazon Web Services. The IDMS should include front-end allowing partners to log-on with different user roles to input and access information and data.

The IDMS should also support recruitment, including a data repository with details of each householder to manage the customer journey and to make data available to relevant parties that they need to carry out their tasks. Given that some of the data held within the IDMS will be personal data, the IDMS will need to include terms and conditions and a Privacy Policy, and the IDMS should follow current industry best-practice with regards to platform security[31].

5.1.3 Develop governance documents

These are to include the base communications and engagement strategy and guidance on conducting all project activity, including in particular, conducting engagement activity in an ethical fashion.

We consider an ethical approach to engagement critical to the project’s success. Therefore, early in the deployment phase, the methodology requires development of a framework and code of practice to inform engagement activity. An ethical approach will ensure that:

- Householders touching the project who are not suited to a heat pump are given appropriate advice about alternatives;
- Vulnerable householders and householders needing retrofit upgrades such as insulation measures and access to retrofit funding are referred to the appropriate services. Through Oxfordshire County Council we will support households who can qualify for support to finance home improvement measures by sign-posting to the council’s existing advice service run by Better Homes Better Health https://www.bhbh.org.uk/;
- The Rose Hill community will develop trust in the project and the heat pump offer; and
- Participants in the project will have a good experience and consequently be much more likely to recommend participation to others.

We believe formally developing a guide to ethical conduct for the project represents an innovation in governance for projects of this type.

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[31] https://docs.aws.amazon.com/wellarchitected/latest/security-pillar/welcome.html

5.2 Understand the neighbourhood

It is essential, at the project outset, to gain a deep understanding of the capabilities, priorities and key points of social influence ion the target communities. This understand informs design of the engagement strategy, the value proposition and other interventions. It also facilitates trust and community ownership of the project to develop. Our approach to understanding the neighbourhood has four main components.

5.2.1 Community survey

A key part of the methodology during the householder engagement phase is a community survey of the area to understand how the community is structured, its priorities and attitudes, key points of influence and basic technical information about the home its energy services. The technique we recommend is adapted from a successful deployment in the Netherlands and entails a door-to-door survey using a carefully crafted questionnaire. Completion of the survey should be incentivised. The community survey should be followed up with a number of focus groups to flesh out the quantitative responses. As well as capturing social and technical information about each household in the area, completion of the questionnaire is an opportunity for initial engagement with all the households in the target areas. Deployment of the innovative community survey methodology will be a key step in the design of the targeted engagement strategy and in design of smart interventions.

5.2.2 Demand profiling

We have developed a novel method of creating demand profiles based on cluster analysis of smart meter data collected as part of the EDRP project. Using information about internal and external temperatures and deriving Seasonal Coefficient of Performance we have been able to calculate how a gas demand profile transposes to electrical demand where a heat pump is used instead of a gas boiler to heat space and hot water. We have further developed a novel methodology for associating demand profiles with ACORN classifications. This allows us to analyse the socio-economic and demographic variables which influence demand profiles such as occupancy and lifestage and to develop tailored heat pump value propositions related to adoption of the heat pump and to design interventions (such as ToU tariffs and Direct Load Control) to change the shape of electricity demand. To our knowledge this has not been attempted before in a heat pump trial.

We have further developed a methodology to link these profiles to postcodes in our target area via the geodemographic ACORN classification tool and the MOSAIC classification tool. This allows us to design engagement strategies tailored for each postcode and anticipate how various smart interventions (e.g. ToU tariff, Direct Load Control, energy advice and feedback) will influence demand profiles we find there.

5.2.3 Understand key nodes and points of influence in the community

Further information capture and co-design sessions should be conducted to further understand the social structure of the community, local culture, priorities and key points of influence. Groups to be consulted should include residents, local groups and other embedded “middle” actors such as social housing landlords, local heating system installers. These sessions will create further trust and ownership in the project amongst key influencers and also generate invaluable information to inform engagement and communications.

5.2.4 Mapping social, economic, technical and personal capability

Using our LEMAP mapping tool we have built up a detailed description of the socio-economic, technical, and digital capability profile of each postcode in our target area. This allows us to develop highly targeted value propositions and to anticipate, and plan for, the number of likely customers for the heat pump offer in each area. LEMAP also contains layers showing the headroom of each secondary substation in our target areas. Therefore, we can anticipate where concentrations of heat pumps could lead to network problems and work with our partner SSEN to develop smart solutions to head off network issues.

5.3 Identify target areas for high-density deployment

The next step is to work with a mapping tool provider to find the most suitable neighbourhoods within the Local Authority area to target. To do this the methodology should map, at postcode level, the technical, economic and social "capability" of households to adopt a heat pump using the methodology. For an example of how this can be applied to a local area in Oxford, see Appendix 7: Requisite partners and skills for dense heat pump deployment

Methodology Project Manager

A project manager to manage delivery, coordinate the partners, and manage the business case, financial and commercial agreements.

Information and Data Management System (IDMS) provider

A partner who can set-up the information and data management system (see more details in the section below).

Heat Pump Technology provider

There needs to be a technology provider who can provide the heat pump equipment and provide technical information and guidance and input into the various work packages.

Local Authorities

The Local City Authority provides a dedicated Local Energy Project Officer who will become the human face of the project, be embedded and present in the targeted area and will be the first point of engagement with local residents. The officer will act as the "convenor" of local project events and meetings including leading co-design of energy and low carbon plans with local groups (much like the convenor role anticipated for Local Area Energy Planning); interpreting technical surveys; advising on post install optimisation of the system and otherwise guiding participants through all stages of the customer journey. The Local County Authority provides strategic and policy inputs and steer. Also links to services for retrofit funding and general welfare and energy advice.

Mapping tool provider

The methodology needs a mapping tool provider who can provide a mapping tool capable of identifying the most suitable secondary substations for high-density deployment within the local authority area. The provider should be able to provide data capture, spatial analysis, mapping, targeting and monitoring services.

Data Forecaster
The methodology needs a provider who can estimate the electricity demand of homes with a smart meter (i.e. gas boiler to heat pump usage translation algorithm) or without a smart meter (heat pump demand forecaster).

Householder Engagement specialists
The methodology needs behaviour and feedback specialists to develop and implement a localised engagement strategy based on input from a community survey exercise.

Heat Pump Installation Service Coordinator
The methodology uses a service provider to manage and be responsible for the surveying, design, supply, technical support, commissioning (and quality control), charging, building regulations and service and warranty.

Heat Pump installer
The methodology uses a local installation business to subcontract the installation work. The installers will be upskilled heating engineers, the majority of whom will be gas boiler installers.

Smart Meter installation and Data partner
Given the importance of granular energy data to the householder offer, the methodology needs a company able to advise and carry out Smart Meter installations on behalf of Energy Suppliers. In addition, the methodology needs a partner who is a DCC user who is able to access data from a customer’s smart meter.

Renewable Heating System Consultant
Required to provide work on monitoring, quality assurance, installer training and optimisation of installations.

Distribution Network Operator
Required to provide data and substation level monitoring services. They will also provide technical guidance to help with the design of a smart solution where there is a risk of network constraint and work with the project to provide smoothed connection processes.

Heat Pump Optimisation and Flexibility Provider
Technology platform provider that allows smart control of the heat pumps, modulating flow rate and temperature in response to e.g. Time of Use tariff schedules developed by Energy Supplier.

Energy Supplier
If possible, data on expected half-hourly electricity usage following heat pump installation should be provided to an innovative energy supplier. The energy supplier pricing team should
Price a tariff for the customers in the local area a.) without any flexibility service (static changes only to field settings) and b.) with a dynamic flex service provided by the Heat Pump Optimisation and Flexibility Provider.

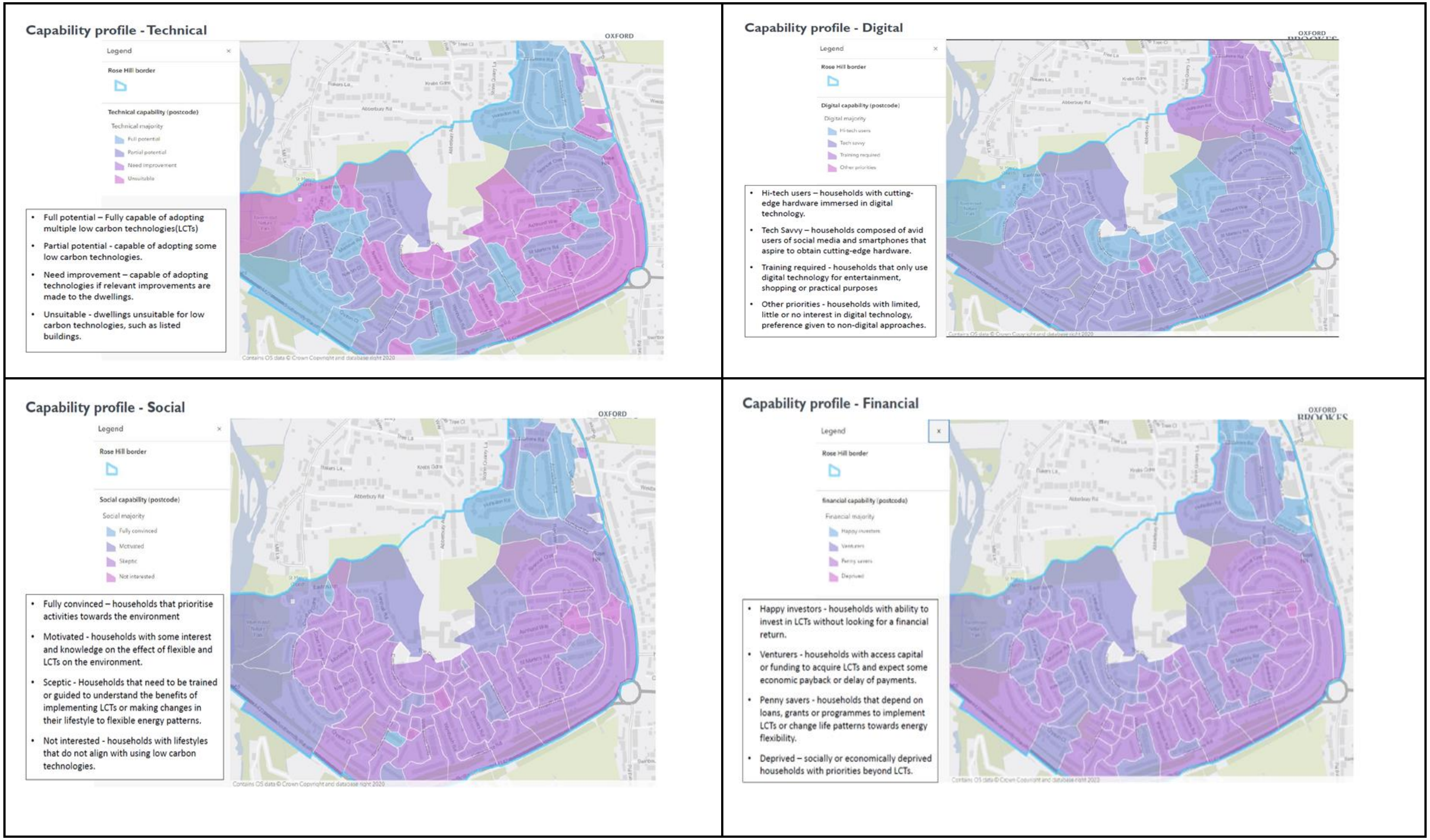
Local Community Groups
The involvement of local community groups is key to successful promotion and recruitment.

Other Local Organisations

Other relevant local organisations should be identified and asked to participate. For example, in Oxford Better Homes Better Health is Oxford County Council's contracted agency giving energy and welfare advice and assisting residents through the grant and funding application processes

Heat Pump Champions and Show Home Owners
The champions should be local residents and key to peer-to-peer social learning about the benefits of the technology.

Appendix 8: Mapping and targeting suitable areas and dwellings. The capability assessment includes consideration of technical suitability, likely economic circumstances, social and digital characteristics of each household in the target areas.



Capability profile - Technical

- Full potential – Fully capable of adopting multiple low carbon technologies(LCTs)
- Partial potential - capable of adopting some low carbon technologies.
- Need improvement – capable of adopting technologies if relevant improvements are made to the dwellings.
- Unsuitable - dwellings unsuitable for low carbon technologies, such as listed buildings.

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Capability profile - Digital

- Hi-tech users – households with cutting-edge hardware immersed in digital technology.
- Tech Savvy – households composed of avid users of social media and smartphones that aspire to obtain cutting-edge hardware.
- Training required - households that only use digital technology for entertainment, shopping or practical purposes
- Other priorities - households with limited, little or no interest in digital technology, preference given to non-digital approaches.

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Capability profile - Social

- Fully convinced – households that prioritise activities towards the environment
- Motivated - households with some interest and knowledge on the effect of flexible and LCTs on the environment.
- Sceptic - Households that need to be trained or guided to understand the benefits of implementing LCTs or making changes in their lifestyle to flexible energy patterns.
- Not interested - households with lifestyles that do not align with using low carbon technologies.

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Capability profile - Financial

- Happy investors - households with ability to invest in LCTs without looking for a financial return.
- Venturers - households with access capital or funding to acquire LCTs and expect some economic payback or delay of payments.
- Penny savers - households that depend on loans, grants or programmes to implement LCTs or change life patterns towards energy flexibility.
- Deprived – socially or economically deprived households with priorities beyond LCTs.

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Figure 9 Map layers showing indicators of technical, digital, social and financial “capability”

Further data layers include provisional DNO data provided by the local DNO quantifying headroom of the secondary substations, and also household tenure.

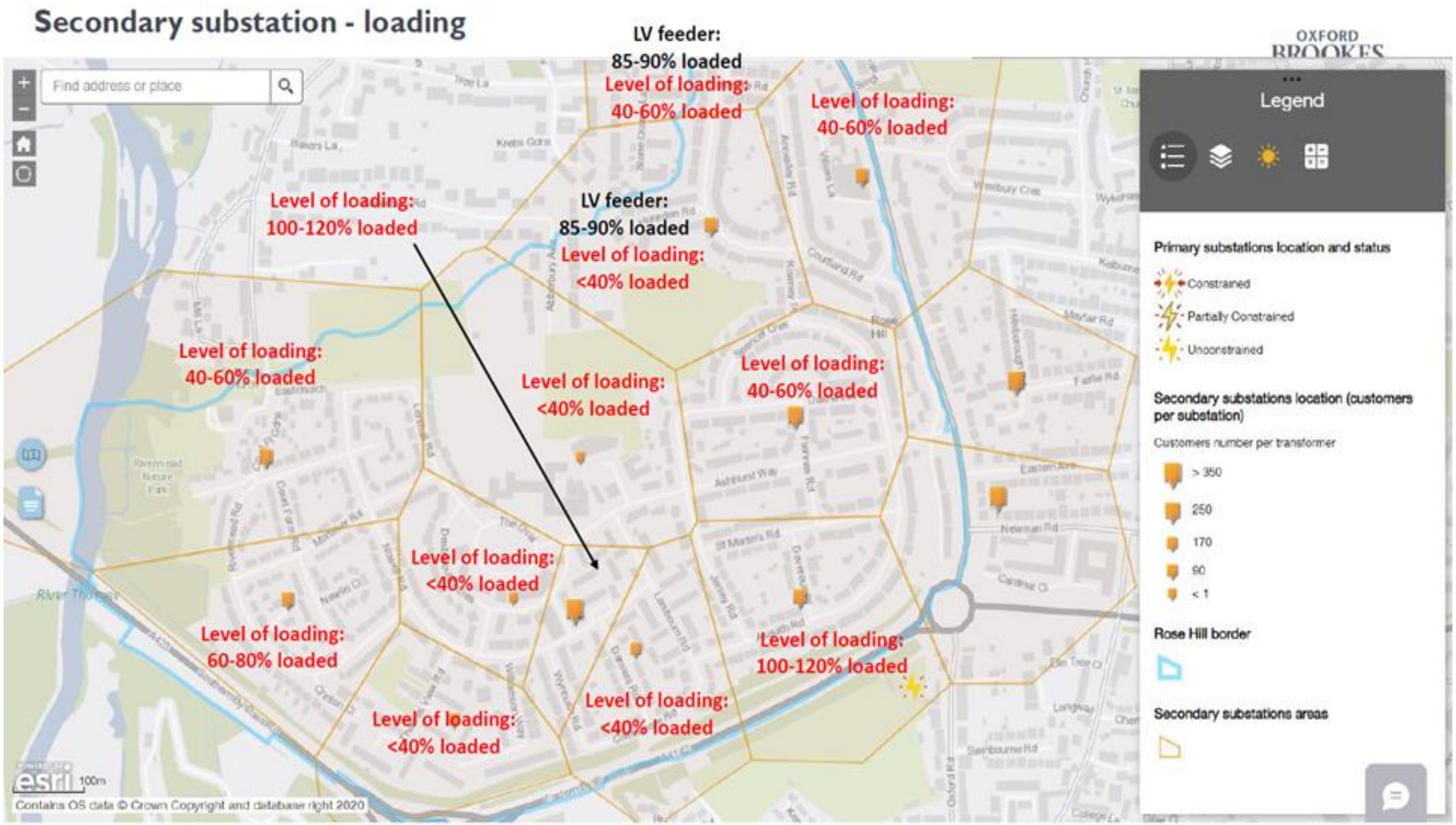
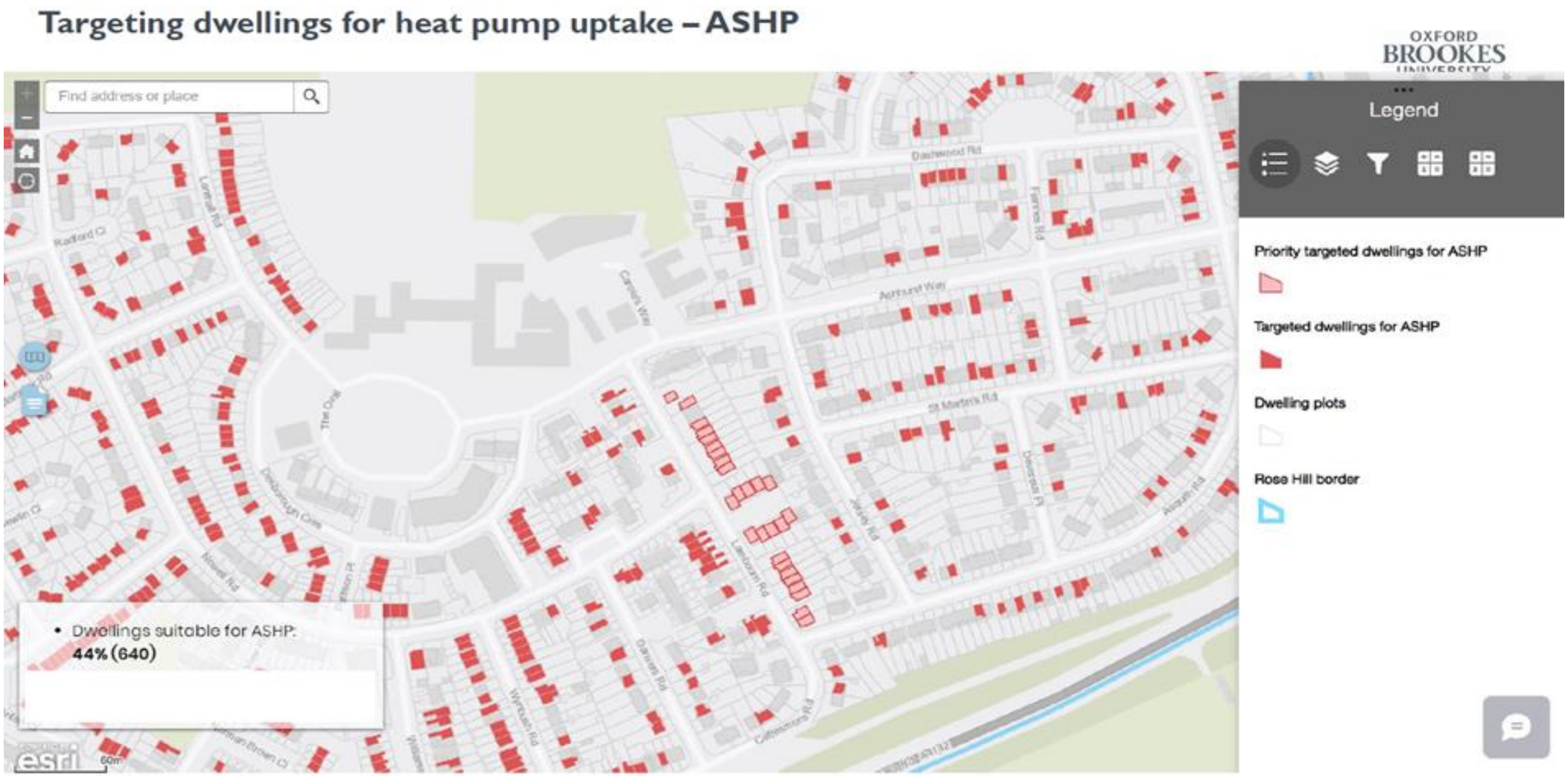


Figure 10: Map of substation loading in the target areas

Capability layers can be combined with information about network constraints to create a feasibility score for every property and postcode in the target areas. This allows a ranking to be produced and therefore a means of targeting the heat pump offer.



Targeting dwellings for heat pump uptake – ASHP

- Dwellings suitable for ASHP: **44% (640)**

Figure 11 Target dwellings for the CHS offer based on technical feasibility alone

These data allow the methodology to score and rank every postcode in the target area on the basis of technical suitability for a heat pump and the likelihood of householders to be both interested and capable of taking the offer.

This scoring and ranking allow us to develop a map for targeting individual households and postcodes with the methodology. Because the methodology provides data identifying both capabilities and wider priorities of the householder, our approach allows us to develop value propositions which can be targeted at individual postcodes and clusters of postcodes sharing the same attributes. Target areas suggested by the mapping tool should then be presented to Local Community Organisations in a workshop to verify the conclusions of the analysis and to capture further information about the neighbourhoods' social and economic structure, priorities and engagement strategy.

The methodology then further enriches datasets from the mapping tool with social, economic and technical information captured by our social "fingerprinting" method (see below). The method, deployed as a precursor to strategic local energy planning and in development of engagement strategy is innovative in a UK context and, we believe, will dramatically drive down marketing and other transaction costs when refined and scaled.

5.4 Develop the value proposition

CHS focus groups with local residents and the RHILC group, insights from the IPSOS Mori research and internal workshops with partners have been used to develop our engagement strategy. These sessions demonstrated the need to emphasise that in most circumstances the heat pump will save money versus incumbent gas boiler technology. See Focus group 1 Analysis for focus group findings. IPSOS research backed this up: "There was a clear view that whilst living more sustainably sits with people's values, it is not their priority. Their main priority is ensuring financial stability and a good quality of life for their households".

CHS focus groups also suggested a need to evidence benefits and savings from heat pump adoption for the customer - ideally using data about the householder's individual circumstances: rules of thumb and generalisations are far less persuasive than a savings model tuned to the household's unique circumstances. For this reason, we will, where available, use household smart meter data to calculate likely changes to electricity demand resulting from heat pump installation in the pre-design stages and also deploying Ivie Bud energy monitors as part of our digital engagement strategy giving real time data on energy consumption and savings. Where smart meter data is not available we will also explore use of a cost calculator which is sensitive to the demand profile of individual households and the technical characteristics of their home (floor area, EPC rating, built form). This will be informed by our innovative demand profiling method.

CHS focus groups also explored various financing offers to fund heat pump installation. This resulted in some clear recommendations e.g. a wish for a finance model where the monthly repayments on a low interest loan were matched to the savings from the heat pump. These insights suggest an engagement strategy which:

- Should calculate costs and benefits based on the household's unique circumstances;
- Offers a price for the heat pump installation that is similar to that of installing a gas boiler;
- Demonstrates that the running costs of a heat pump will be lower than those of using gas for heating and hot water;

- Provides ongoing feedback on savings and energy use once the system is installed to give useful feedback which will be helpful in engaging the householder and operating the system in a cost-efficient way.

Our research also suggests that non-financial aspects of the value proposition can be influential. For example, it was thought that owner occupiers of the Courtland Rd neighbourhood would be more interested in the environmental benefits of the technology. This evidence supports the segmentation approach we have taken throughout our engagement strategy - characterising each postcode on socio-economic and attitudinal characteristics as well as on the basis of technical feasibility of installation. These Insights from LEMAP and the focus groups were used to develop 4 distinct value propositions targeted at the following tenure-based segments:

1. Owner occupiers
2. Tenants - both private rented and social
3. Social housing landlords
4. Private rented landlords

Deployment of our methodology should include a community surveying approach and further workshops with community groups to develop these value propositions. See Value Propositions in Appendix 4: Evidence review: delivering flexibility from heat pumps

Below we provide the evidence review underpinning our findings on the behavioural and technical bases for delivering heat pump flexibility. The review was conducted by Dr Bryony Parrish at the Energy Group, Environmental Change Institute, University of Oxford.

Technical, economic and social capability to deliver flexibility from heat pumps

The deployment of electric heat pumps in UK households is expected to increase dramatically as part of heat decarbonisation (HM Government, 2021). As most UK home heating is currently provided by burning natural gas in individual boilers, the associated increase in peak electricity demand will pose challenges for electricity system operation by increasing the requirement for electricity generation and network capacity (Turvey, Clarke and Calder, 2018; Wilson, Taylor and Rowley, 2018). Flexible operation of heat pumps could reduce this requirement by shifting electricity demand away from peak periods; it could also provide other useful services as part of a decarbonising energy system, such as response and reserve services and load shifting to support increased penetrations of variable renewables (Turvey, Clarke and Calder, 2018; Rosenow *et al.*, 2020; Vaillant and geo, 2022). This short review focusses on evidence relating to shifting heat pump electricity demand away from peak periods because this is likely to be of more relevance at the distribution network level, and it is also the focus of the majority of evidence identified.

The need for flexible operation of heat pumps therefore originates with the needs of the electricity system, but it has the potential to impact on households in multiple ways; as such, it will depend on successfully engaging households to be both technically effective, and just or fair. To aid our understanding of household engagement, this work stream documents a range of capabilities that can support the flexible operation of heat pumps in homes. The capabilities approach is useful because it helps us to consider the influence of a holistic range of factors influencing the potential for heat pump flexibility at the household level: from technical and material, to financial, personal, and social (Roberts et al., 2020). It also helps us to consider how relevant capabilities may be distributed between households as users of heat pumps, and providers of flexibility services via the ways in which their offers may be designed and delivered (Banks, 2021). For brevity, this document refers to these two categories as 'household-side capabilities' and 'supplier-side capabilities' respectively.

The discussion is structured in two parts. The first part relates to capabilities that can support engagement with different forms of demand side response (DSR) – in other words, the mechanisms (such as time varying pricing, automation, or direct load control) that may be used to signal the timing of heat pump operation and respond to these signals. Such capabilities include, for example, access to enabling technologies and the ability to bear financial risk. This first section focuses on evidence related to household engagement with DSR in general, as well as evidence on DSR involving heat pumps. The second part relates to capabilities that can support changing the timing of heat pump operation in response to electricity system needs. These include, for example, the level of thermal storage provided by building fabric insulation. Reflecting the evidence identified, this relates only to flexing the timing of space heating, not domestic hot water provision

Capabilities for engaging with demand side response (DSR)

In general, DSR can involve manual demand shifting (in response to time varying pricing, or more rarely, information provision), direct control of household appliances or 'loads' by external parties (often known as direct load control or DLC), or automated response to time varying pricing (Parrish et al., 2020). None of the studies reviewed here involve manual demand shifting, which may reflect that heating is already largely automated via for example timers and thermostats, as well as that flexible operation of heat pumps may involve smart automation such as pre-heating. In BAU applications of DLC (many with AC in the US) households have typically been financially rewarded for participation (though this seems not to be the case in the trials reported here). The characteristics of different forms of DSR will influence the capabilities that are relevant to engaging with them, which are discussed further below.

Digital/technical: Access to, and capabilities to engage with, different types of digital technologies

Households will need access to appropriate smart meters and home broadband to engage with DSR. It is recognised that the reliability of home broadband connections can also limit DSR reliability (Frontier Economics, 2015; NEDO, 2017; Sweetnam et al., 2019).

Capabilities to engage with different types of user-facing controls are also key to households actively engaging with DSR. For example, within NEDO low engagement with pre-opt out of DLC events occurred because this function could only be performed via an app, and many households reported low desire or ability to engage with the tablet provided as part of the trial (Calver, Mander and Abi Ghanem, 2022). On the supplier-side, the design of user-facing controls can therefore strongly influence households' capability to engage with DSR in the intended ways. It can also influence perceived control, with potential implications for acceptance of DSR. For example, the EcoGrid EU (2016) evaluation found that participants with more control options felt more positive about DLC, although they did not override control any more frequently than other groups. Conversely, Sweetnam et al. (2019) describes participants feeling a lack of control because their user interface did not provide any feedback on the timing of temperature changes when they make adjustments to heating schedules; similarly, Calver, Mander and Abi Ghanem (2022) found some households preferred their previous analogue temperature controllers (such as pin controllers) that clearly showed the heating schedule.

Financial: Capability to bear financial risk

If DSR signals involve time varying pricing there is a risk that households may pay more for electricity if they do not sufficiently flex the operation of heat pumps (and potentially other electrical loads). Some households will have greater capability to bear this risk than others because of their financial situation. There is also a risk that households with less financial capability feel compelled to flex electricity use in response to time varying pricing, even though this may have negative impacts in other ways (Crawley et al., 2021).

DSR providers can support the capability to bear financial risk by offering shadow billing/bill guarantees. In this arrangement, households are able to trial time varying pricing for a defined period of time with the guarantee that they will not be charged more than they would have been charged on a flat rate (Parrish et al., 2020). Bill calculators can also be used to offer households an idea of whether they will save money on time varying pricing, but their effectiveness depends on households being able to predict the extent to which they will be able to flex demand, which may not be possible for novel loads like heat pumps.

Financial risk can also be reduced through developing household-side and supplier-side capabilities that support flexible heat pump operation, as described above, and through DSR offers do not involve time varying pricing. Financial incentives or rewards for DSR can still be offered through, for example, payments for participating in DLC for reducing demand below a calculated baseline during defined peak periods.

Personal/social: Knowledge and understanding of DSR

Flexible operation of heat pumps was automated in some way in all studies reviewed. Nonetheless, these studies indicate that the technical effectiveness of heat pump flexible operation can be limited if household members are not effectively made aware of or do not fully understand direct load control of their heat pumps or automated responses to time varying pricing. Equally importantly, this can risk fairness to households and their trust in DSR over the longer term.

Frontier Economics (2015) and Calver, Mander and Abi Ghanem (2022) suggest that low awareness of when DLC is happening – and, in the case of Calver, Mander and Abi Ghanem (2022), what DLC actually entails – can lead to households unintentionally overriding DLC events by interacting with thermostat controls. Similarly, Sweetnam et al., (2019) reported households overriding automated responses to time varying pricing. It is not clear whether this resulted from a lack of understanding or knowledge of DSR, issues with thermal comfort, or both. However, Sweetnam et al., (2019) also note that night-time operation can cause confusion about whether system was operating incorrectly or wasting electricity, which does indicate a lack of understanding of pre-heating.

Overriding by households has the potential to limit the effectiveness of heat pump flexibility from the electricity system perspective, and in the case of automated response to time varying pricing, risks households paying higher bills. Low knowledge and understanding of DSR is also a risk to achieving fairness and justice in the implementation of heat pump flexibility (Calver, Mander and Abi Ghanem, 2022); to households' trust in DSR over the longer term (Parrish et al., 2020); and to the extent to which we can conclude, based on trial data, that households would be accepting of DLC as part of a wider roll out (NEDO, 2017; Parrish, Hielscher and Foxon, 2021).

In CLNR, participants were unaware of the timing of DLC because the controls/user interface were not designed to notify participants of when events was happening (Frontier Economics, 2015). In the NEDO trial, households had low awareness of DLC overall, which resulted from a combination of factors (Calver, Mander and Abi Ghanem, 2022). DLC was implemented by default when households accepted heat pumps as part of the trial. At the start of the trial, households often felt overwhelmed by information, and although written information about DLC was provided in a booklet along with information about heat pumps and other aspects of the trial, this may have been too lengthy and unclear to be useful. Households were unable to opt-out from DLC altogether, and although they were notified of and able to pre-opt-out from individual DLC events, as discussed above these functions were only available via an app that few participants actually engaged with. Participants could also opt-out from DLC by adjusting the thermostat while DLC events were taking place, but as in CLNR, the absence of effective notification means they may have been unaware that this is what they were doing.

On the supplier-side, households' knowledge and understanding of DSR could therefore be supported through more effective design of user interfaces (considering what information is provided, and through what means) and through more effective provision of information (which could helpfully include follow up information provision over the course of the trial, as well as clearer signposting of relevant information in written brochures or other materials). More generally, evidence from these studies indicates that it is important for households to have some knowledge and understanding of heat pump flexibility even when this is mediated by automation or DLC (i.e. does not require manual demand shifting). This will likely need to be combined with other capabilities that support flexible heat pump operation, as described above.

Social: Trust in DSR offers

In general, trust in DSR offers may be reduced when households have concerns around privacy and autonomy connected to direct load control and suppliers' motivations for pursuing it (AECOM, 2011; Bartusch et al., 2011; Wiekens, van Grootel and Steinmeijer, 2014; Lopes et al., 2016). Trust may be promoted through transparency around the timing and purpose of DLC or automation (Lopes et al., 2016) (Buchanan et al., 2016; Lebosse, 2016) (Carmichael et al., 2014; Wiekens, van Grootel and Steinmeijer, 2014), as well as through providing information on DSR from independent sources (Hall, Jeanneret and Rai, 2016) and involving trusted actors in recruitment (Bird, 2015; Western Power Distribution, 2016).

When considering trust in flexible operation of heat pumps specifically, it is worth noting that many of the studies reviewed were conducted in the context of social housing. Engagement with DSR is therefore likely to be based on existing trusted relationships with social housing providers, and as described above, may involve low awareness of DSR amongst households; in turn, this may contribute to relatively low levels of reported concern about loss of control, data privacy and similar issues (Calver, Mander and Abi Ghanem, 2022). However, it should be noted that not implementing DSR in a transparent way risks damaging trust in the longer term, both within households and through reputational effects (Parrish et al., 2020).

Capabilities for flexing the operation of heat pumps

In contrast to the previous section, which related to capabilities for engaging with different forms of demand side response (DSR), this section discusses capabilities relevant to engaging with actually shifting heat pump electricity demand in time. It first considers capabilities on the household-side: that in some way increase thermal storage, thus decoupling changes in electricity demand from changes in heat provision in the home, and that support living with changes in home heating resulting from heat pump flexibility. It then discusses how the design of heat pump flexibility offers might support household engagement with heat pump flexibility, and supplier-side capabilities that may be required to manage heat pumps' impact on the low voltage network as a result of such changes in heat pump flexibility offers.

Household-side capabilities that may increase potential for flexible operation of heat pumps

Technical/material and financial: access to thermal storage

Greater levels of building insulation and thermal mass can support the flexible operation of heat pumps by helping to maintain indoor temperatures despite reduced electricity supply to heat pumps (Vaillant and geo, 2022). Retrofitting building fabric insulation can therefore increase the potential for heat pump flexible operation, as well as reducing heat pump peak demand and impact on the low voltage network. Dedicated thermal storage, in the form of hot water buffer tanks or heat batteries utilising phase-change materials, can also support heat pump flexibility (Rosenow et al., 2020; Vaillant and geo, 2022). Some homes will have existing hot water buffer tanks that can be used for this purpose, but many homes in the UK have removed hot water tanks after installing combi-boilers (Sweetnam et al., 2019). Additional thermal storage could be added alongside heat pump installation, but requires sufficient space; this suggests a possible link between the size of homes and the affluence of households, and their capabilities for heat pump flexibility (Crawley et al., 2021). Phase-change material heat batteries are both smaller and lighter per unit of heat stored, which can make them easier to fit into homes (Energy Saving Trust, 2022).

Technical/material, personal and social: capabilities that support living with changing heating patterns

Flexible operation of heat pumps has the potential to change the indoor temperatures experienced by households, as well as the noise of heating system operation at different times. Amongst the studies reviewed, pre-heating is a notable control strategy in this regard. This involves increasing indoor temperatures in advance of DSR events, in order to limit any drop in temperature below users' settings during DSR periods (Turvey, Clarke and Calder, 2018; Sweetnam et al., 2019). While the emphasis is on maintaining minimum indoor temperatures during peak demand periods, pre-heating can also have the effect of increasing indoor temperatures during night-time and daytime periods, as well as creating noise from heating system operation at those times (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021). This control strategy may therefore require capabilities that enable households to avoid, tolerate or appreciate higher room temperatures and any noise from heating system operation at these times. More constant operation can also improve the efficiency of heat pump operation independently of demand shifting, so such capabilities can also support more efficient heat pump operation in general.

Day-time heating: Although many UK households typically do not heat homes during the day time, even if they are at home (Hanmer et al., 2019), more constant daytime heating may be appreciated by households who spend time at home during the day or enjoy warmer temperatures when returning home in the evening (Parrish, Hielscher and Foxon, 2021; Calver, Mander and Abi Ghanem, 2022). Households who already heat homes during the daytime can also benefit because the technical characteristics of heat pumps may allow this heating schedule to be provided at lower cost than alternatives such as gas boilers. Understanding that, in contrast with gas boilers, more constant operation of heat pumps can reduce running costs may help households to appreciate daytime heating (Sweetnam et al., 2019).

Night-time heating: households often find sleeping in warmer temperatures uncomfortable; pre-heating during night-time can therefore be supported by capabilities that allow households to avoid experiencing warmer temperatures within bedrooms, including the presence and use of thermostatic radiator valves on bedroom radiators, as well as sufficient thermal insulation between rooms (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021). These capabilities could be enhanced through installing thermostatic radiator valves and supporting households to use them effectively. It may also be helpful to assess levels of internal thermal insulation and, where appropriate, discuss the possibility that households may experience higher night-time temperatures, whether this is something they are willing to try, and what strategies they might use to respond. For example, opening bedroom windows can help to avoid the experience of night-time heating (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021) but will reduce heating system efficiency and would preferably be avoided.

Capabilities to avoid or tolerate noise from night-time heating operation can also support this form of pre-heating (Parrish, Hielscher and Foxon, 2021). Different people have different sensitivities to noise while sleeping, but these capabilities could potentially be enhanced if it is possible to locate heating equipment – including heat pump units, but also central heating pumps – at a greater distance from bedrooms.

While the logic of pre-heating is to limit decreases in internal temperature, if there are unavoidable impacts on household comfort it may be useful to consider changing the offer by reducing the extent of pre-heating and allowing indoor temperatures to drop to some extent (Sweetnam et al., 2019). Even when pre-heating was not applied, control strategies applied in the reviewed studies were limited: for example, in the NEDO trial DLC automatically ended if room temperatures fell below 18^{o}C or more than 2^{o}C below thermostat set temperature (NEDO, 2017). However, as noted by Crawley et al., (2021), while this function is designed to protect customers it also has the effect of reducing their agency to choose when and how flexibility is provided. Thus, it may also be useful to consider which capabilities may enable households to tolerate decreases in room temperature in peak demand periods, during, for example, a limited number of critical periods each year.

Evidence related to DSR more generally suggests that capabilities to support this may include the availability of alternative sources of heating such as fireplaces (VTT, 2004; Lebosse, 2016) or the ability to spend time outside the home during DSR events (Strengers, 2010; Carmichael et al., 2014). More broadly, Strengers (2010) observed that flexible operation of AC in Australia was supported when households had maintained knowledge and skills in traditional ways to keep cool at home, which provided alternatives to AC use. In the context of heating, this might include, for example, access to and willingness to use warm indoor clothing and slippers. However, any such approach would need to ensure avoidance of any negative impacts on households – including the possibility that less affluent households may feel pressure to participate in DSR despite possible negative impacts (Crawley et al., 2021) and the potential for detrimental health impacts, particularly for household members such as young children, older people or people with limited mobility or existing health conditions.

Supplier-side capabilities relevant to flexing the operation of heat pumps

Suppliers of heat pump flexibility products and services could support the development of the household-side capabilities outlined above in various ways, which also require relevant capabilities on the supplier-side. For example, installer interactions with households could provide an opportunity to develop capabilities related to living with changed patterns of heating – but installers may lack the social capabilities to engage in this type of work (Parrish, Hielscher and Foxon, 2021). In addition, designing DSR offers to enable household engagement with heat pump flexibility may affect the potential for electricity system services provision, and require actors such as distribution system operators to possess capabilities to manage the electricity system in other ways. This is the topic of this sub-section.

Limiting the duration of DSR events can limit reductions in indoor temperatures, even in homes with limited technical capabilities to enable thermal storage. For example, in the CLNR and NEDO trials direct load control was limited to between 30 minutes and 1 hour (Frontier Economics, 2015; NEDO, 2017). However, relatively short duration DSR will obviously tend to reduce the time over which flexible heat pump operation can reduce peak electricity driven network congestion; some trials have tested staggering DSR across different populations of heat pumps to extend the total period of demand reduction, but secondary demand peaks limit the effectiveness of this approach (Frontier Economics, 2015; NEDO, 2017), although they could potentially be addressed through more sophisticated control strategies (Frontier Economics, 2015). Lowering heat pump flow temperatures (rather than curtailing electricity supply) may provide an alternative approach to limit decreases in indoor temperature while maintaining DSR for longer periods within individual households.

The timing of DSR events may also be designed to limit impact on households: in the NEDO trial, DSR design avoided night-time operation of heat pumps, at the request of social housing managers who were concerned this may be disturbing to tenants (NEDO, 2017). Limiting the timing of DSR events will obviously limit the times at which DSR can provide electricity system services, implying that capabilities for alternative/additional forms of electricity system management may also be required. However, supporting the development of household-side capabilities that enable heat pump flexibility could reduce the need for such supplier-side capabilities, demonstrating their interrelationship and the value of the capabilities approach.
Appendix 5: Value propositions for four tenure segments.

5.5 Householder engagement, advice and recruitment

It should be noted that the methodology in this section has been constrained by the conditions that BEIS placed on the methodology deployment. BEIS required the methodology to include stage gates, which meant the methodologies cannot include immediate installations to householders when they are recruited. If the methodology is replicated, we recommend not following the stage-gate approach as it means that households in most need of a new heating system (those whose heating systems are end-of-life) cannot be recruited unless they are prepared to live with an end-of-life heating system for weeks or months. Once the secondary substation areas have been selected, the targeted address list, together with publicly available data (such as EPC, council tax band, etc…) should be made available to partners via the IDMS.

5.5.1 General approach

Innovative energy technology and practices spread through communities through social networks: people tend to trust the opinions and experiences of their neighbours and friends more than information from institutions or businesses. The denser and more trusted the network of relationships are, the quicker and deeper the innovation will spread so long as the innovation confers an advantage over the incumbent technology (here, the gas boiler) (McMichael and Shipworth, 2013).

First-hand experience of the technology and social learning is also highly effective - seeing a heat pump in action, feeling the warmth it provides, seeing a successful installation in the home of someone local, someone like 'me'. For these reasons, key components of our engagement strategy will involve:

- Working with trusted embedded individuals and organisations in the target community;
- Working with, and building where possible, social capital in the area (where "social capital" describes the density and range of trusted social relationships in the area);
- Creating opportunities for social and peer-to-peer learning including through the use of two show homes on each secondary substation catchment which will each have an open day every 2 months. The show homes will alternate their open day so that there is one open day in each secondary substation catchment every month through phase 2a of the project (each show home therefore running approximately 6 over the course of the year);
- The owners of the show homes will become advocates of the project - heat pump champions. They will be supported by project staff throughout with materials and staff resources; and
- We will also support those installing a heat pump through the project to become advocates for the project with their friends and neighbours.

Recognising the critical importance of social relations and making this foundational in our engagement approach is, we believe, quite innovative and will serve the broader purpose of driving down transaction costs in the heat pump offer.

5.5.2 Start with the groups most likely to adopt to secure critical early installations

Our methodology suggests we need to first engage the early adopters (who will become "heat pump advocates") but then very quickly engage the much larger group of householders who must follow if dense installation of 25% of homes is to be achieved. This group, often termed the early majority, has different priorities to the early adopters e.g. this group is thought to need to see "social proof" that others in the area are adopting the technology suggesting that establishing a social norm for heat pump adoption will be important in our engagement strategy. The early majority are also thought to be more concerned with financial aspects than early adopters. There are a number of specific areas in the early stages where best practice and innovation will apply.

5.5.3 Initial engagement

The first step in the engagement and recruitment process will be a door-to-door survey to collect details and data from householders within the target areas, conducted by the Local Energy Project Officer. This "Fingerprint survey" will help gain a richer understanding of the community but will also be used to identify households with a smart meter. If the household doesn't have a smart meter, they will be directed to information on how to obtain one via the IDMS. For the households owning a smart meter, consent forms for the access to their energy data will be integrated into the survey. These householders will be offered an Ivie Bud – external link, to improve data accuracy for the process following householder recruitment.

5.5.4 Develop the digital and non-digital engagement strategies

Using data collected from the Fingerprint survey and insights gained from the CHS focus groups, the following digital and local engagement strategies will be deployed by the Local Energy Project Officer and Householder Engagement specialists:

- Recruitment of 6 local residents in the targeted substation areas to become Heat Pump Champions;
- Local events in the community, including the school and community centre;
- Face to face interactions with local groups and clubs;
- Distribution of posters and leaflets advertising the project;
- Advertising in local newspapers and newsletters;
- Digital advertising geo-fenced for the target area and Google search ads;
- Social media marketing with local groups and influencers; and
- Dedicated forum on the project website to stimulate peer-to-peer to support and advise householders at all stages in the process, from different stages of the engagement through to post heat pump instalment stages.

All streams of engagement will direct householders to a link to the IDMS where they can access information about the project and to sign up their interest.

5.5.5 Building trust and interest in the offer

To further develop trust in the offer we will show householders all costs associated with the installation and running of their heat pump throughout the householder journey. These cost estimates will increase in accuracy, from the initial estimate at “expression-of-interest” stage, to a refined estimate following a home survey with capital plus install costs fixed and a more accurate estimate of running costs. Post installation we will provide data on actual running costs to provide user assurance. This is particularly important given the IPSOS householder research that users find the idea that having the heating “always-on” can be cheaper and is counter-intuitive.

By integrating GenGame/Chameleon’s software and hardware technology as part of the methodology we will be able to improve the accuracy of predicted energy profiles and costs for a heat pump installed in the householders property.

At the ‘expression-of-interest’ stage, using GenGame’s innovative algorithms, householders' historical energy profile data of the existing heating system will be used to make comparative energy usage and costs for a heat pump system in similar property type and circumstances. This technique can also be applied to post-install households, with a direct comparison of householders' energy usage and costs of their heat pump against their old heating system. The ability of householders to view these comparisons will have several impacts:

- Providing data based on the householder's own circumstances will increase the accuracy and engagement;
- Data gained from post installation households can be used on CHS platforms and in social media to drive more engagement for heat pump uptake for other households in the area;
- Householder data stored on the GenGame utility dashboard can be one of the data sets to evaluate the project.

GenGame’s tools give the householder a unique perspective to help them understand and monitor their energy usage and costs through forecasting features and granular insights. Personalised advice based on the householder energy profile and behaviour will also be used to support more efficient running operations of their heat pump.

5.6 Feasibility, design and installation

Following receipt of expression of interest there are number of steps required to determine suitability of the home, design, install and commission the system. These are described below:

5.6.1 Information collection and input stage

During the recruitment stage householders should be given the link to the IDMS. When they sign-up they should provide sufficient data to match the household to an archetype and complete an initial MCS compliant cost estimate (installation plus running costs). If the customer has a smart meter the IDMS will request access to the smart meter data via the Smart Meter Data partner to improve the ballpark estimate. Where more information is needed, engineers from the Heat Pump Installation Service Provider should contact customers to request further information and photos or videos.

In terms of suitability, a home will be judged as suitable if the system will have a seasonal coefficient of performance of at least 2.8 at a design temperature of under 55 degrees. If the home is not judged as suitable, the local authority convenor should suggest energy efficiency measures to allow the home to meet the minimum standard. This would be paid for separately by the homeowner, or by using grants where the homeowner qualifies.

5.6.2 Pre-design stage

The household will then move to the pre-design stage where the methodology will calculate expected heat-loss based on the information from the input stage. This will generate an annual energy performance estimation and initial quote. The householder will then indicate through the IDMS their wish to move forward to the survey stage to confirm the initial quote.

5.6.3 Survey and design stage

At the survey stage, a home survey should be conducted by the installation service provider design specialists. Once the survey is complete, the Heat Pump Installation Service Coordinator will either confirm the initial quotation, or update the quotation based on the survey findings.

The “minimum viable quote” will include minimal alterations or additional works to achieve a SCoP of over 3 and design temperature under 55 degrees; as well as the minimum viable quote, the survey will include upgrade options with the costs and energy savings of optional works.

This will be made available to the Local Energy Project Officer (Convenor) via their log-in to the IDMS who will visit the home to talk the homeowner through the survey. This approach gives the homeowner options and reduces drop-out due to the perceived barrier of “additional and significant costs required to adapt homes for their use such as insulation, fitting underfloor heating and new pipes and radiators”. Once a householder is happy with the quote they will confirm by making a payment to the installation service provider, accepting the terms and conditions and booking in a date for the installation.

5.6.4 Installation Stage

The Installation Stage is focused on achieving the highest installation and system efficiency output. Using inputs from the design phase to produce a configuration file for the Unit to allow pre or remote configuration. We will also organise and quality assure the installer's work.

5.6.5 Post installation Stage

Using in-situ monitoring data and customer feedback post-installation we will refine the configuration of the Unit (using remote configuration capability) to improve efficiency and performance. A key component of the post installation stage will involve a in home visit from the local energy officer to ensure the system has been commissioned to meet occupant heating requirements, answer any questions, solve any minor snagging issues etc. We hope that by investing in post install support in this way, households will feel confident in operating their new systems and have the knowledge and skills to operate their systems correctly thereby achieving cost saving and environmental benefits. They will also be enabled to become skilled advocate for the project and the technology amongst their friends, neighbours and family.

5.7 Responding to network issues - demand profiles and interventions

Involvement of the DNO is essential to the success of the methodology. To reduce the risk the DNO should be involved in the consortium deploying the methodology. The DNO should deploy low voltage (LV) network monitoring devices to the transformers being targeted to provide visibility to all parties of network demand impacts. During deployment the partners should work with the DNO to:

- Use data from redeployed monitoring devices to update network readiness estimates used during the mapping stage;
- Carry out connection designs, and explore options for overcoming constraints. This will involve assessing connection requests and looking at different impacts of setups, i.e. standard HP connections, those with some randomisation applied to timings, and those with more flexibility built in;
- Assess expected load profiles, reviewing against design standards, confirming how the DNO will model connections;
- Explore integration between LV monitoring data and the in-home LCT control systems
- Support the FSV setting process, and imparting DNO experience on use of randomisation and schedules in Load Managed Areas;
- Explore how the DNO could update their connection process based on the innovative methodology and/or solutions demonstrated in project.

Installations and post installation monitoring

Prior to installations, the heat pump units should be either be pre-loaded with the recommended settings for the household (recommended by the installation service provider and stored in the IDMS), or the settings should be set using remote commissioning at the end of the installation process.

A key part of the methodology is to remove the installer from the commissioning, set-up and post installation process, but there will be some training to ensure that installers understand the methodology as they will be householder facing.

The main training provided should be for the design and commissioning engineers at the Installation Service Provider, for the local energy convenor and for the heat pump evangelists. These will be the parties responsible for explaining the initial survey, then the pre- and post-install householder contact.

Following the installation, the installation service provider should refine the field-setting values (including but not limited to the weather compensation curve) at two points post-installation: firstly - to check the hot water heating performance 1 month post installation; and secondly - to check the space heating performance either 1 month post installation if during the heating season, or 1 month after the start of the heating season if the installation is not during the heating season. This check will comprise:

- Performance check using performance data retrieved from the heat pump via a remote monitoring system;
- User comfort check via call with the end user to discuss their heating and hot water experience;
- Remote changes to FSVs to improve performance and comfort.

This is a highly innovative approach as there is currently little innovation in FSV configuration to "keep things simple" for installers who currently configure settings manually.

6 Areas of Innovation

Our methodology has innovation at all stages of the householder journey. We draw on the social science of innovation adoption, behavioural science as applied to communications, novel statistical approaches to cluster analysis to create demand profiles, latest techniques for mapping technical and socio-economic data, new systems for remote commissioning of heat pumps and innovative business models to provide back office services to heating installers. Further detail of the innovation at each stage of the customer journey is provided below.

6.1 The Information and Data Management System

A central part of the methodology is the Information and Data Management System. This will include a user role for the householder to register their interest and then to manage their customer journey, and for each consortium partner to have access to the information and data they need to carry out their tasks.

6.2 Umbrella back office services for installers

The installation service provider services will provide “umbrella” back office services to a pool of local installers to oversee customer journey and installer workflow management and tackle some of the design and administrative barriers allowing existing local heating engineers (typically microbusinesses) to focus on heat pump and hydronic system installation.

6.3 Community surveying

A key part of the methodology during the householder engagement phase is a community survey of the area to understand how the community is structured, its priorities and attitudes, key points of influence and basic technical information about the home and its energy services[32]. Deployment of the innovative community survey methodology will be a key step in the design of the targeted engagement strategy and in smart interventions.

6.4 Demand profiling

We have developed a novel method of creating demand profiles based on cluster analysis of smart meter data collected as part of the EDRP project. Using information about internal and external temperatures and deriving Seasonal Coefficient of Performance we have been able to calculate how a gas demand profile transposes to electrical demand where a heat pump is used instead of a gas boiler to heat space and hot water. We have further developed novel methodology for associating demand profiles with ACORN classifications. This allows us to analyse the socio-economic and demographic variables which influence demand profiles such as occupancy and life stage and to develop tailored heat pump value propositions related to adoption of the heat pump and to design interventions (such as ToU tariffs and Direct Load Control) to change the shape of electricity demand. To our knowledge this has not been attempted before in a heat pump trial.

We have further developed methodology to link these profiles to postcodes in our target area via the geodemographic ACORN classification tool and the MOSAIC classification tool. This allows us to design engagement strategies tailored for each post code and anticipate how various smart

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[32] See Bouw, K. et al Social fingerprints: Social characterisation of neighbourhoods as design frame for sustainable communities. (ECEEE summer study proceedings 2022).

interventions (e.g. ToU tariff, Direct Load Control, energy advice and feedback) will influence demand profiles we find there.

6.5 Mapping social, economic, technical and personal capability

Using our LEMAP mapping tool we have built up a detailed description of the socio-economic, technical, and digital capability profile of each postcode in our target area. This allows us to develop highly targeted value propositions and to anticipate, and plan for, the number of likely customers for the heat pump offer in each area. LEMAP also contains layers showing the headroom of each secondary substation in our target areas. Therefore, we can anticipate where concentrations of heat pumps could lead to network problems and work with our partner SSEN to develop smart solutions to head off network issues.

6.6 Local Area Energy Planning, co-design and value proposition development

Our methodology involves local community groups and residents to develop the value proposition for different segments and to get community inputs into other planning and engagement activities taking place in the area. Many of the engagement activities are informed by a Local Area Energy Planning approach. Drawing on experience from LEO we have developed a methodology for working up value propositions with local residents in a workshop setting. Local Area Energy Planning approaches are still being tested and represent a genuine innovation in planning processes for facilitating net zero initiatives at the Grid Edge. Scenario modelling using the LEMAP tool and central involvement of a trusted dedicated local energy officer or “convenor” (employed by Oxford City Council) to oversee the customer journey of each client are other instances of a LAEP approach.

6.7 Ethical engagement

We consider an ethical approach to engagement critical to the project’s success. Therefore, early in the deployment phase, the methodology requires development of a framework and code of practice to inform engagement activity. We believe formally developing a guide to ethical conduct for the project represents an innovation in governance for projects of this type.

6.8 Digital engagement

Our partner, GenGame, has developed a digital engagement strategy which ensures CHS has a presence on the major social media platforms as well as local online publications and social networks. In addition, the methodology includes a forum, evolved from the LEMAP tool to encourage interaction between people at different stages of the householder journey. The forum will be integrated into the project IDMS together with use cases and video testimonies, for people to share their personal experiences of getting a heat pump; thereby supporting peers who are at an earlier stage of the journey.

7 Costs to Householders

To achieve a high-density take up, the offer must be competitive with the cost of a replacement gas boiler and the running costs must be lower than the running costs of a gas boiler. If the methodology can't assure householders on this it will be impossible to move beyond the eco-conscious householder segment.

By following the methodology we anticipate savings of over 40% compared to the benchmark costs provided by BEIS prior to the feasibility study[33]. The cost reductions are achieved through:

- Reducing selection, engagement and marketing costs (i.e. transaction costs) by targeting households whose homes are most suitable and who are most likely to take up the offer of a heat pump;
- Dramatically increasing the penetration of awareness of the offer by working with embedded organisations and using social learning techniques (heat pump champions and show homes). This will significantly reduce marketing costs;
- Reducing drop-out rates by creating a compelling value proposition tailored to targeted areas and postcodes and providing trusted support to the householder via the project officer hand holding customers through the customer journey. Dropout rates are also reduced by automating the initial sign-up and survey stage, allowing an initial estimate and offer to be made to the householder before a full survey takes place;
- Specialisation to separate out design and administration tasks (that can be done by more specialised and experienced workers, and part-automated) from the installation activity that can be carried out by upskilled gas heating engineers. This reduces the cost of installation as under this model the installation day rates are the same as for gas heating installers;
- Use of archetypes for the heat pump design which are matched to a household at pre-design stage and then confirmed with a home survey;
- Reducing equipment costs through scale (heat pumps provided direct from Heat Pump Technology Provider to the Heat Pump Installation Service Provider);
- Our work to set complex default FSV settings at commissioning will allow more efficient running of the systems resulting in cost savings for end-users;
- A high-density of heat pump surveys and installations slightly reduces travelling time between appointments, though this is not a significant saving.

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[33] See https://www.contractsfinder.service.gov.uk/Notice/Attachment/003dd4f0-cfb1-4d61-b85d-5b1633376c6c page 17

8 Recommendations

Our methodology is innovative, identifies areas which are best suited for high-density deployment, and leads to significant cost savings allowing an attractive offer to be made to homeowners to replace their non-renewable heating system. It provides support throughout the process and uses locally trusted groups (people embedded in the community) to provide help and support.

Whilst we expect the costs associated with the purchase, design and installation of heat pumps to fall further as volumes increase, the equipment needed and the design and installation time will always be higher than that required to replace a boiler like-for-like. Therefore, for our methodology to be successful without the £5k per unit subsidy, it will require Government to follow through with commitments to either increase the cost of a gas boiler swap-out, restrict the installation of gas-systems and/or adjust policy to ensure that the gas to electricity tariff ratio is guaranteed to remain below 2 or 3 (i.e. if electricity price is 30p then the gas price should be at least 10 or 15p/kWh.

As long as a gas boiler replacement remains an easy and cheap option, it will be impossible to achieve scale. To achieve a successful high-density deployment we recommend the following steps:

8.1 Project management and skills required

1. Develop a consortium comprising:

    - Methodology Project Manager;
    - Information and Data Management System (IDMS) provider;
    - Heat Pump Technology provider(s);
    - Local Authority;
    - Mapping tool provider;
    - Data Forecaster;
    - Householder Engagement specialists;
    - Heat Pump Installation Service Coordinator;
    - Heat Pump installer;
    - Smart Meter installation and Data partner;
    - Renewable Heating System Consultant;
    - Distribution Network Operator;
    - Heat Pump Optimisation and Flexibility Provider;
    - Energy Supplier;
    - Local Community Groups and Organisations.

2. Set-up necessary commercial agreements between the parties to ensure they can work together to deliver a high-density deployment;

3. Set-up work streams within the consortium and agree efficient project management processes;

4. Set up an Information and Data Management System, including a front-end allowing partners to log-on with different user roles to input and access information and data;

5. Develop project support and guidance documents. In particular, develop documentation describing the detail of how the project will be conducted ethically. Key to project success will be creating trust in the offer and the entity delivering the offer. Ethical delivery of the project is key to trust building and therefore to project success.

6. Work with a Data Forecaster to estimate the changes to gas and electricity profiles (half-hourly usage) from a household switching from a gas boiler to a heat pump (including use of smart meter data where available);

7. Work with an organisation with expertise in mapping technical, economic and social variables to find the most suitable neighbourhoods within the Local Authority area to target. We recommend a “capability” lens framework as well suited to this task.

8.2 Working with local communities

8. Always capitalise on existing relationships with the target community – local groups, clubs, centres of congregation etc. Where relationships are vestigial or non-existent we recommend that significant resource is invested in building relationships and therefore trust through organising events, giving talks, building a project presence in the community and a sense of community ownership.

9. If a local group with a general interest in sustainability exists within community, reach out to it and involve it from the earliest stages in informing project design. Consider giving the group a formal role in the project with budget ring fenced for its activities. The evidence suggests that a critical factor determining success of community energy projects is the presence of an engaged, skilled and resourced local group embedded in the community (Bridgeman et al 2019).

10. Work with the Local Authority to employ and train a dedicated Local Energy Project Officer whose role is to act as the “convenor” of the local project - interpreting technical surveys; advising on post install optimisation of the system and otherwise guiding participants through all stages of the customer journey. We judge it critical to project success to have an embedded trusted organisation such as the local authority to act as the friend face of the project and to be the first point of engagement from the local community.

11. Adapt the offer to make it as inclusive as possible. This means working with the capabilities, skills and priorities that are found in the community. Also, seek to build community capabilities wherever possible – such as by ensuring that householders are made aware of all grants, benefits and entitlements they are entitled to during home visits. With the household’s consent refer households to appropriate sources of guidance and further information.

12. Social learning processes are key to the diffusion of innovative (energy) technologies. Therefore, maximise social learning opportunities in the project design. Show homes and technology champions have been found to be effective means of creating social learning opportunities therefore recruit households in each targeted area to receive an early installation and training to act as show homes/ heat pump champions to showcase the technology to their neighbours;

8.3 Understand social, technical and economic dimensions of target areas and map indicators

13. Verify the selected areas with the Local Authority, the Local Community Groups and the DNO;

14. Work with the DNO to maximise the number of heat pumps that can be installed in the area by adjusting the initial field-setting values and agreeing an approach to real-time control if available;

15. Conduct a community survey of the local area as the initial householder engagement step;

16. Use information from the comunity survey and community-level engagement to develop a local engagement and recruitment strategy;

8.4 Develop a targeted value proposition that can be targeted at distinct community segments

17. Work with Heat Pump Installation Service Coordinator and Householder Engagement Specialists to develop an attractive householder offer for different house archetypes;

18. Work with an Energy Supplier and Heat Pump Optimisation and Flexibility Provider to develop a cheaper energy tariff than the standard variable tariff;

19. Separate out the Design and Specification tasks from the Installation tasks to allow specialisation and reduce installation costs;

20. It is critical to ensure that the heat pump will be installed into households where the building fabric (heat loss) can be achievable with the heat pump performance range/capability, and the heat pump will be able to provide the heating energy in extreme weather condition (the new Samsung ASHP able to operate down to -20'C). This is particularly important for fuel poor households and households on low incomes. Ethical guidance developed for the project should be clear that even if households are requesting a heat pump through the project, unless the project can be satisfied that the home is (or could be made) heat pump ready and the household has the means to make this happen and to operate the heat pump correctly, an installation should not go ahead.

8.5 Develop tools and conduct surveys that allow transparent analysis of the feasibility of the heat pump

21. Use information from the community survey and from the householder to provide an accurate estimate of heat pump installation and running costs. Evidence suggests that the more specific the modelled results are to the household in question the more trust will be created in the offer and therefore the more likely it will be that the household acts on the information;

22. Conduct a full survey in homes who have expressed an interest and requested a survey;

23. Conduct a follow-up visit to the survey to explain the survey results and installation options. It is critical that the householder is made fully aware of the costs, benefits and the terms of the offer and that this information is transmitted in a friendly, trustworthy and comprehensible way. This

is a key component of conducting the project in an ethical fashion and is therefore another means of building trust in the offer leading to greater take up of the offer in the community.

8.6 Installation, commissioning, snagging and follow up

24. Install heat pumps with pre-loaded optimised field-setting values – optimised both for householder cost and comfort, but also to minimise the impact on the local grid;

25. Support internet-connectivity and work with a Heat Pump Optimisation provider to update field-setting values and/or update flow temperatures in real-time to optimise the running of the system;

26. Conduct follow-up calls/visits at fixed points after installation to monitor and evaluate the performance of the hot water and the heating use remote control to update settings following evaluation visits/calls. Again, critical to project success, is delivering an excellent experience to householders. This includes taking the time to answer any questions, find solutions to snagging issues etc. The best advocates for heat pumps in the community will be those households that have had a heat pump installed through CHS;

27. Offer regular maintenance and servicing, including evaluation of field-setting values once a year, and after installation of any changes to the household (e.g. extensions, fabric improvements, etc).

9 Conclusion

Clean Heat Streets has developed a set of processes and tools which uses latest thinking in a number of key areas including community engagement, the social science of technology diffusion and the development of value propositions and business models to address each of the main barriers to deployment of heat pumps in high densities.

Our overarching approach has been to reframe the requirement for dense installation rates as an opportunity rather than an insurmountable challenge. Our evidence review and adoption of the Capability Lens as a conceptual framework has helped create a methodology which leverages the skills and capabilities embedded within communities and uses the power of social learning and social norms to drive awareness and interest in the offer.

We have also found that dense installation can lead to efficiencies in the installation processes, for example, by contracting a single company to design and commission the systems and administrate this part of the customer journey, local installers are freed up to install the systems as cost efficiently as possible.

Our proposed methodology recognises the critical importance of creating trust and buy-in for the CHS offer and so we have created processes which broadly follow aspects of the Local Area Energy Planning model.

These include partnering with the Local Authority to employ a dedicated energy officer to be a trusted single point of contact for the project and to guide local residents through the customer journey, working intensively with a local group with an interest in sustainability, involving middle actors at every opportunity and in conducting rigorous spatial analysis of the capabilities, attributes and priorities of the target community.

Principal barriers to dense installation were identified as:

1. Reduction of upfront and running costs to provide an answer to the common question: “Why should I get a heat pump if getting a new gas boiler is easier and cheaper?”.

   To overcome this barrier, we have:

   - Analysed the customer journey to identify key stages where transaction and capital cost can be driven down to the lowest possible levels whilst still maintaining a viable business model;
   - Researched how the value proposition for heat pump adoption can highlight non-financial benefits;
   - Develop analytic and mapping techniques to allow precise targeting of the offer thereby dramatically reducing marketing and engagement costs;
   - Developed processes which should ensure the heat pump is operated as efficiently and optimally as possible to drive down running cost.

2. High densities of heat pumps could potentially cause problems on the low voltage electricity distribution network.

To overcome this barrier, we have:

- Developed a partnership with the local Distribution Network Operator to co-develop solutions;
- Mapped areas of network constraint;
- Developed modelling tools to indicate likely changes in loads at the secondary substation;
- Developed demand profiling tool which will inform design of interventions which can shift energy demand;
- Developed "static" and "dynamic" control strategies which should mitigate issues.

3. Heat pump technology is innovative and requires different heating practices and control strategies to incumbent gas boiler heating systems to get the best out of it. Consequently, there are a range of social, cultural and behavioural barriers that stand in the way of heat pump adoption and optimal use.

   To overcome this barrier, we have:

   - Developed an innovative approach to project management and the tools and processes needed to ensure a high-quality experience for the customer and all stakeholders involved;.
   - Taken a rigorous evidence-based approach to mapping the capability of the target areas to accept the heat pump offer which will allow precise targeting and informs development of the value proposition;
   - Developed engagement and communication processes which maximise opportunities for social learning, post install support and will create ongoing interest in the offer and installed performance.

We believe our recommended methodology has the best chance of meeting the dense installation rates required whilst ensuring the project is delivered ethically and fairly. Further, the methodology has the best chances of success, *because* it must be delivered ethically and fairly.

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11 Appendices

Appendix 1: Detailed methodology for cluster analysis

Stage 1 (Data Pre-Processing):
Developing a data pre-processing algorithm to select households with dual fuel (gas and electricity) from the EDRP dataset, and combine the EDRP gas and EDRP electricity in January as the typical winter month data. There are a total of 2,354 properties in the sub-dataset with an associated ACORN classification of which 1,129 properties are dual fuel. Other single fuel properties (using electricity only) and incomplete data are disregarded.

Stage 2 (ACORN matching):
The table matching EDRP participants to their ACORN classification is available as a separate file. Therefore an initial step is to link each property with its corresponding ACORN classification in one database. The current ACORN classification uses:

- 6 categories,
- 18 groups, and
- 62 types of demographic features of householders[34].

For instance, the ACORN classification, ‘1,B,7’ indicates:

- Category 1 (Affluent achievers),
- Group B (Affluent Greys), and
- Type 7 (Old People, Detached Homes).

Stage 3 (Cluster Analysis):
The clustering algorithm is developed based on a technique called “dynamic time warping”[35]. Similar profiles are merged and profiles with a low probability are dropped in an iterative process. This results in the most typical, highly probable profiles emerging as distinct clusters. This clustering algorithm aims to:

- Find the 12 most typical electricity and gas profiles (6 for each, with one cluster of electricity corresponding to one cluster of gas), based on all EDRP gas and electricity data in January; and
- Find the distribution of ACORN types associated with each cluster.

Steps in the clustering algorithm are:

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[34] The classification is set out in the ACORN user guide. The current version is available from CACI here: https://acorn.caci.co.uk/downloads/Acorn-User-guide.pdf. However, the EDRP dataset uses a 2010 version of the ACORN classification and CACI currently do not support the user guide for this vintage. However, a copy of this 2010 user guide was eventually obtained by the authors and will be made available for anyone wishing to use the data.

[35] There is a large amount of guidance on the use of the technique available on the internet. Specific queries on the use of the technique in this context should be directed to the Engineering Science dept. at Oxford University.

1. Initialise the probability of each profile as the occurrence probability of each electricity-gas profile, and the total number of profiles;
2. Next measure the total “distance” of gas and electricity between any two profiles through using the dynamic time warping method, and calculating the probability distance of any two profiles as the probability distance between the profile and any other profiles. These are the distances measured by the dynamic time warping between the profile and any other profile of gas and electricity, respectively; and
3. Find the profile which has the minimum probability distance with the profile by merging the profile and by removing the profile from the set and adding the probability of the profile to the profile.

The cluster analysis finds 6 distinct clusters.

Stage 4 (ACORN Distribution)

For every merged profile (i.e. each cluster) we identify the associated ACORN types. An example is shown in Table 1 where the clustering has been applied to a random sample of cases from the full EDRP dataset (the sample was built from taking every 40th case from the full EDRP dataset).

Table 10 ACORN types associated with each of the 6 clusters

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'3 ,I ,33'	'3 ,H ,29'
'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'4 ,M ,41'	'3 ,H ,29'
'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'1 ,B ,5'	'1 ,B ,8'
'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'1 ,B ,5'	'1 ,B ,8'
'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,29'		'1 ,B ,8'
'3 ,H ,29'	'3 ,H ,29'	'1 ,B ,8'	'1 ,B ,8'		'1 ,A ,3'
'3 ,H ,29'	'3 ,H ,29'	'3 ,H ,31'	'1 ,B ,8'		'5 ,P ,54'
'3 ,H ,29'	'1 ,B ,8'	'1 ,A ,3'	'1 ,A ,3'		'2 ,F ,21'
'1 ,B ,8'	'1 ,B ,8'	'5 ,P ,54'	'3 ,H ,31'		'1 ,C ,9'
'1 ,B ,8'	'1 ,B ,8'	'3 ,I ,34'	'3 ,H ,31'		'1 ,C ,9'
'1 ,B ,8'	'1 ,A ,3'	'2 ,F ,21'	'3 ,H ,31'		'3 ,H ,28'
'1 ,B ,8'	'1 ,A ,3'	'2 ,F ,21'	'3 ,H ,31'		
'1 ,B ,8'	'5 ,P ,54'	'2 ,F ,21'	'3 ,H ,31'		
'1 ,B ,8'	'3 ,I ,34'	'2 ,F ,21'	'3 ,H ,31'		

	'3 ,I ,34'	'2 ,F ,21'			
	'3 ,I ,34'	'2 ,F ,21'			
	'2 ,F ,21'	'5 ,N ,44'			
		'5 ,N ,44'			
		'5 ,N ,44'			

Histograms showing the association of ACORN types with each demand profile (i.e. cluster types 1-6) are shown in Figure 12

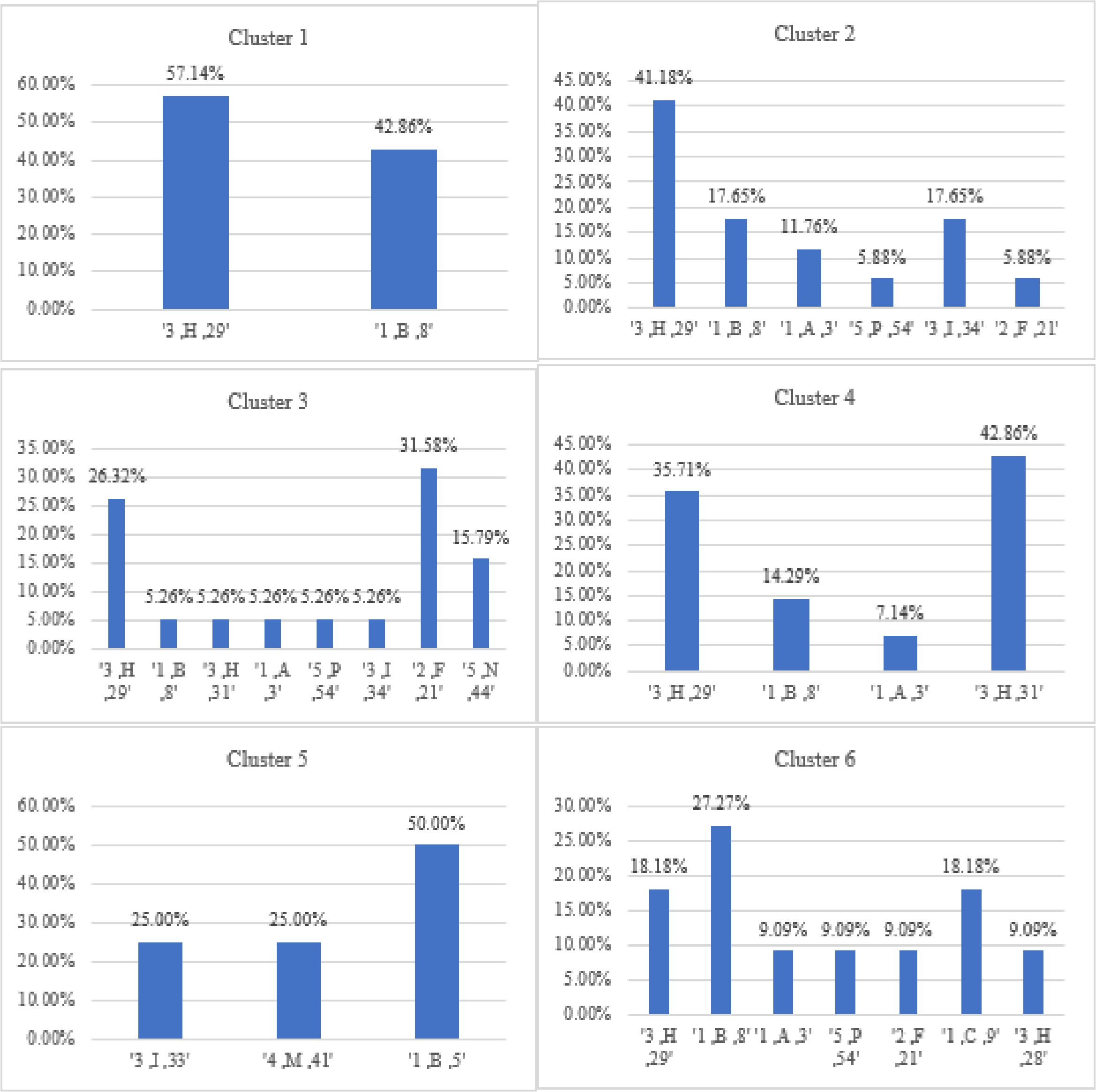

Figure 12 Allocation of ACORN types to Cluster Types 1 to 6

Stage 5 (ACORN Explanation):

The ACORN types associated with each cluster are reviewed to identify common factors which could explain the profile shape and therefore why the cluster exists as distinct from other clusters. In particular, we explore the demographic, socio-economic and lifestyle related information used to characterise ACORN type. This is possible because the ACORN classification contains rich information about:

- The life stage of the occupants (e.g. retired couple, working parents etc);
- Number of occupants;
- Built form of the property including indicative age of the home;
- Number of bedrooms;
- Attitudes, values, hobbies and measures of social capital.

An example of the socio-economic and technical detail available for each ACORN type is shown in Appendix 2: Example description of specific ACORN type for a category 1 (Affluent achievers), group B (Affluent Greys), and type 7 (Old People, Detached Homes).

Stage 6 (Postcode Allocation):
For every postcode in Rose Hill (see Appendix 3: Rose Hill Postcodes, socio-economic and technical characteristics and demand profiles) we have an associated ACORN classification available through a proprietary dataset supplied by Oxfordshire County Council. Therefore, we can match each of our derived demand profiles to each postcode in Rose Hill using the ACORN classification as the common index[36]. For example, OX4 4TP is associated with Acorn type 5,P,53 (2010 ACORN classification) which, from our analysis, is in turn strongly associated with Cluster 6. Appendix 3: Rose Hill Postcodes, socio-economic and technical characteristics and demand profiles shows the allocation of Rose Hill postcodes to demand profile types.

Stage 7 (Heat Pump Projection): The SERL data contains information on electrical power consumption before and after the installation of a heat pump. The EDRP gas consumption data was used to calculate the thermal power supplied to the household in every half hour (factoring in an assumed typical efficiency (70%) for the gas boiler).

Since both SERL data and EDRP data are obtained from UK residential properties and on the same power scale, we were able to match the clusters of electricity consumption of EDRP data, with the electricity consumption of SERL data before the installation of heat pump, by finding the minimum distance using the dynamic time warping approach.

The match is illustrated in the flowchart in Figure 13. The method allows any one component to be calculated, such as the coefficient of performance (CoP) of the heat pump, when given information about the other components. The CoP is also determined by the indoor and outdoor temperature of the property.

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[36] Noting that there is a complication here: the ACORN types in our EDRP dataset used to generate the clusters are from 2010 whilst the ACORN types allocated to Rose Hill are from the 2020 version of the ACORN classification. Unfortunately there is no direct association between a particular 2010 ACORN type and a particular 2020 ACORN type. Consequently, we have manually assigned a 2020 type to each 2010 type based on a common sense assessment of the salient demographic, technical and socio-economic characteristics held in common. We acknowledge that this introduces unwanted noise into the analysis.

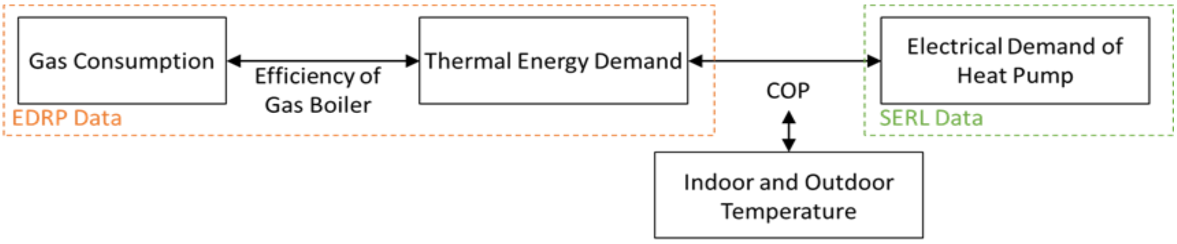

Figure 13 Flowchart for matching the EDRP data with SERL data, under which any component can be calculated given the information of other components

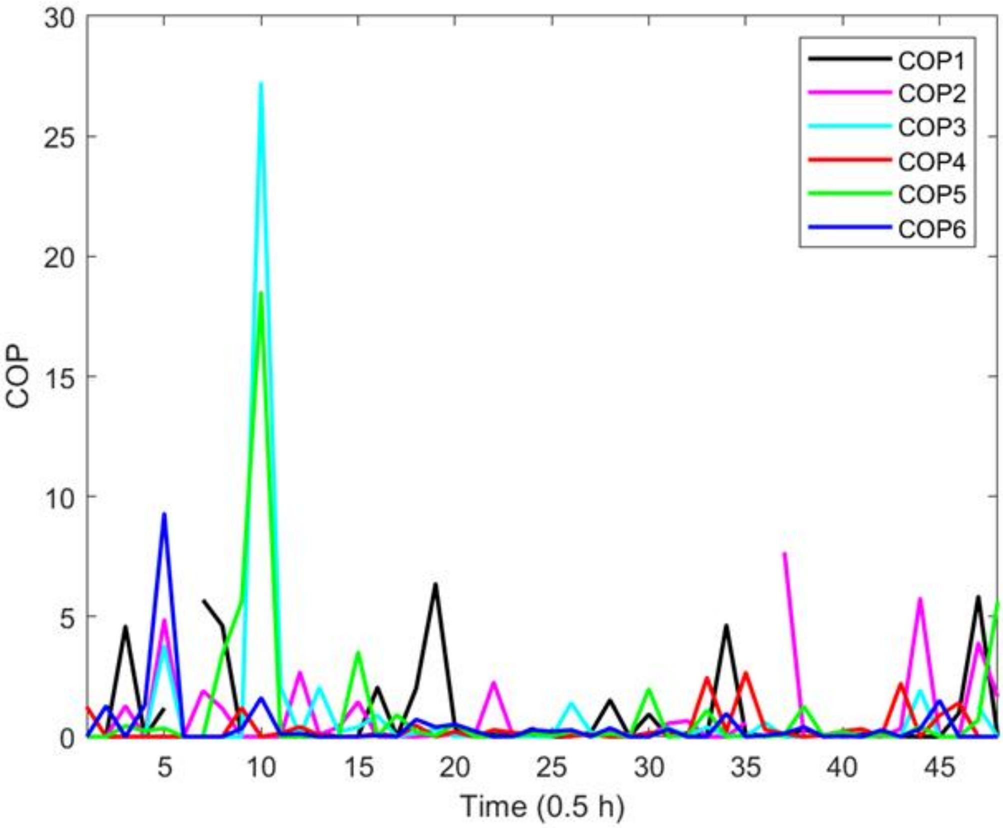

Figure 14 Clusters of coefficient of performance (CoP) generated from the match between EDRP data and SERL data.

In this research, 6 clusters of CoP are generated as shown in Figure 14 through using the flowchart of matching the EDRP data with SERL data. It can be seen that the value of CoP ranges from 0 to 28, averaging at 4[37]. The graph shown here is indicative only. The very high COPs in the 10th half hour period for COP clusters 3 and 5 are the result of outliers in the dataset and should be disregarded for the purposes of interpretation.

Using the CoP, the total electricity consumption that results when the gas boiler is replaced by the heat pump can be projected at each time step. Results of this analysis for each cluster are shown in Figure 15 Comparison of total electricity consumption before and after install of heat pumps .

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[37] For the case where the electrical power consumption of heat pump from SERL data, is calculated as negative, since the power consumption after the installation of heat pump, is less than that before the installation of heat pump, the CoP is set as zero

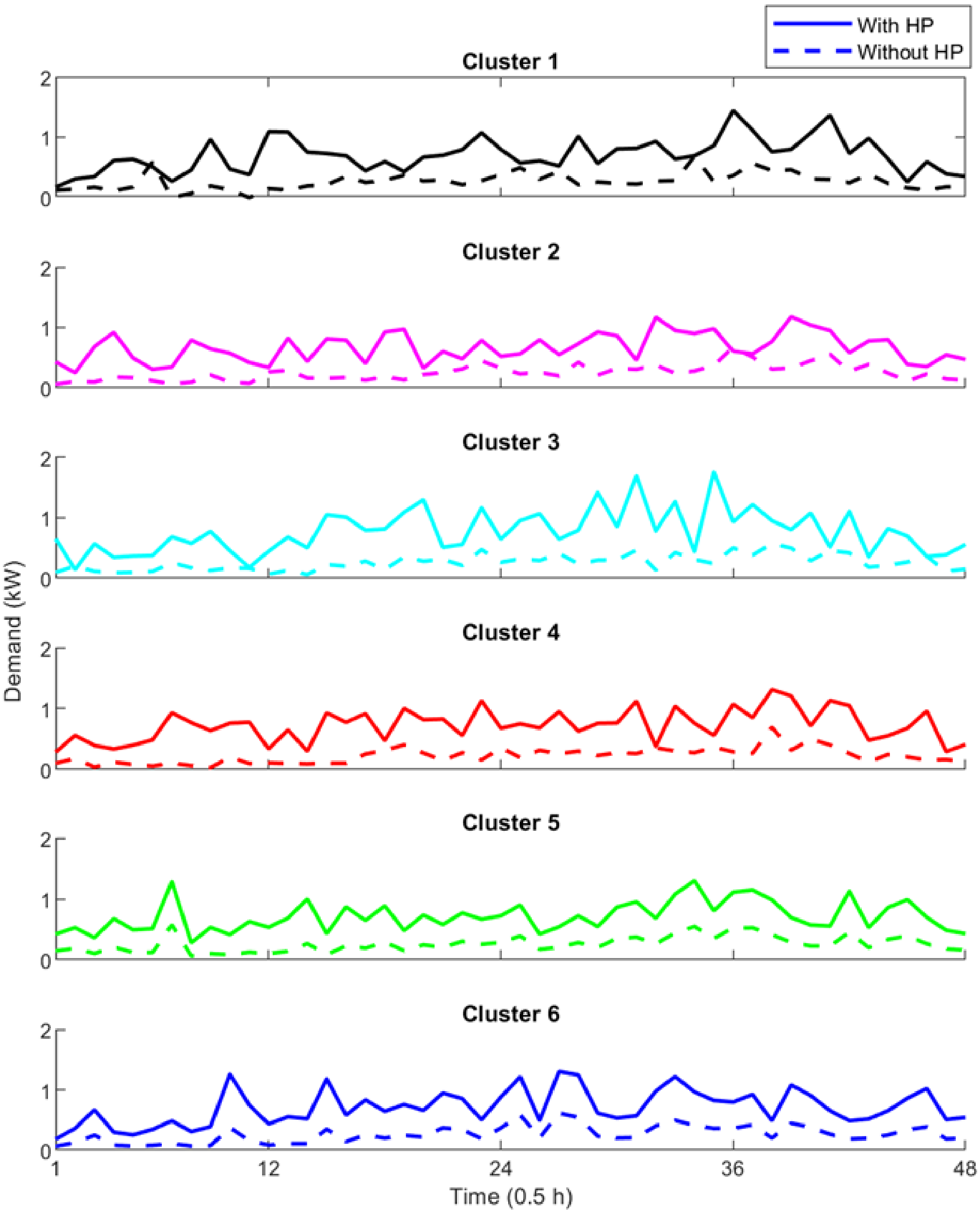

Figure 15 Comparison of total electricity consumption before and after install of heat pumps

Error! Reference source not found. Figure 15 presents an example for projecting the total electricity consumption of the EDRP data when the gas boilers are replaced by heat pumps. The dashed lines are the electricity consumption when the property is heated by gas boilers and the solid lines are the projected electricity consumption when gas boilers are replaced by heat pumps. The electrical power consumption of heat pump is spread out over the day and remains between 0 kW and 2 kW. By comparison, the gas boilers would cause some spikes of gas consumption in certain time intervals of a day.

Stage 8 (Validation):
Using EPC data, a typical home archetype for each postcode was found. The archetype was characterised by floor area, build year, and number of heated rooms. The SMS thermal model was

then used to generate power profiles of the heat pump using floor area, build year, and bedroom number as inputs. The power profiles created by the SMS model can then be compared with the projected profiles calculated by the EDRP method outlined above.

Stage 9 (Heat Pump Potential Analysis):
The potential for heat pump installation can then be assessed based on projected heat pump profile and demographic information in each postcode.

Appendix 2: Example description of specific ACORN type

The ACORN user guide gives key technical, demographic, socio-economic and lifestyle related information for each ACORN type associated with each postcode. For instance:

- Category 1 (Affluent achievers),
- Group B (Affluent Greys), and
- Type 7 (Old People, Detached Homes)

is described as follows:

Category 1:
These are some of the most successful and affluent people in the UK. They live in wealthy, high-status rural, semi-rural and suburban areas of the country. Middle-aged or older people predominate, with many empty nesters and wealthy retired. Some neighbourhoods contain large numbers of well-off families with school-age children, particularly the more suburban locations. These people live in large houses, which are usually detached with four or more bedrooms. Almost 90% are owner-occupiers, with half of those owning their home outright. They are very well educated and most are employed in managerial and professional occupations. Many own their own business. Car ownership is high, with many households running two or more cars. Incomes are high, as are levels of savings and investments. These people are established at the top of the social ladder; they are healthy, wealthy and confident consumers.'

Group B:
These people tend to be older empty nesters and retired couples. Many live in rural towns and villages, often in areas where tourism is important. Others live in the countryside where the economy is underpinned by agriculture. The Affluent Greys are prosperous, live in detached homes and many have two cars. Over the past five years, more of these people have been buying one, or more, second homes and now nearly one in six families will do so. Employment is typically in managerial and professional roles. Given the rural locations, there is also a significant number of farmers. Unemployment is low but rising faster than average, with skilled trades being badly hit. These are high-income households and even those who have retired have good incomes. Since it contains older people, it is unsurprising that 10% of the income of this group is in the form of a pension – a significantly greater proportion than any other group. A further 12% of income comes from benefits of one form or another, perhaps for carers, the disabled, and incapacity benefit. Across the group as a whole benefit income is double the income derived from investments. The majority own their homes outright, and with no mortgage to pay are able to invest their money in a wide range of financial products. A few, perhaps a quarter, still have a mortgage, but these are rarely recent mortgages so they are among the least likely to be in negative equity. The recession has had less of an effect on the housing market in these areas. In their leisure time they enjoy gardening and golf. They appreciate good food and wine and will go on regular holidays. They are likely to have cut back on spending during the recession, perhaps buying cheaper rather than fewer clothes. Some of the high spending, often by mail order, on gardening and furnishing the home may also have been curtailed. Since they live further away from shopping facilities or their place of work, it is not surprising their environmental concern does not include a willingness to cut down on their use of the car. They tend to conserve energy, recycle and probably compost their garden waste. These older, affluent people have the money and the time to enjoy life.'

Type 7:
These people live in prosperous areas, often where tourism is important and holiday homes are popular. The overall population is relatively old, with more than 35% aged over 65 and twice the national average level of over-85s. Most households are older couples, although the number of single pensioners is also relatively high. While there are high numbers of retired householders, residents who do work tend to be in well-paid senior management and professional occupations or work in agriculture. These are affluent people and they tend to live in detached homes with three or four bedrooms. Since these areas are quite sought-after, the housing market has suffered less badly than average. Those who are already retired are to a great extent protected from the recession. Others, who may be approaching retirement, will fear that their pensions have suffered and their savings and investments are offering much lower returns than anticipated. They like to take advice on their financial affairs and have a range of investments in stocks and shares, unit trusts and high-interest accounts. They are also comfortable using credit cards, preferring to pay off the balance each month. Given the rural feel to some of these neighbourhoods, there is a need for a car, and householders generally have access to at least one vehicle and in many cases two or more. They are less keen on the effort of visiting shopping centres, and buy quite a lot of things by mail order. Gardening equipment, plants, healthcare products, clothing, books and luxury food items are all purchased in this manner. This type appreciate good food and wine and enjoy eating out on a regular basis. They also enjoy hobbies such as golf and gardening and visiting National Trust properties. Like other types within the group, they choose to read the Daily and Sunday Telegraph and may subscribe to gardening magazines. Some will read newspapers online, although they do not use the internet extensively other than to buy wine or plants, to plan trips and to keep in contact with friends. It is probable that people consider there to be a close community of broadly shared values in these areas. Neighbourhood Watch schemes are well supported. Although residents are less likely to have been victims of any crime, they tend to feel crime is increasing and that the courts are too lenient, particularly with youth crime. Being older, some people may have health issues; perhaps difficulties in managing stairs or walking distances. Rural areas with smaller market towns are the main locations for this type. This includes Somerset, the Cotswolds and the Lake District.’

Appendix 3: Rose Hill Postcodes, socio-economic and technical characteristics and demand profiles

Postcode	ACORN Code 2010	Age Range	House Tenure	Number of Bed	Children at Home	Family Structure	House Type	Income	Cluster
OX4 4EH	1,A,1	45-64	Owned Outright	4	2	Couple	Detached	60k	5,6
OX4 4EU	1,A,4	55-74	Owned Outright	4+	0	Couple	Detached	72k	5,6
OX4 4EW	1,A,1	45-64	Owned Outright	4	2	Couple	Detached	60k	5,6
OX4 4FE	5,O,51	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4FF	5,O,51	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4FG	5,O,51	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4GN	5,N,49	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4GW	4,L,40	25-34	Private Renting	2	1	Single Parent	Terraced	30k	5
OX4 4HP	1,B,8	65+	Owned Outright	4	0	Couple	Detached	46k	1
OX4 4HS	2,D,14	65+	Owned Outright	4	0	Couple	Detached	46k	3
OX4 4HX	5,Q,55	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4HY	1,C,9	45-64	Owned Outright	4	2	Couple	Detached	60k	6
OX4 4HZ	2,E,17	25-44	Privately Renting	1-2	1	Couple with Children	Flat or Maisonette	47k	3
OX4 4JA	3,G,24	25-44	Mortgaged	2	1	Couple with Children	Terraced	43k	1,2
OX4 4JB	2,D,14	65+	Owned Outright	4	0	Couple	Detached	46k	3
OX4 4JD	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3

OX4 4JE	3,G,25	25-44	Mortgaged	2	1	Couple with Children	Terraced	43k	1,2
OX4 4JF	1,C,9	45-64	Owned Outright	4	2	Couple	Detached	60k	6
OX4 4JG	1,C,9	45-64	Owned Outright	4	2	Couple	Detached	60k	6
OX4 4JH	1,C,9	45-64	Owned Outright	4	2	Couple	Detached	60k	6
OX4 4JQ	3,H,27	25-44	Mortgaged	2	1	Couple with Children	Terraced	43k	1,2
OX4 4QR	5,P,54	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	6
OX4 4RA	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4RB	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4RD	5,P,54	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	6
OX4 4RE	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4RF	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4RG	4,L,40	25-34	Private Renting	2	1	Single Parent	Terraced	30k	5
OX4 4RH	4,M,42	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4RJ	5,N,46	25-34	Private Renting	2	1	Single Parent	Terraced	30k	3
OX4 4RN	4,M,42	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4RP	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4RQ	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4RR	4,M,42	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5

OX4 4RS	4,M,42	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4RT	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4RW	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4SA	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4SB	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4SD	5,O,51	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4SE	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4SH	2,F,20	20-34	Privately Renting	4+	0	Single	Flat or Maisonette	32k	3
OX4 4SJ	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4SL	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4SN	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4SP	5,O,51	65+	Social Renting	1	0	Single	Flat or Maisonette	20k	3
OX4 4SW	3,H,30	65+	Social Renting	1	0	Single	Flat or Maisonette	20k	5
OX4 4TA	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4TB	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4TD	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4TE	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4TG	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5

OX4 4TP	5,P,53	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	6
OX4 4TQ	5,N,49	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4TR	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4TS	5,N,49	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4TT	4,M,42	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4TU	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4TX	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4TY	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4TZ	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4UA	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4UB	2,E,17	25-44	Privately Renting	1-2	1	Couple with Children	Flat or Maisonette	47k	3
OX4 4UD	3,H,27	25-44	Mortgaged	2	1	Couple with Children	Terraced	43k	1,2
OX4 4UE	4,M,42	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4UF	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4UG	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4UH	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4UJ	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3

OX4 4UL	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4UN	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4UP	3,H,27	25-44	Mortgaged	2	1	Couple with Children	Terraced	43k	1,2
OX4 4UQ	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4UR	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5
OX4 4US	5,O,52	25-34	Social Renting	1	1	Single Parent	Flat or Maisonette	20k	3
OX4 4UU	5,N,44	25-34	Social Renting	3	3+	Single Parent	Terraced	27k	3
OX4 4UX	4,L,40	25-44	Social Renting	3	3+	Single Parent	Semi-detached or Terraced	32k	5

Appendix 4: Evidence review: delivering flexibility from heat pumps

Below we provide the evidence review underpinning our findings on the behavioural and technical bases for delivering heat pump flexibility. The review was conducted by Dr Bryony Parrish at the Energy Group, Environmental Change Institute, University of Oxford.

Technical, economic and social capability to deliver flexibility from heat pumps
The deployment of electric heat pumps in UK households is expected to increase dramatically as part of heat decarbonisation (HM Government, 2021). As most UK home heating is currently provided by burning natural gas in individual boilers, the associated increase in peak electricity demand will pose challenges for electricity system operation by increasing the requirement for electricity generation and network capacity (Turvey, Clarke and Calder, 2018; Wilson, Taylor and Rowley, 2018). Flexible operation of heat pumps could reduce this requirement by shifting electricity demand away from peak periods; it could also provide other useful services as part of a decarbonising energy system, such as response and reserve services and load shifting to support increased penetrations of variable renewables (Turvey, Clarke and Calder, 2018; Rosenow *et al.*, 2020; Vaillant and geo, 2022). This short review focusses on evidence relating to shifting heat pump electricity demand away from peak periods because this is likely to be of more relevance at the distribution network level, and it is also the focus of the majority of evidence identified.

The need for flexible operation of heat pumps therefore originates with the needs of the electricity system, but it has the potential to impact on households in multiple ways; as such, it will depend on successfully engaging households to be both technically effective, and just or fair. To aid our understanding of household engagement, this work stream documents a range of capabilities that can support the flexible operation of heat pumps in homes. The capabilities approach is useful because it helps us to consider the influence of a holistic range of factors influencing the potential for heat pump flexibility at the household level: from technical and material, to financial, personal, and social (Roberts et al., 2020). It also helps us to consider how relevant capabilities may be distributed between households as users of heat pumps, and providers of flexibility services via the ways in which their offers may be designed and delivered (Banks, 2021). For brevity, this document refers to these two categories as ‘household-side capabilities’ and ‘supplier-side capabilities’ respectively.

The discussion is structured in two parts. The first part relates to capabilities that can support engagement with different forms of demand side response (DSR) – in other words, the mechanisms (such as time varying pricing, automation, or direct load control) that may be used to signal the timing of heat pump operation and respond to these signals. Such capabilities include, for example, access to enabling technologies and the ability to bear financial risk. This first section focuses on evidence related to household engagement with DSR in general, as well as evidence on DSR involving heat pumps. The second part relates to capabilities that can support changing the timing of heat pump operation in response to electricity system needs. These include, for example, the level of thermal storage provided by building fabric insulation. Reflecting the evidence identified, this relates only to flexing the timing of space heating, not domestic hot water provision[38]

Capabilities for engaging with demand side response (DSR)

In general, DSR can involve manual demand shifting (in response to time varying pricing, or more rarely, information provision), direct control of household appliances or 'loads' by external parties (often known as direct load control or DLC), or automated response to time varying pricing (Parrish et al., 2020). None of the studies reviewed here involve manual demand shifting, which may reflect that heating is already largely automated via for example timers and thermostats, as well as that flexible operation of heat pumps may involve smart automation such as pre-heating. In BAU applications of DLC (many with AC in the US) households have typically been financially rewarded for participation (though this seems not to be the case in the trials reported here). The characteristics of different forms of DSR will influence the capabilities that are relevant to engaging with them, which are discussed further below.

Digital/technical: Access to, and capabilities to engage with, different types of digital technologies

Households will need access to appropriate smart meters and home broadband to engage with DSR. It is recognised that the reliability of home broadband connections can also limit DSR reliability (Frontier Economics, 2015; NEDO, 2017; Sweetnam et al., 2019).

Capabilities to engage with different types of user-facing controls are also key to households actively engaging with DSR. For example, within NEDO low engagement with pre-opt out of DLC events occurred because this function could only be performed via an app, and many households reported low desire or ability to engage with the tablet provided as part of the trial (Calver, Mander and Abi Ghanem, 2022). On the supplier-side, the design of user-facing controls can therefore strongly influence households' capability to engage with DSR in the intended ways. It can also influence perceived control, with potential implications for acceptance of DSR. For example, the EcoGrid EU (2016) evaluation found that participants with more control options felt more positive about DLC, although they did not override control any more frequently than other groups. Conversely, Sweetnam et al. (2019) describes participants feeling a lack of control because their user interface did not provide any feedback on the timing of temperature changes when they make adjustments to heating schedules; similarly, Calver, Mander and Abi Ghanem (2022) found some households preferred their previous analogue temperature controllers (such as pin controllers) that clearly showed the heating schedule.

Financial: Capability to bear financial risk

If DSR signals involve time varying pricing there is a risk that households may pay more for electricity if they do not sufficiently flex the operation of heat pumps (and potentially other electrical loads). Some households will have greater capability to bear this risk than others because of their financial

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[38] Empirical evidence on the flexibility of domestic hot water provision by heat pumps was identified as a gap, which work on Clean Heat Streets will contribute to address.

situation. There is also a risk that households with less financial capability feel compelled to flex electricity use in response to time varying pricing, even though this may have negative impacts in other ways (Crawley et al., 2021).

DSR providers can support the capability to bear financial risk by offering shadow billing/bill guarantees. In this arrangement, households are able to trial time varying pricing for a defined period of time with the guarantee that they will not be charged more than they would have been charged on a flat rate (Parrish et al., 2020). Bill calculators can also be used to offer households an idea of whether they will save money on time varying pricing, but their effectiveness depends on households being able to predict the extent to which they will be able to flex demand, which may not be possible for novel loads like heat pumps.

Financial risk can also be reduced through developing household-side and supplier-side capabilities that support flexible heat pump operation, as described above, and through DSR offers do not involve time varying pricing. Financial incentives or rewards for DSR can still be offered through, for example, payments for participating in DLC for reducing demand below a calculated baseline during defined peak periods.

Personal/social: Knowledge and understanding of DSR

Flexible operation of heat pumps was automated in some way in all studies reviewed. Nonetheless, these studies indicate that the technical effectiveness of heat pump flexible operation can be limited if household members are not effectively made aware of or do not fully understand direct load control of their heat pumps or automated responses to time varying pricing. Equally importantly, this can risk fairness to households and their trust in DSR over the longer term.

Frontier Economics (2015) and Calver, Mander and Abi Ghanem (2022) suggest that low awareness of when DLC is happening – and, in the case of Calver, Mander and Abi Ghanem (2022), what DLC actually entails – can lead to households unintentionally overriding DLC events by interacting with thermostat controls. Similarly, Sweetnam et al., (2019) reported households overriding automated responses to time varying pricing. It is not clear whether this resulted from a lack of understanding or knowledge of DSR, issues with thermal comfort, or both. However, Sweetnam et al., (2019) also note that night-time operation can cause confusion about whether system was operating incorrectly or wasting electricity, which does indicate a lack of understanding of pre-heating.

Overriding by households has the potential to limit the effectiveness of heat pump flexibility from the electricity system perspective, and in the case of automated response to time varying pricing, risks households paying higher bills. Low knowledge and understanding of DSR is also a risk to achieving fairness and justice in the implementation of heat pump flexibility (Calver, Mander and Abi Ghanem, 2022); to households’ trust in DSR over the longer term (Parrish et al., 2020); and to the extent to which we can conclude, based on trial data, that households would be accepting of DLC as part of a wider roll out (NEDO, 2017; Parrish, Hielscher and Foxon, 2021).

In CLNR, participants were unaware of the timing of DLC because the controls/user interface were not designed to notify participants of when events was happening (Frontier Economics, 2015). In the NEDO trial, households had low awareness of DLC overall, which resulted from a combination of factors (Calver, Mander and Abi Ghanem, 2022). DLC was implemented by default when households accepted heat pumps as part of the trial. At the start of the trial, households often felt overwhelmed by information, and although written information about DLC was provided in a booklet along with information about heat pumps and other aspects of the trial, this may have been too lengthy and unclear to be useful. Households were unable to opt-out from DLC altogether, and although they were notified of and able to pre-opt-out from individual DLC events, as discussed above these functions were only available via an app that few participants actually engaged with. Participants could also opt-out from DLC by adjusting the thermostat while DLC events were taking place, but as in CLNR, the absence of effective notification means they may have been unaware that this is what they were doing.

On the supplier-side, households' knowledge and understanding of DSR could therefore be supported through more effective design of user interfaces (considering what information is provided, and through what means) and through more effective provision of information (which could helpfully include follow up information provision over the course of the trial, as well as clearer signposting of relevant information in written brochures or other materials). More generally, evidence from these studies indicates that it is important for households to have some knowledge and understanding of heat pump flexibility even when this is mediated by automation or DLC (i.e. does not require manual demand shifting). This will likely need to be combined with other capabilities that support flexible heat pump operation, as described above.

Social: Trust in DSR offers

In general, trust in DSR offers may be reduced when households have concerns around privacy and autonomy connected to direct load control and suppliers' motivations for pursuing it (AECOM, 2011; Bartusch et al., 2011; Wiekens, van Grootel and Steinmeijer, 2014; Lopes et al., 2016). Trust may be promoted through transparency around the timing and purpose of DLC or automation (Lopes et al., 2016) (Buchanan et al., 2016; Lebosse, 2016) (Carmichael et al., 2014; Wiekens, van Grootel and Steinmeijer, 2014), as well as through providing information on DSR from independent sources (Hall, Jeanneret and Rai, 2016) and involving trusted actors in recruitment (Bird, 2015; Western Power Distribution, 2016).

When considering trust in flexible operation of heat pumps specifically, it is worth noting that many of the studies reviewed were conducted in the context of social housing. Engagement with DSR is therefore likely to be based on existing trusted relationships with social housing providers, and as described above, may involve low awareness of DSR amongst households; in turn, this may contribute to relatively low levels of reported concern about loss of control, data privacy and similar issues (Calver, Mander and Abi Ghanem, 2022). However, it should be noted that not implementing DSR in a transparent way risks damaging trust in the longer term, both within households and through reputational effects (Parrish et al., 2020).

Capabilities for flexing the operation of heat pumps

In contrast to the previous section, which related to capabilities for engaging with different forms of demand side response (DSR), this section discusses capabilities relevant to engaging with actually shifting heat pump electricity demand in time. It first considers capabilities on the household-side: that in some way increase thermal storage, thus decoupling changes in electricity demand from changes in heat provision in the home, and that support living with changes in home heating resulting from heat pump flexibility. It then discusses how the design of heat pump flexibility offers might support household engagement with heat pump flexibility, and supplier-side capabilities that may be required to manage heat pumps' impact on the low voltage network as a result of such changes in heat pump flexibility offers.

Household-side capabilities that may increase potential for flexible operation of heat pumps

Technical/material and financial: access to thermal storage

Greater levels of building insulation and thermal mass can support the flexible operation of heat pumps by helping to maintain indoor temperatures despite reduced electricity supply to heat pumps (Vaillant and geo, 2022). Retrofitting building fabric insulation can therefore increase the potential for heat pump flexible operation, as well as reducing heat pump peak demand and impact on the low voltage network. Dedicated thermal storage, in the form of hot water buffer tanks or heat batteries utilising phase-change materials, can also support heat pump flexibility (Rosenow et al., 2020; Vaillant and geo, 2022). Some homes will have existing hot water buffer tanks that can be used for this purpose, but many homes in the UK have removed hot water tanks after installing combi-boilers (Sweetnam et al., 2019). Additional thermal storage could be added alongside heat pump installation, but requires sufficient space; this suggests a possible link between the size of homes and the affluence of households, and their capabilities for heat pump flexibility (Crawley et al., 2021). Phase-change material heat batteries are both smaller and lighter per unit of heat stored, which can make them easier to fit into homes (Energy Saving Trust, 2022).

Technical/material, personal and social: capabilities that support living with changing heating patterns

Flexible operation of heat pumps has the potential to change the indoor temperatures experienced by households, as well as the noise of heating system operation at different times. Amongst the studies reviewed, pre-heating is a notable control strategy in this regard. This involves increasing indoor temperatures in advance of DSR events, in order to limit any drop in temperature below users' settings during DSR periods (Turvey, Clarke and Calder, 2018; Sweetnam et al., 2019). While the emphasis is on maintaining minimum indoor temperatures during peak demand periods, pre-heating can also have the effect of increasing indoor temperatures during night-time and daytime periods, as well as creating noise from heating system operation at those times (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021). This control strategy may therefore require capabilities that enable households to avoid, tolerate or appreciate higher room temperatures and any noise from heating system operation at these times. More constant operation can also improve the efficiency of heat pump operation independently of demand shifting, so such capabilities can also support more efficient heat pump operation in general.

Day-time heating: Although many UK households typically do not heat homes during the day time, even if they are at home (Hanmer et al., 2019), more constant daytime heating may be appreciated by households who spend time at home during the day or enjoy warmer temperatures when returning home in the evening (Parrish, Hielscher and Foxon, 2021; Calver, Mander and Abi Ghanem, 2022). Households who already heat homes during the daytime can also benefit because the technical characteristics of heat pumps may allow this heating schedule to be provided at lower cost than alternatives such as gas boilers. Understanding that, in contrast with gas boilers, more constant operation of heat pumps can reduce running costs may help households to appreciate daytime heating (Sweetnam et al., 2019).

Night-time heating: households often find sleeping in warmer temperatures uncomfortable; pre-heating during night-time can therefore be supported by capabilities that allow households to avoid experiencing warmer temperatures within bedrooms, including the presence and use of thermostatic radiator valves on bedroom radiators, as well as sufficient thermal insulation between rooms (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021). These capabilities could be enhanced through installing thermostatic radiator valves and supporting households to use them effectively. It may also be helpful to assess levels of internal thermal insulation and, where appropriate, discuss the possibility that households may experience higher night-time temperatures, whether this is something they are willing to try, and what strategies they might use to respond. For example, opening bedroom windows can help to avoid the experience of night-time heating (Sweetnam et al., 2019; Parrish, Hielscher and Foxon, 2021) but will reduce heating system efficiency and would preferably be avoided.

Capabilities to avoid or tolerate noise from night-time heating operation can also support this form of pre-heating (Parrish, Hielscher and Foxon, 2021). Different people have different sensitivities to noise while sleeping, but these capabilities could potentially be enhanced if it is possible to locate heating equipment – including heat pump units, but also central heating pumps – at a greater distance from bedrooms.

While the logic of pre-heating is to limit decreases in internal temperature, if there are unavoidable impacts on household comfort it may be useful to consider changing the offer by reducing the extent of pre-heating and allowing indoor temperatures to drop to some extent (Sweetnam et al., 2019). Even when pre-heating was not applied, control strategies applied in the reviewed studies were limited: for example, in the NEDO trial DLC automatically ended if room temperatures fell below 18^{o}C or more than 2^{o}C below thermostat set temperature (NEDO, 2017). However, as noted by Crawley et al., (2021), while this function is designed to protect customers it also has the effect of reducing their agency to choose when and how flexibility is provided. Thus, it may also be useful to consider which capabilities may enable households to tolerate decreases in room temperature in peak demand periods, during, for example, a limited number of critical periods each year.

Evidence related to DSR more generally suggests that capabilities to support this may include the availability of alternative sources of heating such as fireplaces (VTT, 2004; Lebosse, 2016) or the ability to spend time outside the home during DSR events (Strengers, 2010; Carmichael et al., 2014). More broadly, Strengers (2010) observed that flexible operation of AC in Australia was supported when households had maintained knowledge and skills in traditional ways to keep cool at home, which provided alternatives to AC use. In the context of heating, this might include, for example, access to and willingness to use warm indoor clothing and slippers. However, any such approach would need to ensure avoidance of any negative impacts on households – including the possibility that less affluent households may feel pressure to participate in DSR despite possible negative impacts (Crawley et al., 2021) and the potential for detrimental health impacts, particularly for household members such as young children, older people or people with limited mobility or existing health conditions.

Supplier-side capabilities relevant to flexing the operation of heat pumps

Suppliers of heat pump flexibility products and services could support the development of the household-side capabilities outlined above in various ways, which also require relevant capabilities on the supplier-side. For example, installer interactions with households could provide an opportunity to develop capabilities related to living with changed patterns of heating – but installers may lack the social capabilities to engage in this type of work (Parrish, Hielscher and Foxon, 2021). In addition, designing DSR offers to enable household engagement with heat pump flexibility may affect the potential for electricity system services provision, and require actors such as distribution system operators to possess capabilities to manage the electricity system in other ways. This is the topic of this sub-section.

Limiting the duration of DSR events can limit reductions in indoor temperatures, even in homes with limited technical capabilities to enable thermal storage. For example, in the CLNR and NEDO trials direct load control was limited to between 30 minutes and 1 hour (Frontier Economics, 2015; NEDO, 2017). However, relatively short duration DSR will obviously tend to reduce the time over which flexible heat pump operation can reduce peak electricity driven network congestion; some trials have tested staggering DSR across different populations of heat pumps to extend the total period of demand reduction, but secondary demand peaks[39] limit the effectiveness of this approach (Frontier Economics, 2015; NEDO, 2017), although they could potentially be addressed through more sophisticated control strategies (Frontier Economics, 2015). Lowering heat pump flow temperatures (rather than curtailing electricity supply) may provide an alternative approach to limit decreases in indoor temperature while maintaining DSR for longer periods within individual households.

The timing of DSR events may also be designed to limit impact on households: in the NEDO trial, DSR design avoided night-time operation of heat pumps, at the request of social housing managers who were concerned this may be disturbing to tenants (NEDO, 2017). Limiting the timing of DSR events will obviously limit the times at which DSR can provide electricity system services, implying that capabilities for alternative/additional forms of electricity system management may also be required. However, supporting the development of household-side capabilities that enable heat pump flexibility could reduce the need for such supplier-side capabilities, demonstrating their interrelationship and the value of the capabilities approach.

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[39] Secondary demand peaks, or snap back, describe the phenomenon of demand increasing immediately after the end of DSR periods as heat pumps or similar loads switch back on and work harder to return room temperatures to thermostat set points and/or restore hot water stores after these have fallen/been depleted.

Appendix 5: Value propositions for four tenure segments

OWNER OCCUPIERS			
Service provider: Project consortium	Beneficiary: Owner occupiers	Outcome	
Service or offer Clean Heat Streets project	Job to be done: Reduce heating running costs (and carbon emissions) while maintaining or improving comfort. Have a reliable heating system with assurance that support is available if something goes wrong.	Capabilities required **Technical:** Adequate insulation levels. Sufficiently large heat emitters **Social:** Trust in information and advice offered. **Social, personal, technical:** Capability to operate heat pump in an efficient way: intended use of controls, ability to avoid, tolerate, or appreciate experience of more constant operation of heating system during day and night. **Financial:** TBD	Approaches to develop capabilities Both will be assessed, and heat emitters will be assessed and upgraded if necessary. Working with RHILC and other organisations already trusted in the local community; working with heat pump champions; developing project's visibility in the community. Discuss heating wants and needs during installation and handover. Ensure sufficient understanding of HP operation and role in heating home. Provide range of post-install support to suit different needs, enabling households to get the best out of their HP.
Gain offer	High-quality installation, plus range of post-install support to suit different needs will enabling households to get the best out of their HP.	Gain	Maintaining or increasing comfort while decreasing running costs (and carbon emissions).

Pain reliever	Range of funding offers including a leasing model to reduce up-front costs of ASHP. Project will provide a trusted route to identify skilled installers and coordinate survey, design and installation through a single point of contact. Funded survey will provide assurance of property suitability for ASHP and information about expected running costs (and carbon savings), enabling households to make an informed decision prior to install.	Pain	Up-front costs of ASHP may be too high for many households, even with the availability of government subsidies. Difficult to select appropriate high-quality ASHP and find trusted local installers to conduct high-quality survey, system design and installation. Concerns and uncertainties about suitability of ASHP for property, comfort levels and running costs.

SOCIAL LANDLORDS					
Service provider Project consortium		Beneficiary social housing landlords		Outcome	
Service or offer Clean Heat Streets Project		Job to be done Keep tenants happy, healthy and comfortable. Reduce tenants' energy bills to make them more affordable. Council: reduce carbon emissions from council owned housing in line with internal targets (zero carbon by 2040).		Capabilities required **Technical:** Adequate insulation levels. Sufficiently large heat emitters **Financial:** Access funding for costs of ASHP installation beyond those covered by the project. **Social:** Ability to engage tenants in the offer.	Approaches to develop capabilities Both will be assessed, and heat emitters will be assessed and upgraded if necessary. Provision of value proposition, including pre-installation engagement and post-installation support, to engage and inform tenants in the offer, support them to make a decision about ASHP suitability considering their own wants and needs, and assure support to get the best out of ASHP if they choose to proceed.
Gain offer	High performance on all measures assured through access to high SCOP ASHPs, skilled design and installation, smart control and post-install support.	Gain	Reduced carbon emissions alongside improved comfort and affordability for tenants. Reduce issues for tenants, and maintenance requirements, by installing more reliable technology.		

Pain reliever	Range of post-install support available to suit different tenants’ needs, enabling them to get the best out of their HP.[BP1] Project will provide a trusted route to coordinate the full customer journey on behalf of social housing providers.	Pain	Past experiences in social housing suggest tenants may be dissatisfied with ASHP installed to replace gas boilers, as they feel less able to control the new technology and housing managers and maintenance people may be unable to help. Due to ASHP novelty social housing providers may be uncertain of how best to source ASHP, assess their suitability for tenants and organise high-quality surveys and installation by local installers.		

<table>
<tr><td colspan="6">PRIVATE LANDLORDS</td></tr>
<tr><td colspan="2">Service provider
Project consortium</td><td colspan="2">Beneficiary
Private housing landlords</td><td colspan="2">Outcome</td></tr>
<tr><td colspan="2">Service or offer

Clean Heat Streets Project</td><td colspan="2">Job to be done

Prepare for potential tightening of statutory requirements for minimum EPC level for rented properties.

Keep tenants happy and reduce energy bills to reduce risk of rent arrears (or reduce need to increase rent where bills are included).</td><td rowspan="3">Capabilities required

Technical:
Adequate insulation levels.
Sufficiently large heat emitters

Financial:
Access funding for costs of ASHP installation beyond those covered by the project.

Social:
Ability to engage tenants in the offer.</td><td rowspan="3">Approaches to develop capabilities

Both will be assessed, and heat emitters will be assessed and upgraded if necessary.

Range of funding offers including a leasing model to reduce up-front costs of ASHP.

Provision of value proposition, including pre-installation engagement and post-installation support, to engage and inform tenants in the offer, support them to make a decision about ASHP suitability considering their own wants and needs, and assure support to get the best out of ASHP if they choose to proceed.</td></tr>
<tr><td>Gain offer</td><td>Range of post-install support available to suit different tenants’ needs, enabling them to get the best out of their HP.</td><td>Gain</td><td>Well-designed and installed, and effectively operated pump can improve tenants’ comfort while reducing costs.</td></tr>
<tr><td>Pain reliever</td><td>Funded expert survey provided by the project.
High quality HP with 7-year warranty.</td><td>Pain</td><td>Landlords may find it difficult to assess the extent to which ASHP installation would raise the EPC rating of their property, and to plan and coordinate a high-quality installation.</td></tr>
</table>

<table>
<tr><td colspan="6">TENANTS</td></tr>
<tr><td colspan="2">Service provider
Project consortium</td><td colspan="2">Beneficiary
Tenants (private and social housing)</td><td colspan="2">Outcome</td></tr>
<tr><td colspan="2">Service or offer

Clean Heat Streets Project</td><td colspan="2">Job to be done
Reduce heating running costs (and carbon emissions) while maintaining or improving comfort. Have a reliable heating system with assurance that support is available if something goes wrong.

Be able to persuade landlord to invest in improvements.</td><td rowspan="2">Capabilities required

Technical:
Adequate insulation levels. Sufficiently large heat emitters

Social:
Ability to engage with landlord.[BP1]

Trust in information and advice offered.

Social, personal, technical:
Capability to operate heat pump in an efficient way: intended use of controls, ability to avoid, tolerate, or appreciate experience of more constant</td><td rowspan="2">Approaches to develop capabilities

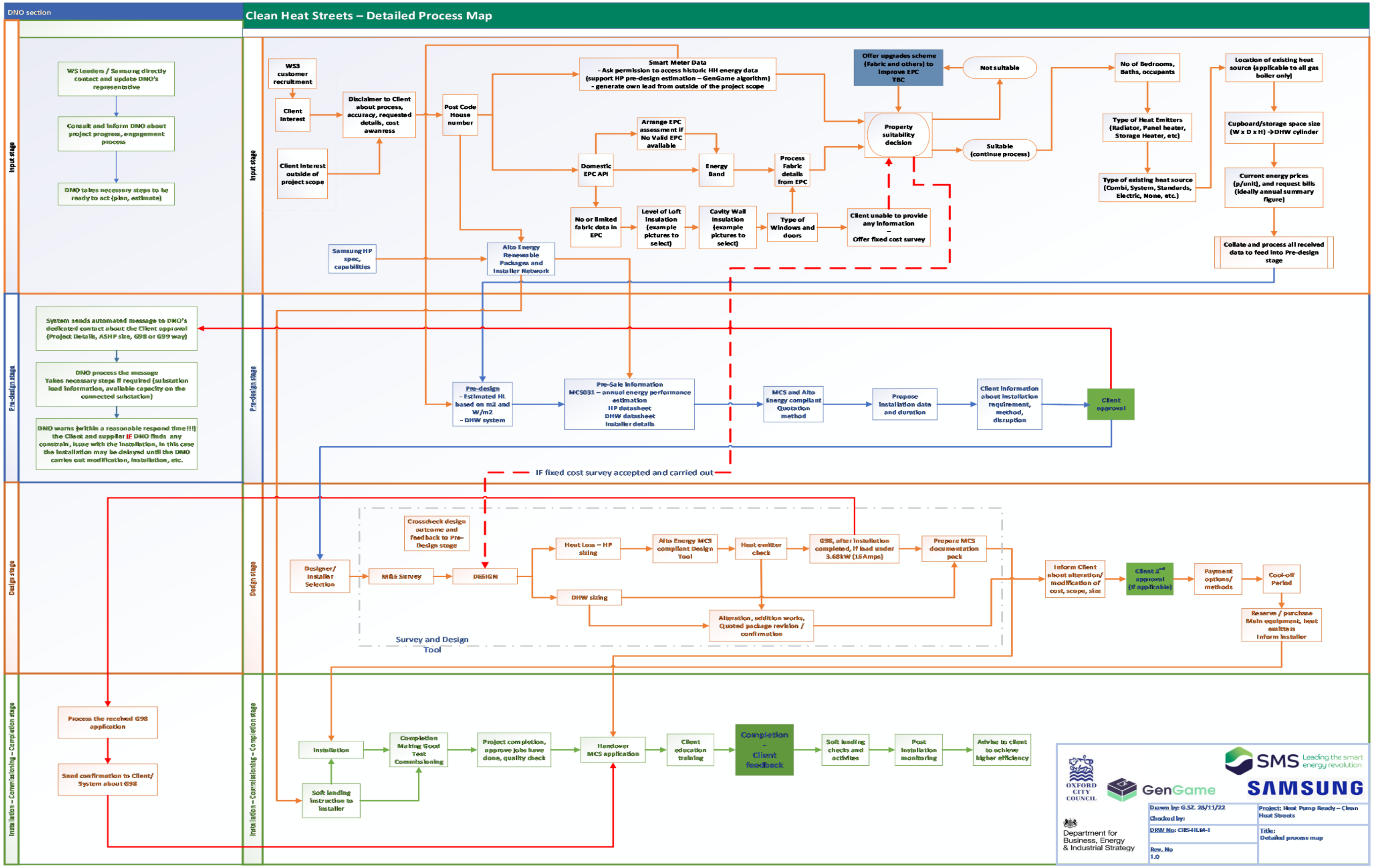
Both will be assessed, and heat emitters will be assessed and upgraded if necessary.

Working with RHILC and other organisations already trusted in the local community; working with heat pump champions; developing project’s visibility in the community.

Discuss heating wants and needs during installation and handover. Ensure sufficient understanding of HP operation and role in heating home. Provide range of post-install support to suit different needs, enabling households to get the best out of their HP.</td></tr>
<tr><td>Gain offer</td><td>High-quality installation, plus range of post-install support to suit different needs will enabling households to get the best out of their HP.</td><td>Gain</td><td>Maintaining or increasing comfort while decreasing running costs (and carbon emissions).</td></tr>
</table>

Pain reliever	The development of value propositions that tenants can use to engage landlords with the project, potentially leading to investment in ASHP. The availability of a range of post-install support to suit different tenants' needs, enabling them to get the best out of their HP.	Pain	Tenants do not have control over heating technology installed in their property: If they want an ASHP, they may find it hard to persuade landlord to invest. If landlords want to install ASHP, tenants may have concerns and uncertainties about comfort levels and running costs, and their ability to operate the new, unfamiliar system in the best way.	operation of heating system during day and night.	

Appendix 6: Detailed process map



Appendix 7: Requisite partners and skills for dense heat pump deployment

Methodology Project Manager

A project manager to manage delivery, coordinate the partners, and manage the business case, financial and commercial agreements.

Information and Data Management System (IDMS) provider

A partner who can set-up the information and data management system (see more details in the section below).

Heat Pump Technology provider

There needs to be a technology provider who can provide the heat pump equipment and provide technical information and guidance and input into the various work packages.

Local Authorities

The Local City Authority provides a dedicated Local Energy Project Officer who will become the human face of the project, be embedded and present in the targeted area and will be the first point of engagement with local residents. The officer will act as the “convenor” of local project events and meetings including leading co-design of energy and low carbon plans with local groups (much like the convenor role anticipated for Local Area Energy Planning); interpreting technical surveys; advising on post install optimisation of the system and otherwise guiding participants through all stages of the customer journey. The Local County Authority provides strategic and policy inputs and steer. Also links to services for retrofit funding and general welfare and energy advice.

Mapping tool provider

The methodology needs a mapping tool provider who can provide a mapping tool capable of identifying the most suitable secondary substations for high-density deployment within the local authority area. The provider should be able to provide data capture, spatial analysis, mapping, targeting and monitoring services.

Data Forecaster

The methodology needs a provider who can estimate the electricity demand of homes with a smart meter (i.e. gas boiler to heat pump usage translation algorithm) or without a smart meter (heat pump demand forecaster).

Householder Engagement specialists

The methodology needs behaviour and feedback specialists to develop and implement a localised engagement strategy based on input from a community survey exercise.

Heat Pump Installation Service Coordinator

The methodology uses a service provider to manage and be responsible for the surveying, design, supply, technical support, commissioning (and quality control), charging, building regulations and service and warranty.

Heat Pump installer

The methodology uses a local installation business to subcontract the installation work. The installers will be upskilled heating engineers, the majority of whom will be gas boiler installers.

Smart Meter installation and Data partner
Given the importance of granular energy data to the householder offer, the methodology needs a company able to advise and carry out Smart Meter installations on behalf of Energy Suppliers. In addition, the methodology needs a partner who is a DCC user who is able to access data from a customer's smart meter.

Renewable Heating System Consultant
Required to provide work on monitoring, quality assurance, installer training and optimisation of installations.

Distribution Network Operator
Required to provide data and substation level monitoring services. They will also provide technical guidance to help with the design of a smart solution where there is a risk of network constraint and work with the project to provide smoothed connection processes.

Heat Pump Optimisation and Flexibility Provider
Technology platform provider that allows smart control of the heat pumps, modulating flow rate and temperature in response to e.g. Time of Use tariff schedules developed by Energy Supplier.

Energy Supplier
If possible, data on expected half-hourly electricity usage following heat pump installation should be provided to an innovative energy supplier. The energy supplier pricing team should
Price a tariff for the customers in the local area a.) without any flexibility service (static changes only to field settings) and b.) with a dynamic flex service provided by the Heat Pump Optimisation and Flexibility Provider.

Local Community Groups
The involvement of local community groups is key to successful promotion and recruitment.

Other Local Organisations
Other relevant local organisations should be identified and asked to participate. For example, in Oxford Better Homes Better Health is Oxford County Council's contracted agency giving energy and welfare advice and assisting residents through the grant and funding application processes

Heat Pump Champions and Show Home Owners
The champions should be local residents and key to peer-to-peer social learning about the benefits of the technology.

Appendix 8: Mapping and targeting suitable areas and dwellings

LEMAP is a versatile mapping tool designed to be at the heart of a Local Area Energy Planning approach. We have used LEMAP In order to decide upon the locations for high-density deployment by using the tool to map, at postcode level, the capability of households to adopt a heat pump through the CHS programme. Our capability assessment includes consideration of technical suitability, likely economic circumstances, and social and digital characteristics of the household. Further data layers allowing targeting of the CHS offer include DNO data quantifying headroom of the secondary substation in the Rose Hill area and also household tenure. These data allow us to score and rank every postcode in Rose Hill on the basis of its suitability for a heat pump. The results are visualised and mapped allowing identification of target postcodes and even individual households. Because we have data identifying both capabilities and wider priorities of the householder our approach allows us to develop value propositions which can be targeted at individual postcodes and clusters of postcodes sharing the same attributes.

Three aspects of evaluation were undertaken to identify appropriate postcodes for targeting heat pump installation. These were:

- Dwelling suitability
- Socio-economic capability
- Grid loading

The following table indicates the data and primary sources for these data.

Table 11 Method and data for heat pump targeting

No.	Evaluation	Data	Primary source
1	Dwelling suitability	Dwelling characteristics	Energy performance certificate (EPC), Geomni, Experian's Mosaic
2	Capability assessment	Socio-economic census data	Experian's Mosaic
3	Grid loading	Secondary substation data	SSE energy services

Dwelling suitability assessment

Each dwelling in Rose Hill was assessed for the following criteria based on EPC and Geomni data:

- Wall, roof, floor energy efficiency must be above 'average' in EPC, that is not rated as very poor, poor, or average[1].
- There cannot be single glazing as shown in the EPC.

After all the filters are applied, each dwelling was assessed as suitable or not suitable. Of 1457 buildings 44% (n=640 dwellings) were deemed suitable for ASHP installation.

Capability assessment

Capability assessment is based on the capability lens approach developed by the Centre for Sustainable Energy (CSE). The assessment helps to find out how likely households are to adopt different Low Carbon Technologies (LCTs) and those who may be left behind based on their socioeconomic characteristics. It can give an idea of the technical, digital, financial as well as social propensity of the households to take up low carbon technologies. The capability assessment in the LEMAP tool for Rose Hill was conducted using data from EPC, Geomni and Mosaic datasets for Rose Hill.

The capability categories are described in more detail below; however, in summary:

Table 12 Capability weights

No.	Technical	Digital	Financial	Social
1	Full potential	High tech user	Happy investor	Fully convinced
2	Partial potential	Tech. savvy	Venturers	Motivated
3	Need improvement	Training required	Penny savers	Sceptical
4	Unsuitable	Other priorities	Deprived	Not interested

- Each capability weight was summed for each dwelling in Rose Hill to create an overall capability grade for each dwelling.
- These are then summed within postcodes to order postcodes from high to low

Technical capability

- Full potential – Fully capable of adopting multiple LCTs
- Partial potential - capable of adopting some LCTs.
- Need improvement – capable of adopting technologies if relevant improvements are made to the dwellings.
- Unsuitable - dwellings unsuitable for LCTs, such as listed buildings.

Digital capability

- Hi-tech users – households with cutting-edge hardware immersed in digital technology.
- Tech Savvy – households composed of avid users of social media and smartphones that aspire to obtain cutting-edge hardware.
- Training required - households that only use digital technology for entertainment, shopping or practical purposes
- Other priorities - households with limited, little or no interest in digital technology, preference given to non-digital approaches.

Financial capability

- Happy investors - households with ability to invest in LCTs without looking for a financial return.
- Venturers - households with access capital or funding to acquire LCTs and expect some economic payback or delay of payments.
- Penny savers - households that depend on loans, grants, or programmes to implement LCTs or change life patterns towards energy flexibility.
- Deprived – socially or economically deprived households with priorities beyond LCTs.

Social capability

- Fully convinced – households that prioritise activities towards the environment
- Motivated - households with some interest and knowledge on the effect of flexible and LCTs on the environment.
- Sceptic - Households that need to be trained or guided to understand the benefits of implementing LCTs or making changes in their lifestyle to flexible energy patterns.
- Not interested - households with lifestyles that do not align with using LCTs

Secondary substation considerations

High capability, i.e., priority postcodes were finally grouped to find the secondary substations with the highest number of priority postcodes. These postcodes were also verified to have higher counts of suitable dwellings (from step 1).

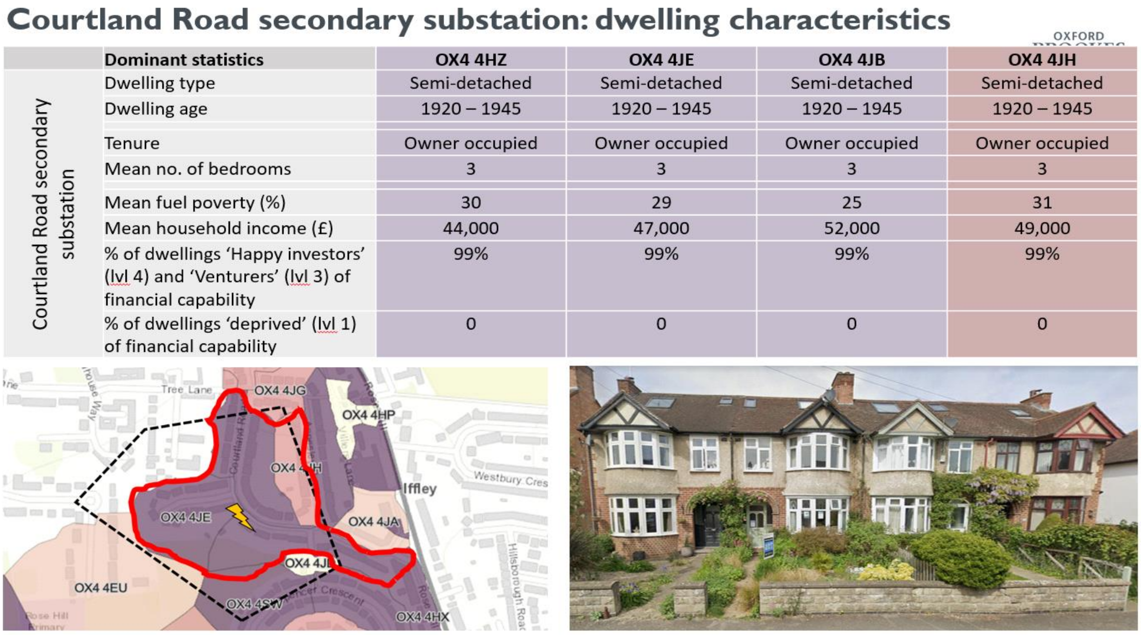
Three postcodes were identified in the following secondary substation areas:

- Courtland Road secondary substation (postcode and total dwelling): OX4 4HZ (n=50 dwellings), OX4 4JE (n=34 dwellings), OX4 4JB (n=29 dwellings), OX4 4JH (n=20 dwellings)
- Fiennes Road secondary substation (postcode and total dwelling): OX4 4SN (n=56 dwellings), OX4 4SW (n=32 dwellings), OX4 4SJ (n=25 dwellings), OX4 4SL (n=21 dwellings)
- Rivermead Road Garages secondary substation (postcode and total dwelling): OX4 4TB (n=42 dwellings), OX4 4UE (n=33 dwellings), OX4 4UD (n=32 dwellings), OX4 4UL (n=19 dwellings)

These postcodes were then listed with relevant characteristics.

Courtland Road secondary substation

- Level of loading: <40%
- LV feeder 85-90% loaded
- 162 customers total
- Selected postcodes account for 80% of dwellings in secondary substation area
- Dominate dwelling age band: 1920 – 1945
- Dominate tenure: owner-occupied
- Mean fuel poverty 25-31%
- Mean household income £44,000 – 52,000

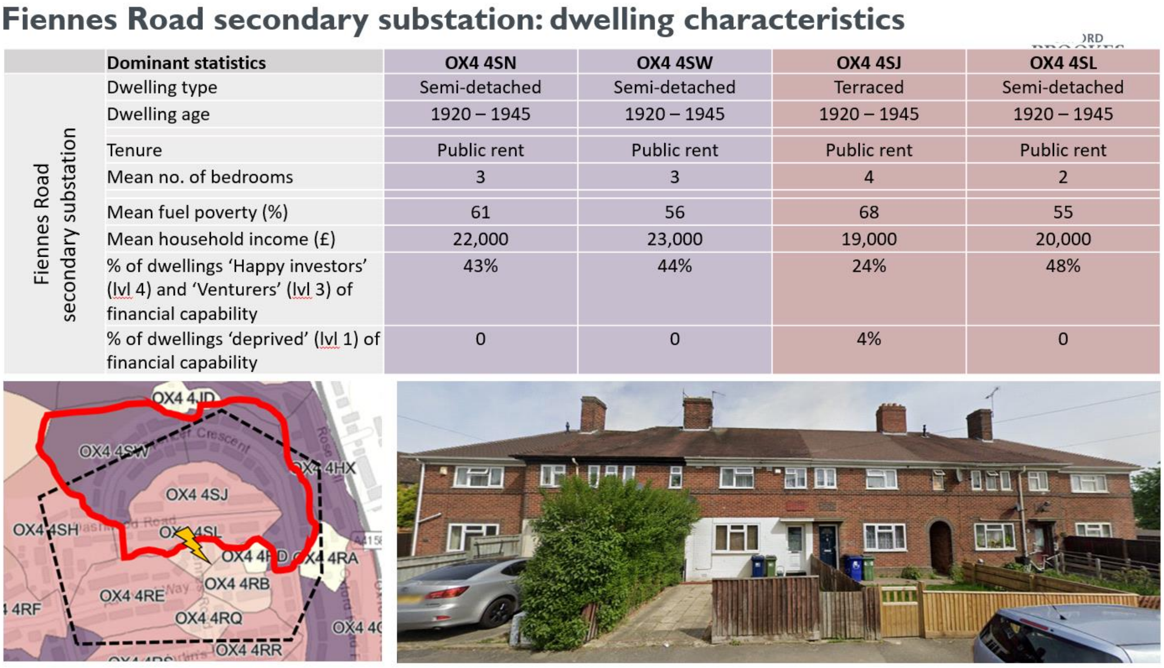


Courtland Road secondary substation: dwelling characteristics

	Dominant statistics	**OX4 4HZ**	**OX4 4JE**	**OX4 4JB**	**OX4 4JH**
Courtland Road secondary substation	Dwelling type	Semi-detached	Semi-detached	Semi-detached	Semi-detached
	Dwelling age	1920 – 1945	1920 – 1945	1920 – 1945	1920 – 1945
	Tenure	Owner occupied	Owner occupied	Owner occupied	Owner occupied
	Mean no. of bedrooms	3	3	3	3
	Mean fuel poverty (%)	30	29	25	31
	Mean household income (£)	44,000	47,000	52,000	49,000
	% of dwellings 'Happy investors' (lvl 4) and 'Venturers' (lvl 3) of financial capability	99%	99%	99%	99%
	% of dwellings 'deprived' (lvl 1) of financial capability	0	0	0	0

Fiennes Road secondary substation

- Level of loading: 40-60%
- LV feeder not overloaded
- 265 customers total
- Selected postcodes account for 50% of dwellings in secondary substation area
- Dominate dwelling age band: 1920 – 1945
- Dominate tenure: public rent
- Mean fuel poverty 55-68%
- Mean household income £19,000 – 23,000

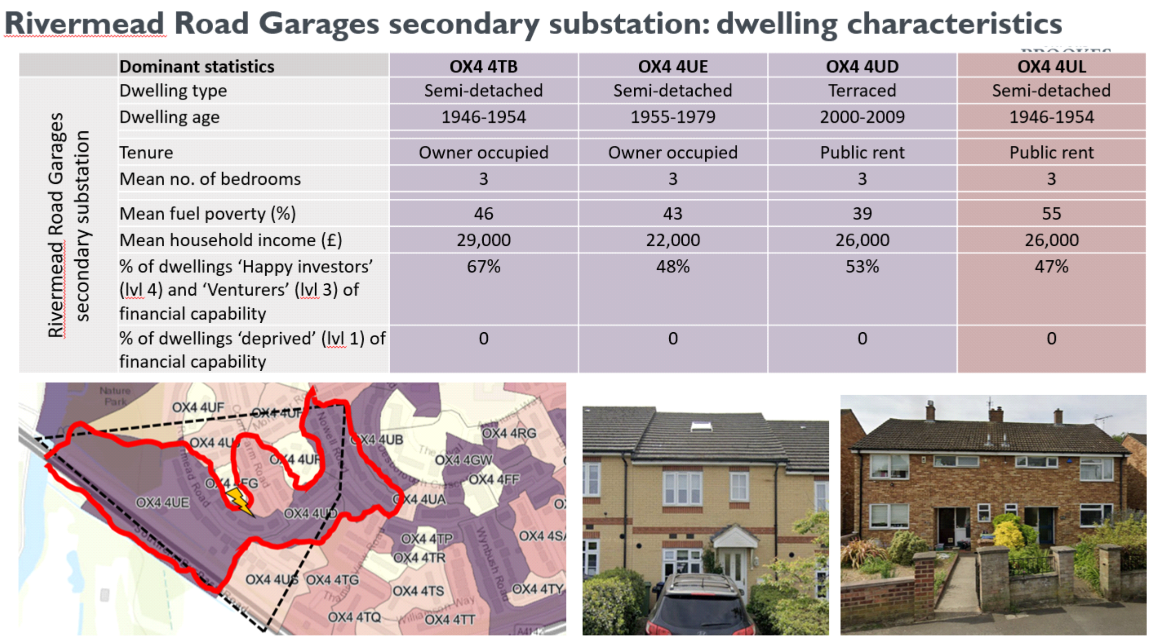


Fiennes Road secondary substation: dwelling characteristics

	Dominant statistics	OX4 4SN	OX4 4SW	OX4 4SJ	OX4 4SL
Fiennes Road secondary substation	Dwelling type	Semi-detached	Semi-detached	Terraced	Semi-detached
	Dwelling age	1920 – 1945	1920 – 1945	1920 – 1945	1920 – 1945
	Tenure	Public rent	Public rent	Public rent	Public rent
	Mean no. of bedrooms	3	3	4	2
	Mean fuel poverty (%)	61	56	68	55
	Mean household income (£)	22,000	23,000	19,000	20,000
	% of dwellings 'Happy investors' (lvl 4) and 'Venturers' (lvl 3) of financial capability	43%	44%	24%	48%
	% of dwellings 'deprived' (lvl 1) of financial capability	0	0	4%	0

Rivermead Road Garages secondary substation

- Level of loading: 60-80%
- LV feeder not overloaded
- 150 customers total
- Selected postcodes account for 80% of dwellings in secondary substation area
- Dominate dwelling age band: 1946-1954
- Dominate tenure: owner occupied / public rent
- Mean fuel poverty 47-67%
- Mean household income £22,000 – 29,000



Rivermead Road Garages secondary substation: dwelling characteristics

	Dominant statistics	OX4 4TB	OX4 4UE	OX4 4UD	OX4 4UL
Rivermead Road Garages secondary substation	Dwelling type	Semi-detached	Semi-detached	Terraced	Semi-detached
	Dwelling age	1946-1954	1955-1979	2000-2009	1946-1954
	Tenure	Owner occupied	Owner occupied	Public rent	Public rent
	Mean no. of bedrooms	3	3	3	3
	Mean fuel poverty (%)	46	43	39	55
	Mean household income (£)	29,000	22,000	26,000	26,000
	% of dwellings 'Happy investors' (lvl 4) and 'Venturers' (lvl 3) of financial capability	67%	48%	53%	47%
	% of dwellings 'deprived' (lvl 1) of financial capability	0	0	0	0

Dwellings to be targeted

Using the suitability analysis and sorting dwellings by financial capability*, roughly 25% of the dwellings in each postcode grouping were selected for precise targeting. The following tables indicate some dwellings characteristics of these sets. Most dwellings in the total selected set are terraced although Courtland Road and Rivermead Garages are a majority semi-detached. Most dwellings are owner occupied; however, social renters are a close second.

Table 13 Number of dwellings in the targeted substation area by form

	Flat	Mid-terrace	End-terrace	Semi-detached	Detached	Total
Courtland Rd	0	6	5	31	1	43
Fiennes Rd	0	41	21	5	0	67
Rivermead Rd G	0	7	8	24	1	40
Total	0	54	34	60	2	150

* Note: all dwellings are cavity wall construction whether declared in EPC, Geomni, or assumed based on other characteristics. A majority are assumed.

Table 14 Number of dwellings in the targeted substation area by tenure

	Owner occupied	Social rent	Private rent	Total
Courtland Rd	43	0	0	43
Fiennes Rd	16	48	3	67
Rivermead Rd G	24	14	2	40
Total	83	62	5	150